Demonstration of Intelligent grid technologies for renewables Integration and Interactive consumer participation enabling Interoperable market solutions and Interconnected stakeholders

WP 8 – Replicability, Scalability and Exploitation

Definition of Scenarios and Methodology for the Scalability and Replicability Analysis
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<th>Partner</th>
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<td>INESC</td>
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Executive Summary

The goal of this document is to present the methodology and the scenarios developed to evaluate the Scalability and Replicability potential of the systems and solutions. It is intended to be used as a manual guide for the stakeholders involved in the analysis.

In the scope of the InteGrid project, Smart Grid technologies are implemented and tested in demonstrators located in Portugal, Slovenia and Sweden. In order to avoid that these experiments remain local and are not deployed at large-scale, it is necessary to identify the factors impacting the deployment potential of these technologies. Therefore, a Scalability and Replicability Analysis (SRA) will be performed in WP8, covering the technical, economic and regulatory domains. Given the growing importance of the ICT, the technical analysis is divided into the functionality-oriented domain and the ICT-oriented domain. Since InteGrid is using the SGAM (Smart Grid Architecture Model) approach, aligning the SRA methodology to the five layers of the SGAM (i.e. Business, Functional, Information, Communication and Component layers) makes the analysis more comprehensive.

Within the InteGrid project, the Smart Grid technologies are grouped into 12 High-Level Use Cases (HLUCs) that represent the high-level solutions proposed to be explored and tested (represented in Figure 3), whereas the Primary Use Cases (PUC) represent the functionalities that support the HLUC. Since InteGrid aims at identifying promising business models, the SRA, and by consequence its corresponding methodology, are focused on the business view point as a whole, which means that the conclusions on the Scalability and Replicability potential will be drawn at HLUC level.

Figure 1: Overview of the 12 High-Level Use Cases (HLUCs) (from D1.2)
Considering the large number and the diversity of HLUCs and Smart Grid technologies involved in this project, it is crucial to identify the most promising solutions, so as to reduce the potential number of simulations and as to concentrate the available resources on the most relevant business and solutions. Therefore, prior to the definition of scenarios and the Scalability and Replicability analysis, a qualitative pre-evaluation must be performed.

The goals of the pre-evaluation are to get a concise high-level understanding of each HLUC and to decide whether an extended analysis (quantitative or qualitative), or no analysis at all, should be performed in each domain (Functional, ICT, Economic & Regulatory). The pre-evaluation also aims at identifying the most relevant attributes affecting the scalability and the replicability and the outputs to be produced (KPIs). For each domain, the following specificities were considered:

- **Functionality**-oriented domain: the methodology we used is inspired from approach developed in the Grid4EU project, which consists in considering two dimensions for scaling-up (density and size dimensions) and for the replication (intranational and international dimensions). The pre-evaluation of the functionality-oriented SRA has been the conceptual support for the design of the simulation scenarios, which are created prior the functional-analysis of the HLUC. Therefore, the main factors impact Scalability and Replicability have been identified, along with their expected effect.

- **ICT**-oriented domain: the pre-evaluation aims at identifying the critical components and how they affect the communication and information layers. It is based on the SGAM diagrams available for each demonstration site (information, communication and components layers).

- **Economic** domain, the pre-evaluation aims at identifying the boundary conditions, the parameter to vary as well as the monetizable KPIs to produce. Additionally, the necessary input data is also highlighted.

- Finally concerning the **Regulatory** domain, all the relevant aspects of the analysis have been identified in a previous step of the project (Task 1.4) and the SRA will be essentially based on qualitative analysis. Given that all HLUC will be evaluated, the regulatory part is not thoroughly considered during the pre-evaluation phase.

As for the ICT-oriented SRA, selecting a HLUC has been a pragmatic choice considering the limited amount of resources available compared to the functionality-oriented SRA. The HLUCs showing challenges in terms of implementation have been selected in priority. Although some HLUC have not be selected, they are partially covered by other HLUC (e.g. HLUC05 is partially covered by HLUC01 and HLUC12). Finally, the cost data of the ICT infrastructure will be an input for the economic-SRA, which means that dedicated scenarios can be created in the future to produce these inputs (this is not considered as an ICT-oriented SRA).

Table 1 below presents the results of the pre-evaluation for the functional and ICT domains. The information whether an in-depth analysis of the HLUC will be performed or not is provided, as well as the countries that will be considered for the analysis.
Regarding the functionality-oriented SRA, the main criteria for selecting a HLUC is the existence of smart grid functions. Hence, the HLUCs n°04, 06 and 07 are discarded and they will not be further analysed. The expected work load may vary significantly from one HLUC to another (e.g. between HLUC01 (“Operational Planning” which makes use of three smart grid functions) and HLUC10 (“Aggregation of LV customers”, using the market price forecasting function)), therefore the allocation of resources between the HLUC is distributed accordingly. It is worth mentioning that at the time of writing this document, technical details about the development and the implementation of certain HLUC is not available (e.g. for HLUC03 and HLUC10), therefore the information contained in the table might change in the future.

As for the ICT-oriented SRA, selecting a HLUC has been a pragmatic choice considering the limited amount of resources available compared to the functionality-oriented SRA. The HLUCs showing challenges in terms of implementation have been selected in priority. Although some HLUC have not be selected, they are partially covered by other HLUC (e.g. HLUC05 is partially covered by HLUC01 and HLUC12). Finally, the cost data of the ICT infrastructure will be an input for the economic-SRA, which means that dedicated scenarios can be created in the future to produce these inputs (this is not considered as an ICT-oriented SRA).

### Table 1: Results of the pre-evaluation for the ICT and functional domains

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<tr>
<td>HLUC11</td>
<td>Yes</td>
</tr>
<tr>
<td>HLUC12</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The results of the regulatory pre-evaluation have not been presented since all HLUCs will be evaluated. Unlike the technical analysis, it will not be bounded to the three demo countries, but it will be extended to Spain and Austria, two countries members of the consortium.

The economic SRA has not been illustrated in the table neither as a different approach will be used. Indeed, certain HLUCs are “enablers” (e.g. the g-m Hub platform enables the implementation of several HLUCs) so it is more relevant to integrate certain use case in sets for the economic analysis. At this moment, we consider that HLUC01, HLUC02, HLUC03 and HLUC04
shall be analysed individually and we propose to create three HLUC sets (i.e. Large Customer VPP, Open VPP and LV customer empowerment), as shown in Figure 2 below.

Following the pre-evaluation, the analysis of the Scalability and Replicability with respect to the functionalities will be mainly quantitative, based on simulations. The design of a simulation scenario follows the following steps:

1) Identification of the function or a set of functions to be evaluated,
2) for each factor identified in the pre-evaluation phase, determine the type of impact produced on the system/function(s), in terms of technical impact on the scalability in size/density or in terms of intranational/international replicability.
3) Identification for each factor of its impact on the system/function(s) in terms of outputs (technical KPIs). For each factor, it is necessary to decide the value the corresponding input variables should take. This process is somehow arbitrary, and a trade-off is essential. Indeed, from one side, a larger resolution should provide meaningful results of the impact of a specific factor. However, on the other side, the number of HLUC and relevant factors as well as the amount of simulations needed to analyse suggests the need of reducing as much as possible this resolution. Hence, an effort has been done to limit the analysis, by producing meaningful scenarios in a reduced number (e.g. by...
focusing on worst case scenarios rather than performing an in-depth sensitivity analysis).

An example of simulation scenarios with the corresponding baseline is provided hereinafter for HLUC02:

**Scenario #1:** (real-time baseline scenario)

- **Additional comments:** A typical Portuguese network, with around 30 homogeneously distributed nodes, low X/R ratio, access to perfect SM information

**Scenario #3**

- **Scaling dimension:** real-time SM readings unavailability.
- **Scaling range:** Around 50% of meters besides the minimum requirements of one SM per feeder and phase, and 12 months of historical data.
- **Objective:** state estimation (considering uncertainty) and its influence on the real-time control.
- **Additional comments:** different levels of risk exposure are considered (minimum of 30%, 40% and 50% probability of occurring overvoltage/under voltage).
- **Baseline:** Scenario #1.

The ICT-oriented SRA will be mainly qualitative, given the inherent complexity of ICT-systems to be simulated. The evaluation of the ICT-oriented scalability consists in assessing the modularity of the systems, in the sense of system integration and system reliability. By system integration, one refers to the integration of additional components affecting the communication and information layers, therefore the scalability analysis with respect to this parameter will consist in evaluating the complexity of integrating new systems or components. Concerning the system reliability, the scalability analysis will seek at assessing the effect of scaling the system on the ICT performance (over data process, data storage and data exchange) and the security. The replicability analysis will evaluate how to replicate the ICT from one demo to another, by means of interoperability (interfaces and connections used among different actors) and interchangeability (exchange of certain devices/components of the demo without compromising the performance or functionality supported).

Concerning the economic analysis, the business models and the economic model of the Cost-Benefit Analysis (CBA) will be built in WP7 and will later be adapted for the specificities of the SRA, so no detailed scenarios were yet available.
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# Abbreviations and Acronyms

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<th>Description</th>
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<tr>
<td>AMI</td>
<td>Advance Metering Infrastructure</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>BAU</td>
<td>Business As Usual</td>
</tr>
<tr>
<td>BMS</td>
<td>Battery Management System</td>
</tr>
<tr>
<td>BRP</td>
<td>Balancing Responsible Party</td>
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<tr>
<td>CA</td>
<td>Consortium Agreement</td>
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<tr>
<td>CAPEX</td>
<td>Capital Expenditure</td>
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<td>CO2</td>
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<td>Customer Relationship Management</td>
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<td>Internal Rate of Return</td>
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<td>Net Present Value</td>
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<td>Inductance</td>
</tr>
<tr>
<td>XML</td>
<td>Extensible Markup Language</td>
</tr>
</tbody>
</table>
1. Introduction

1.1. About InteGrid Scalability and Replicability

In the last years, numerous initiatives on Smart Grid projects have arisen to address the multiple challenges the power system is currently facing, such as the integration of renewable energy sources (RES) and electrical vehicles (EVs), the development of demand response (DR) and smart metering or the automation of the distribution. While most of the projects are still in the demonstration phase, the declared goal of the stakeholders is the roll-out to industrial scale of the most promising R&D solutions in a near future. To achieve this objective, a suitable degree of Scalability and Replicability of the Smart Grid projects and solutions is required. Therefore, the numerous innovative solutions and Use Cases developed and demonstrated in the scope of the InteGrid, such as the Operational planning of medium-voltage (MV) distribution networks or the technical Virtual Power Plant (tVPP), must be thoroughly analysed with respect to their Scalability and Replicability potential.

The Scalability and Replicability topics have been covered in various domains such as software (SW) development or database design. Recently, various European projects such as Grid4EU, EvolvDSO or IGREENGrid have applied it to Smart Grid projects. On the one hand, Scalability refers to the ability of a system, network or process to increase its size/scope/range to adequately meet a growth in demand. On the other hand, Replicability denotes the capability of a system for being duplicated at another location or time. In order to deploy a solution such as those proposed in the InteGrid project, Scalability and Replicability must be guaranteed from the technical, economic and regulatory perspectives.

Within the InteGrid project, the Smart Grid technologies are grouped into 12 High-Level Use Cases (HLUCs) that represent the high-level solutions proposed to be explored and tested (see Figure 3), whereas the Primary Use Cases (PUC) represent the functionalities that support the HLUC. Indeed, InteGrid aims at identifying promising business models to bridge the gap between citizens, technology and the other players of the energy system, so that all stakeholders can actively participate in the energy market and distribution grid management. Hence the SRA, and by consequence its corresponding methodology, is focused on the business view point as a whole, which means that the conclusions on the Scalability and Replicability potential will be drawn at HLUC level.
Figure 3: Overview of the 12 High-Level Use Cases (HLUCs)
1.2. Scope and objective of the document

The aim of this document is to present the methodology and the scenarios developed for evaluating the Scalability and Replicability potential of the HLUCs, with respect to the technical, economic and regulatory factors. It is intended to be used as a manual guide for the stakeholders involved in the analysis, so differences may arise during the proper SRA elaboration between the suggested scenarios presented here as guidelines and the final scenarios considered in the actual analysis. At the present date, certain HLUC and functionalities remain unclear as they are still under specification.

Considering the number and the diversity of HLUCs (and the associated PUCs), it is crucial to identify the most promising solutions, so as to reduce the potential number of simulations and as to concentrate the available resources on the most relevant business. For instance, some HLUCs (e.g. HLUC07) are purely based on the development of a business process or an ICT system and don’t rely on any Smart Grid functionality hence a functional-oriented SRA is not applicable. Therefore, prior to the definition of scenarios for the technical, economic and regulatory analysis, a qualitative analysis for each HLUC (called pre-evaluation) has been performed as part of the proposed methodology. The goal of these pre-evaluations is to get a concise high-level understanding of each HLUC to decide whether an extended qualitative analysis, quantitative analysis, or no analysis at all, should be performed in each domain (Functional, ICT, Economic & Regulatory), as well as to identify the relevant attributes and KPIs. These pre-evaluations have also been the conceptual support for the design of the simulation scenarios to be analysed for the functional SRA. At the present date, the ICT-architecture of the demonstrators (and so of the HLUCs implementation) is under specification, and therefore it is not yet possible to produce scenarios as detailed as for the functionality-oriented SRA. Concerning the economic analysis, the business models and the economic model of the Cost-Benefit Analysis (CBA) will be built in WP7 and will later be adapted for the specificities of the SRA, so no detailed scenarios were yet available.

1.3. Document structure

This document is divided into 5 main chapters representing the body of the document. In Chapter 2 the pre-evaluation as well as the specific methodology for the functional, ICT, economic and regulatory SRA are presented. Chapter 3 contains the analysis of the pre-evaluation performed for each HLUC. Finally, Chapter 4 contains the scenarios for the functional SRA.
2. InteGrid SRA methodology

InteGrid’s methodology for Scalability and Replicability analysis is organized around the following main scopes:

- **Technical scope**, consisting of the following domains:
  - Functional domain
  - Information and Communication Technologies (ICT) domain

- **Non-technical scope**, consisting of the following domains:
  - Economical domain
  - Regulatory domain

Since InteGrid is using the SGAM (Smart Grid Architecture Model) approach, aligning the SRA methodology to the five layers of the SGAM (i.e. Business, Functional, Information, Communication and Component layers) makes the analysis more comprehensive. This correspondence has been guaranteed by matching the four domains aforementioned with the five SGAM layers as follows:

- **SGAM Business layer**: InteGrid Economic and Regulatory domains.
- **SGAM Functional layer**: InteGrid Functional domain.
- **SGAM Information and Communication layers**: InteGrid ICT domain.

Indeed, from the SRA point of view, the business layer can be clearly subdivided in the economic and regulatory domains, that although totally complementary, require different methodological approaches and are better analysed separately, while the information and communication layers, can easily be grouped together in the unique ICT domain.

Due to the large number and variety of HLUCs and their related smart grid functions, and the limited resources, it is vital to properly select the required tools and the SRA depth.

The following subsections include an introduction of the overall methodology proposed, followed by a subsection for each of the four domains addressed (functional, ICT, economic and regulatory) where specific methodological details are provided.
2.1. Proposed methodology

The general SRA has been approached with three consecutive steps:

1) **Pre-Evaluation of HLUCs** to select the most promising HLUCs for the SRA with respect to each domain (functional, ICT, economic and regulatory).
   This first step, which is part of the general SRA methodology, has already been performed and is included in this document in section 3.
   Dependencies among HLUC and HLUCs’ most relevant tools have also been identified in the phase, as well as and the main input factors to be considered for the SRA (at a qualitative level) and the outputs in terms of KPI.
   The impact of each factor in terms of scalability or replicability, and the main domains (Functional, ICT, Economic and Regulatory) affected, have also been identified.

2) **Definition of scenarios** for the Smart Grid functions and for the HLUCs. This part has also been performed at this stage, although as already indicated, the on-going works of the HLUCs allowed only to propose a preliminary set of simulation scenarios (or no scenario at all) that may still change or evolve.
   The scenarios have been defined according to the main factors identified in the pre-evaluation phase, by quantifying this factors with a reduced set of significant alternatives, and by indicating precisely which KPIs should be considered. The outputs from the technical SRA (Task 8.2) will be used as inputs for the economic analysis, therefore common scenarios have been designed for both domains. Indeed, in order to be able to measure the impact of each factors in the SRA results, it has in general be avoided to modify simultaneously more than one factor, unless particular combinations were object of analysis.
   The regulatory SRA may need inputs from both the technical and economical SRA.

3) **Execution of the SRA** for each domain, following the scenarios developed.
   Figure 4 represents InteGrid’s SRA methodology in a compact and clear way.
2.2. Pre-evaluation of the HLUC

As mentioned in the previous section, the pre-evaluation consists in a qualitative analysis of the HLUC, whose main objective is to identify the Scalability and Replicability potential of the HLUC with respect to each domain, so as to decide whether and in-depth analysis of the HLUC will be performed in a later stage. The pre-evaluation also aims at identifying the countries that will be considered in the Replicability analysis, in addition to the pilot country leading the HLUC implementation.

The main ICT systems/functions involved and the boundary conditions are identified in this step, as well as the most relevant factors and parameters affecting the Scalability and the Replicability in each domain. The outputs (i.e. the KPIs) that should be produced by the analysis and the baseline chosen to compare the results are highlighted.
The evaluation is performed with the view of the HLUC objectives. Each domain is assessed independently as follows:

- **Functionality-oriented SRA**: the pre-evaluation is based upon the approach developed in the project Grid4EU, which consists in considering two dimensions for scaling-up (density and size dimensions) and for the replication (intranational and international dimensions). Table 2 here below provides Error! Reference source not found. se four dimensions.

**Table 2: Short description of the SRA dimensions for scaling-up and replication (from the Grid4EU project)**

<table>
<thead>
<tr>
<th>SRA dimension</th>
<th>Short description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaling-up in density</td>
<td>A density increase of a Use case deployment in a given network area is performed without changing the boundary conditions.</td>
</tr>
<tr>
<td>Scaling-up in size</td>
<td>The area where a use case is being deployed is increased, without changing the boundary conditions.</td>
</tr>
<tr>
<td>Replication intranational</td>
<td>A use case is replicated in different networks (of the same or different DSO) in the same country and at a different time, hence boundary conditions are changed.</td>
</tr>
<tr>
<td>Replication international</td>
<td>A use case is replicated in different networks of a different DSO in different countries at a different time, changing boundary conditions.</td>
</tr>
</tbody>
</table>

- **ICT-oriented SRA**: the ICT-SRA performed on the HLUCs will be mostly qualitative-based due to the difficulty to simulate ICT-systems. Therefore, the pre-evaluation aims at identifying the critical components and how they affect the communication and information layers. It is based on the SGAM diagrams available for each demonstration site (information, communication and components layers). The reference ICT architecture on which we base the pre-evaluation is the Leader demo implementation. The choice made to not consider the Learner and Listener demo was motivated by the fact that the ICT architecture was often available for the Leader only. The analysis of the Leader alone is sufficient to estimate the potential of the HLUC. A description of the ICT architecture, to highlight the smart grid functions and their interconnections, as well as the relevant data flows and data sources. This description is a support for the analysis and illustrates the Information, Communication and Components layers in a synthetic way.
• **Economic SRA**: the pre-evaluation aims at identifying the boundary conditions, the parameter to vary as well as the monetizable KPIs to produce. Additionally, the necessary input data is also highlighted.

• **Regulatory SRA**: the relevant regulatory aspects of each HLUC have been identified in a previous step of the project (Task 1.4) and the SRA will be essentially based on qualitative analysis. Given that all HLUC will be evaluated, the regulatory part is not thoroughly considered during the pre-evaluation phase.

In the pre-evaluation, the factors impacting the scalability and replicability in each domain of the HLUCs are addressed. Furthermore, the tools to perform a SRA are described as well as the relevant KPIs to evaluate the HLUCs impact. Finally, a baseline HLUC is defined as guidance for the scenarios. Such baseline is used for a basic requirement description which helps the creation process of the baseline scenario, a central scenario to compare when executing the SRA. Once the pre-evaluation is completed, the required data that need to be provided by DSOs can be defined backed by the pre-evaluation outputs.

The Table 3 aspects that need to be analysed before performing the SRA. The table includes, among others, the main objectives of the HLUC and the SRA methodology (e.g. qualitative, quantitative, technical, economic, regulatory), as well as the KPI to assess its scalability and replicability. This formalized approach allows to provide a standardized and concise summary of each HLUC, helping significantly to select the more relevant HLUC to study the smart grid function and ICT architecture, and the later definition of the simulation scenarios for the SRA.

**Table 3: Template for the pre-evaluation of the HLUCs**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives of the HLUC</td>
<td></td>
</tr>
<tr>
<td>SRA methodology</td>
<td></td>
</tr>
<tr>
<td>Scalability</td>
<td></td>
</tr>
<tr>
<td>Replicability</td>
<td></td>
</tr>
<tr>
<td>Replicability intranational</td>
<td></td>
</tr>
<tr>
<td>Replicability international</td>
<td></td>
</tr>
<tr>
<td>Tools to perform a SRA</td>
<td></td>
</tr>
<tr>
<td>KPIs</td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
</tr>
</tbody>
</table>
2.3. Technical Functionality-oriented SRA

2.3.1. Goal

The goal of the functionality-oriented SRA is to evaluate, from the functional perspective, the technical impact of scaling-up and replicating a smart grid implementation. From the scalability perspective, this means assessing the effectiveness of the system/solutions and the effect on the main stakeholder or system when the site of the demo increases. This scaling-up can be performed according to two dimensions, as described in section 2.2, i.e. in size or in density. For instance, new types of DER may be found in another area of the distribution network or in another country, therefore the performance of the tools will be assessed accordingly. From the replicability perspective, the analysis aims at understanding the effect of new boundary conditions or new environment variables on the performance of the functionalities. The Replicability is also evaluated according to the two dimensions introduced in Grid4EU: the intranational and the international replicability. The first refers to an area of the same country in which different technical boundary conditions may be found (e.g. different types of networks, data available with another resolution). The second refers to the new environment that may be found in another country.

The SRA will only focus on the Smart Grid functions developed in the scope of InteGrid (although the functionalities are always contemplated from the HLUC perspective); it will not consider any enabling function (e.g. the metering or the data acquisition functions supporting a HLUC), since they are part of the DSO infrastructure already. Finally, the technological choices (ICT) made to support these functionalities are evaluated independently in the ICT-oriented SRA.

Example:

*In the HLUC01, three Smart Grid functions are used in the main system, namely the Load/RES forecasting, the Medium-Voltage (MV) Load Allocation and the Multi-Period Optimal Power Flow (MP-OPF) functions. The Functionality-oriented SRA aims at assessing the performance of each of these individual functions and group of functions when scaling-up and replicating (e.g. measuring the effect of scaling-up the demonstration on the MV Load Allocation performance, considering the influence of the forecasting function as well).*

2.3.2. Inputs

The tools and smart grid functions developed in WP2 will be the main support of the analysis. They will be provided by the developing partner (i.e. INESC TEC, AIT, cyberGrid and SAP). However, for certain HLUCs, it might not be possible to use the tools in a simulation environment.
so, instead, the SRA could be based upon an analysis performed in the original environment where the tools are implemented, i.e. the demo themselves.

In addition to the smart grid functionalities, data must be gathered for each HLUC in order to build the simulations scenarios. The data, which is mainly composed of network models and profiles, is identified through the scenarios presented in this document.

### 2.3.3. Method description

Simulations scenarios are created prior the functional-analysis of the HLUC. A simulation scenario consists in identifying 1) a function or a set of functions to be evaluated, 2) the relevant parameters impacting the scalability and/or the replicability and the way they are varying (e.g. the range) as well as 3) the technical KPIs to produced\(^1\).

The design of the simulation scenarios is based on the results of the pre-evaluation and it follows the process described hereinafter:

1. Identification, in the pre-evaluation phase, of the main factors impacting the functionality-oriented scalability and/or replicability.
2. Identification, for each factor, of the type of impact produced on the system/function(s), in terms of technical impact on the scalability in size/density or in terms of intranational/international replicability. While the factors corresponding to scalability in size or in density are in general different, the factors that affect the intranational and international replicability are in general the same, and this distinction affects rather to the value of the inputs than to the inputs factor themselves.
3. Identification for each factor of its impact on the system/function(s) in terms of outputs (technical KPIs). This process helps understanding what the key outputs to be analysed for each scenario and how this output need to be manipulated to produce the KPI that are needed to compare, for a particular factor, the simulation scenarios among them and with the baseline.
4. For each factor, it is necessary to decide the value the corresponding input variables should take. This process is somehow arbitrary, and a trade-off is essential. Indeed, from one side, a larger resolution should provide meaningful results of the impact of a specific factor. However, on the other side, the number of HLUC and relevant factors as well as the amount of simulations needed to analyse suggests the need of reducing as much as possible this resolution. Hence, an effort has been done to limit the analysis, by producing meaningful scenarios in a reduced number (e.g. by focusing on worst case scenarios rather than performing an in-depth sensitivity analysis). In addition, these guidelines will be adapted if needed during the simulation phase according to the particular needs of the SRA and feasibility of producing more scenarios.

---

\(^1\) The Technical KPIs can be selected to evaluate the performance of the individual functions or of the group of functions; they can also target the high-level objectives of the Use Case or they can also be intermediate KPIs to be used later as basis for another analysis (i.e. for the economic analysis).
Following the example of the HLUC01, the process of the scenario creation is illustrated below:

Example:

The three functions to be considered are the Load/RES forecasting, the Medium-Voltage (MV) Load Allocation and the Multi-Period Optimal Power Flow (MP-OPF). With respect to Scalability (in size and density), the main parameters affecting the functions are the dimensions of the networks and the resources available (size, location and availability of the network assets, the DRES and the Loads). It will affect mainly the time performance of each function as well as the distribution network states (i.e. overvoltage’s and overloading’s). As for the Replicability, different grid topologies or the availability of real-time measurements/historical data may affect the performance of the tools such as the estimation and the forecast error.

2.3.4. Outputs

The outputs of the functionality-oriented SRA will be quantitative KPIs produced by means of simulations for each of the scenario created. These outputs will be further analysed to draw conclusions on the technical potential of the Scalability and Replicability of each HLUC. The focus will be on the individual function or the groups of functions and the results will be put into perspective from the HLUC perspective.

Additionality, this task also aims at identifying the barriers and drivers for the technical SRA. The conclusions will be oriented to the DSO, technology providers and functions developers in order to elaborate roadmaps and provide meaningful advices on the best practices.
2.4. Technical ICT-oriented SRA

Information and Communication Technology (ICT) plays a huge role in the deployment of Smart Grids, by supporting their functionalities and services. In the SGAM architecture, the ICT is reflected in the Information, Communication and Components layers, thus we will refer to them in the chapter. The ICT-oriented analysis will not be bounded to an independent analysis of each layer. Instead, it will strive to highlight the interactions between them and the possible implications in terms of Scalability and Replicability.

2.4.1. Goal

The goals of the ICT-oriented SRA are to identify and highlight barriers and constraints which could preclude scalability or/and replicability of a HLUC, and to propose possible solutions to overcome those constraints. The analysis also aims at identifying the potential drivers that could foster the roll-out of a solution.

The evaluation of the ICT-oriented scalability consists in assessing the modularity of the systems, in the sense of system integration and system reliability. By system integration, one refers to the integration of additional components affecting the communication and information layers, therefore the scalability analysis with respect to this parameter will consist in evaluating the complexity of integrating new systems or components. Concerning the system reliability, the scalability analysis will seek at assessing the effect of scaling the system on the ICT performance (over data process, data storage and data exchange) and the security.

Example:

In HLUC12, the Slovenian demo includes a Technical Virtual Power Plant (TVPP) and a Commercial Virtual Power Plant (CVPP). When the demo is extended, the number of flexibility sources, measuring devices, etc. is increasing. A scalable ICT architecture must be able to integrate these new devices into the architecture (system integration) and to guarantee a sufficient level of performance and security (system reliability). These aspects of the modularity are considered in the scalability analysis.

The replicability of an ICT architecture can be approached from two different perspectives: the first option considers two demos implementing the same functionalities (i.e. the same HLUC) with different ICT architecture to support them. The second option considers the migration of the functionalities and the supporting ICT architecture from the demo in which it is implemented to another. In both cases, the analysis will evaluate how to replicate the ICT from one demo to another, by means of interoperability (interfaces and connections used among different actors) and interchangeability (exchange of certain devices/components of the demo without compromising the performance or functionality supported).

2.4.2. Inputs
The mapping of the Information, Communications and Components layers to the demo implementation of the HLUC is presenting in D3.1 (PT), D4.1 (SL) and D5.1 (SW). Finally, the measurements and the results of each demo will be stored on the data warehouse (DWH) and will be used for quantitative assessment of the HLUC.

2.4.3. Methodology description

- **Assessment of the Scalability**

When assessing the Scalability, the pre-evaluation consists in:

- identifying potential critical components, based on their technical characteristics
- assessing the scalability potential of the protocols and communication technologies implemented.
- identifying the critical data sources within the information layer, by examining the frequency of data exchange and the data formats supported.

For those HLUCs which have been selected, the analysis will consist in a qualitative assessment of the system integration and system reliability properties, so as to evaluate the modularity. The process is described hereinafter for each property.

The analysis of the system integration is a qualitative assessment which evaluates the complexity of integrating new systems or components in the demo. The selection is based on the expected impact that a system/component can have on the Information, Communication and Components layers. For instance, the addition of monitored primary substations (to provide active and reactive power measurements for the forecasting) is expected to have a strong impact on the existing ICT-architecture of HLUC01, being a data source. The complexity of integrating new primary substations in each ICT-layer will be assessed and a score is attributed.

Nevertheless, when no devices are added, i.e. the increase frequency of exchange or size, it will result in perfect integration into the system (the system already integrates it). In such case, the integrability analysis will award it with the lowest score possible as no changes are required from the integration point of view. However, adaptability must be studied too.

The system reliability analysis will be a scored based assessment likewise. In this case, the focus is on the system behavior (performance wise and possible security issues). Anew, each layer studies the impact from the technical point of view by means of, specifications (data storage, max. devices supported, bandwidth capacity, formats supported) and cybersecurity. Each modification over a layer will be granted with a score. Again, the higher the score, the higher impact will have into the system behavior, the less adaptable the system is, the lower the scalability results.
• **Assessment of the Replicability**

The goal of the pre-evaluation with respect to replicability is to identify the minimum ICT-requirements to support the key functions, and to evaluate the potential of replication in the other demo (and the feasibility).

The Replicability analysis will be a qualitative-based assessment. Table 4 below presents the relevant factors to be considered in each layer when assessing the interoperability. The definition considered for each factor goes as follows,

- **Ownership**: device ownership is critical to identify for international replication since each country has a different procedure.
- **Standardization**: key enabler for interoperability. If devices, protocols and data formats are standards, they will ease the replication process.
- **Technologies available**: refers to identify if the communication technologies used at the demo side are available at the replicability location.
- **Security**: check security level to set a requirement against possible cyberattacks.
- **Data privacy**: check data privacy policies from the Regulatory SRA which may require an increase in security.

During the evaluation each factor will be addressed and provided with a score. Hence, the higher the overall score is, the less replicable the HLUC becomes.

**Table 4: ICT interoperability factors.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Communication</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ownership</td>
<td>Standardization</td>
<td>Standardization</td>
</tr>
<tr>
<td>Technologies available</td>
<td>Data privacy</td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.5. Economic-oriented SRA

Even if it is technically feasible to scale a project, its economic interest may not be maintained after the scale increase or if the ecosystem (set of economic characteristics of the place where the project is developed) where the project is developed changes. It is up to the economical SRA to investigate this issue. The economical SRA has several relations with the other analysis, as illustrated in Figure 5, which should essentially provide inputs to the economic analysis.

The business model definition (in WP7) will be essential to define the involved stakeholders and the distribution of the benefits. The regulatory analysis will influence the economical SRA since it may change the benefits from country to country. Nevertheless, the key source of input for the economic analysis will be the technical analysis. Indeed, the functionality-oriented analysis is expected to compute the KPIs of the HLUC in several scenarios. Those KPIs that can be translated into quantitative (monetizable) and qualitative benefits will provide the economic assessment needed for the economical SRA. Similarly, the ICT-oriented SRA will also contribute with data to the economical SRA, such as those related to the costs of additional systems needed under scaling scenarios.

Since HLUCs are “enablers” (e.g. the g-m Hub platform enables the implementation of several HLUCs), it makes sense to integrate certain use case in sets for the economic analysis. At this moment, we consider that HLUC01, HLUC02, HLUC03 and HLUC04 shall be analysed individually and we propose to create three HLUC sets (i.e. Large Customer VPP, Open VPP and LV customer empowerment), where for each there will be two scenarios of integration (partial and full), as shown in Figure 6. Each scenario in each set needs to be analysed in terms of the economic interest of scaling it and replicating it. The intention behind this concept is to demonstrate the economic worthiness of the integration of several HLUC.
2.5.1. Goal

Economics will play a key role in determining if a given project will be scaled up or replicated. The goal of the economic scalability analysis will be to conduct investment analysis, namely looking at return rate and present value to conclude on the economic interest of the scale increase. A HLUC or set of HLUCs may be economically viable to scale (have a net present value above zero), but it will only be considered scalable if the net present value and internal rate of return are at least the same as before the scaling.

The replicability analysis assesses the economic interest of the HLUC in different environments than the ones they were originally designed for. Differently from the case of scalability, a HLUC will be considered replicable if its application in another country/region leads to a net present value above zero.

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2 The opposite may also happen, i.e. the HLUC may become viable when the scale increases, and there may even be situations where there is an optimum point in the scale dimension, since the cost (for example IT/communications related or maintenance) may increase so much that the final earnings tend to saturate when the scale of certain projects is too important.

3 For instance, discount rates, costs, depreciation rates or benefits may change depending on regulation from country to country.
2.5.2. Inputs

The use case definitions and corresponding KPIs form an important basis for the analysis. The results of the technical SRA shall also provide important inputs, as they will show the KPIs evolution when the scale increases or when the technical conditions change (as mentioned before there can be changes in infrastructures that will condition the HLUC performance). Dedicated simulations may be required to provide the necessary inputs for the economic analysis. Additional input shall come from the business model definition and the CBA methodology (WP7), since this work should allow to understand which HLUCs are associated to improvements of current business or new sources of revenue to existing or new stakeholders. For example, if the application of a certain HLUC decreases network losses or improves the continuity of supply, this is considered as an improvement to the existing business. In these cases, there is the need to define baselines that will serve as references to compare the business as usual with the improvements brought by the application of the HLUC. On the other hand, there will be HLUC that originate new revenues/benefits (for example, the participation of consumers on flexibility markets will bring revenue to them which was not previously available, and probably benefits to the society in terms of CO₂ emission reductions).

The economic SRA shall also require the implementation costs of each HLUC, in terms of power equipment, sensors, telecom equipment and IT systems, as the size, density or location of the system changes.

2.5.3. Method description

The economic SRA will consist of the following steps:

1. **Categorize the HLUC.** The first step consists in defining the HLUC for which it makes sense to perform an economic SRA. Immediately after, for all HLUC that show potential for economic SRA, it is necessary to understand if, from a cash-flow perspective, the HLUC will allow an improvement to existing business, or if they create new business for stakeholders and therefore new sources of cash-flow.

2. **Define the benefit KPIs.** To carry out the economic SRA, it is necessary have monetizable KPIs for the benefits of each HLUC or set of HLUCs. Therefore, this step consists on turning the technical improvements into economic value. An example of a simple to monetize KPI is a reduction in energy losses. This step will also allow to define what kind of simulations will be required to provide inputs for the analysis, and therefore conclude if the simulations foreseen for the technical SRA need to be extended or not.

3. **Define the cost KPIs.** Each HLUC or set of HLUCs has a certain implementation cost. Costs shall be characterized in terms of CAPEX and OPEX for each HLUC.

4. **Organize the data request.** Considering the above-mentioned cost and benefit KPIs, a data request to the DSO’s will be issued. For the HLUC that constitute improvements to existing business there will be requests around certain present parameters, for example
OPEX related to determined activities, equipment replacement costs or costs of energy not supplied.

5. **Setup the cost-benefit analysis model.** The model for investment analysis shall be structured in MS Excel and it will be able to carry out sensitivity analysis as well as Monte-Carlo analysis. For the matter of Monte-Carlo analysis probabilistic distributions shall be taken for key parameters such as equipment costs.

6. **Run the model.** It shall be run for every applicable HLUC or set of HLUCs. The run includes sensitivity analysis and Monte-Carlo analysis to key parameters like the discount rates.

7. **Qualitative analysis.** In case not enough data is available for certain HLUC or set of HLUCs (to be decided after receiving the feedback to the data requests), a set of generic/typical data shall be proposed as a reasonable replacement to the missing specific data. If no agreement within the consortium about the replacement data is found, a qualitative analysis of the economic SRA shall be realized with the goal of understanding and describing the drivers for the economic interest of the scale increase or replication of the concept and concluding on its potential.

8. **Report.** Develop the WP report. It will describe the applied data, cost-benefit analysis model structure, results and conclusions.

### 2.5.4. Scope

The economic analysis shall be carried out both from the scalability and replicability perspectives.

From a scalability perspective, one key issue is the existence of economies of scale. If the marginal costs of the HLUC (for example the costs applying it to another consumer or producer) decrease as the scale of the project increases, then the project is well positioned to be scalable. One common example of scalable projects is in IT related services, where after the platform is created it can handle an increasing number of clients without much increase in cost. Learning curve effects may also be considered if applicable. From a benefit perspective, their percent increase must at least be kept at the same rate as the cost increase. The definition of the business models may also affect the increase in benefits, because certain services may only be possible to offer after a certain scale is achieved (for example number of participants to be aggregated for an offer of flexibility to a TSO).

From a replicability perspective, one key issue will be to verify how the changes in macro-economic variables from country to country affect the economic interest of the project. Inflation, discount rates/interest rates, carbon prices or even fixed asset depreciation rates will have effects on the economic interest of the when the HLUC is applied to somewhere else. However, there is also the need to verify if the business model holds robust in the context of the different regions. Even if from a regulatory perspective there are no barriers to the application of the HLUC on a different region, it may be that the compensation/remuneration associated to it may not be high enough to justify it. Finally, even within the same country (intranational analysis), there may be changes to certain context variables that not only affect the technical feasibility, but also the economic perspective. For example, when a HLUC is moved from an
urban area to a rural one, it will for sure encounter different electrical and communication infrastructures. If the communication infrastructure in the rural area requires significant upgrades for the HLUC to be applicable, this will result in significant cost which may cause it to lose its economic interest.

Sensitivity analysis to economic parameters such as discount rates/interest rates/cost of capital or scale effects (sensitivity to equipment cost decreases) is also part of the scope of works.

2.5.5. Outputs

The economic SRA will strive to deliver as much quantitative output as possible. In principle, the final outputs shall be the following:

- Conclusions of the economic scalability of each HLUC, based on the results of investment analysis namely regarding Net-Present Value (NPV) and Internal Rate of Return (IRR), as compared to a base case. As described before the HLUC will only be considered scalable if the NPV and IRR are higher or equal to the ones of the base case.
- Conclusions of the economic replicability of each HLUC, based on the results of investment analysis namely regarding NPV and IRR. The HLUC is considered replicable if the NPV is greater than zero and the IRR is higher than the discount rate used in the investment analysis.

When the economic SRA of the HLUC takes scenarios from the technical SRA as input, the output will focus on two scenarios only: the one with the highest KPI’s (NPV and IRR) and the one with lowest KPI’s (NPV and IRR). The results of sensitivity analysis to economic parameters shall also be delivered.

Lack of data could prevent from conducting the quantitative analysis (see step 8 of Error! References source not found.), and the conclusions shall be considered as a qualitative evaluation of the potential for scalability or replicability of the HLUC.

The output must also be coordinated with the Regulatory SRA (WP 8.4). Certain business models may simply not be replicable in different countries or the regulatory barriers may be too difficult to lift. If this is the case, there is no reason carry out economic analysis. In these cases, WP 8.4 shall investigate regulation proposals to remove the identified barriers.
2.6. Regulatory-oriented SRA

The objective of a scalability and replicability analysis (SRA) is to characterise the (expected) outcomes of the different use cases and all the parameters that may influence these outcomes. These parameters can be economic, technical or regulatory parameters, which means that different SRAs have to be carried out. Typically, the impacts for the different aspects can be expressed through different pre-defined KPIs.

2.6.1. Goal

The goal of the regulatory SRA is to identify barriers and drivers for the scalability and replicability of the HLUCs. This analysis will be specific to each target country and HLUC/regulatory topic. Barriers are rules that can be found in all or some of the target countries and that constrain the well-functioning of the HLUCs, defined in WP1.

*Example:* 
In the analysis of HLUC 8, we might identify that there are opportunities for industrial consumers to provide ancillary services in target country X. However, a regulatory barrier, such as the fact that ancillary services can only be offered by generators, might be in place in target Y, which disables the replicability of the business model in country X to country Y.

On the other hand, regulation can also be a driver for certain HLUCs. This typically happens when certain practices are incentivized by regulation.

*Example:* 
Regulation forbidding net-metering and favouring a market-based remuneration for excess production of self-generators, as mentioned in Article 21 of the Proposal for a new RES Directive included in the EC Clean Energy Package, is a driver for HLUCs relying on end-user flexibility, especially when combined with appropriately designed retail tariff.

2.6.2. Inputs

The starting point for this task are the outcomes of WP 1. In this work package, the different use cases are defined and the requirements for each use case are listed. These requirements are a starting point for the regulatory analysis with respect to the SRA for the different High-Level Use Cases (HLUCs). Moreover, a mapping indicating what regulatory topics were the most relevant to each HLUC was done. For the regulatory analysis, a characterization of the current regulation in the different countries was provided in D1.3, from which the previously mentioned barriers and drivers can be extracted.
The recommendations with respect to regulation and the cost-benefit analyses provided in WP7 will also serve as a key input for the SRA. On the one hand, this work package will update the characterization of current regulation carried out in WP1 and propose several recommendations to remove barriers for the development of the InteGrid concept. Furthermore, the CBA results will allow the identification of the most cost-effective solutions.

Specifically, for the regulatory SRA, the outputs of task 8.2 and 8.3 will also serve as an important input. These tasks allow that the regulatory SRA focuses on the most promising HLUCs with respect to technical performance and economic returns, particularly when the implementation of two or more smart grid solutions could be in conflict (e.g. DSO unbundling could be in conflict with a HLUC based on the DSO control of distributed flexibilities). Those solutions that have shown a better performance from a technical and economic standpoint should therefore be prioritized in the SRA and roadmap proposed.

### 2.6.3. Method description

The regulatory SRA will be carried out by following several steps. A first step is implicitly performed by task 8.2 and 8.3, which is the identification of the most promising HLUCs. This reduces the list of HLUCs for which the second step needs to be performed (or provides a list of priorities), which is the mapping of the HLUCs with the different regulatory topics. After the mapping, it is necessary to identify the main drivers and enablers of the most promising HLUCs under the current regulation. Subsequently, a comparison will be made between the regulation in the different countries to finally assess the replicability and scalability of the HLUCs. Lastly, the regulatory SRA will provide feedback to the technical analyses so that sensitivities to alternative economic signals (e.g. demand response under alternative tariff structures) and regulation are run in the latter.

### 2.6.4. Scope

Regulation includes all the rules about which services can be provided, the different roles of agents, the remuneration of certain activities, etc. With respect to replicability, regulation studies whether the use case of one country can be replicated in another target country under the current regulation in that country. To investigate this factor, the steps described in the previous section will be followed for the different target countries to see if the HLUCs are viable under the current regulation or not.

The regulatory topics that will be covered include DSO Economic Regulation, DSOs as a system optimizer and market facilitator, retail tariffs and metering, and aggregation and market design. Regulation about aggregation and market design typically included rules about who can participate in which market.
Example:
Prosumers are allowed to sell their energy back to the net if they have a surplus, which significantly increases the attractiveness of owning a DG-unit for self-generation.

Retail tariffs and metering is together with market access one of the most important topics within regulation when looking at scalability and replicability of use cases. A tariff design can make a business case attractive or do exactly the opposite and make it completely unattractive.

Example:
A tariff in which most of the costs are recovered through an energy component makes self-generation more attractive for prosumers. However, it can create a cost recovery problem hampering scalability in the long-term. On the other hand, a flat retail tariff, which does not expose end-users to time-varying energy prices, effectively discourages storage investments.

Sometimes the rules about DSOs as a system optimizer and market facilitator can be restrictive as well.

Example:
DG units above a certain capacity threshold can be mandated to be connected to a control center with a real-time communication link with the TSO. However, if the DSO is not entitled to access this information, distribution constraints cannot be identified and managed in real-time. Therefore, DSOs would favour CAPEX-based solutions.

2.6.5. Outputs

The output of the regulatory SRA should identify existing barriers and drivers embedded in the regulation that hamper, enable or promote the replication or scaling-up of the InteGrid solutions. The actual conditions in the project’s target countries, together with some additional countries that can be considered interesting from a SRA perspective, will be specifically considered. This work needs to be coordinated with WP7 whose aim is to indicate which rules and regulation should be adapted in the future.

Example:
Regulation that allows net-metering can incentivize the installation of DG-units for self-generation. However, if the regulatory SRA shows that this model might not be scalable or replicable (e.g. due to insufficient incentives for end-users or cost recovery issues), the output should indicate that this net-metering should be abandoned and propose a regulation that would allow scalability and replicability.
3. Pre-evaluation of the High-Level Use Cases

In this section, the pre-evaluation for all HLUCs is performed according to the steps described in section 2.1

3.1. HLUC01 Pre-evaluation (Operational planning of MV distribution network to pre-book available flexibility)

A schematic overview of the tools and functionalities involved in the HLUC01 is shown in Figure 7.

Figure 7: Operational planning tools chain of MV distribution network (HLUC01)

The module for load and RES estimation provides forecasts to the MV load allocation tool, which delivers a snapshot of the network status to be used by the MV multi-period OPF. Therefore, the OPF has the necessary information (i.e. future operating scenarios) to elaborate the flexibility plan usage, consisting on minimizing its cost function, while complying with the technical network constraints (e.g., voltage limits). The objective cost function considers the following factors, to be refined and tuned:

- HV losses (from standard regulated cost tables)
- MV losses (from standard regulated cost tables)
- Flexibility costs, as specified in the corresponding flexibility bids, of the potential flexible resources:
  - Conventional generation
  - Renewable generation
  - Storage systems
  - Loads
RES curtailment and load shedding could also be considered.

All the tools associated with this HLUC can also be used separately, although the MV multi-period OPF is the tool that provides the final outcome of HLUC01. Since the SRA analysis is being performed at the HLUC level, the accuracy of the remaining tools should be indirectly analysed in the output of the MV multi-period OPF. Therefore, the two operation modes of the OPF are briefly described below:

1. **Predictive Operation (Multi-period planning)**
   - Based on the network state estimation and the RES/load forecasts (contributing both to guarantee the network observability), the multi-period OPF determines potential set-points for the available flexible resources while minimizing the objective function. The objective is to reserve the necessary flexibility to avoid potential violations of the technical constraints. This planning module does not consider any investments costs and is based only on the available resources and their cost.
   - Voltage and line/transformer limits are modelled as constraints. Although being rigid constraints, the algorithm convergence is ensured due to the possibility of load shedding and RES curtailment.

2. **Close to real time control**
   - With the latest information from the MV load allocation module, the use or not of the previously estimated set-points of the reserved flexibility is decided with an OPF for the next time period.

In order to support the three key functions aforementioned, the ICT architecture is based on the following interactions and data flows:

- The Load/RES DSO Forecasting module is connected to the Meter Data Management Database and is receiving P & Q measurements of MV/LV substations.
- The MV Load allocation function retrieves data from three different sources: The first one is the Meter Data Management Database from which it receives P & Q measurements of HV/MV substations. The second source is the Load/RES Forecasting function which provides P & Q measurements for MV/LV substations. The last source is the SCADA that provides the network topology and the current OLTC status.
- The MPOPF receives inputs data from the MV load allocation (current and future network operating scenarios) and communicates the results to the gm-Hub (i.e. the flexibility data).
The flexible resources considered to avoid grid constraints and to optimize the network operation are both external resources (DER) and internal resources (DSO-owned equipment, like on-load tap changers -OLTC- or energy storage systems). The main objectives are:

1. Anticipate control actions planning to avoid distribution grid contingencies (being the main goal of this HLUC)
2. This should be done at minimum cost, considering:
   - distribution network losses
   - flexibility resources cost
3. Other expected results should be:
   - DER and RES integration in the most cost-efficient way
   - Deferring distribution grid expansion investments.
   - Quality of service improvement
   - RES curtailment minimization (increasing hosting capacity)

Each one of these individual objectives are part of the total OPF problem but do not necessarily correspond to terms of the OPF objective function, being some of them considered as problem constraints, and none being individually minimized. Therefore, their individual behaviour may show unexpected results for particular scenarios, and a total cost analysis may be required to understand the solution.

The quantitative SRA will be based on a set of selected simulations to assess the scalability and replicability, trying to focus on worst cases so as to limit the number of scenarios.

The following assumptions are made in HLUC01:

Only networks with voltage or overload problems will be considered, since otherwise the multi-temporal optimization module will not perform any action.

The economic analysis will be based on these monetizable KPI’s:

- Value of losses (as compared to a baseline)
- Avoided RES curtailment (also as compared to base line)
- Avoided investment in the grid (also as compared to base cases and focused on the scalability in density analysis – high RES/load volumes)

Therefore, the economic analysis will require the following data:

- Cost of losses for DSO at MV level (€/MWh) in each country;
- Cost of CO₂ in each country (present and future projection);
- Average CO₂ emissions per MWh of generated electricity in each country;
- Price of energy sold at MV level by RES (euro/MWh) and, if applicable, the value of the compensations applied to curtailed RES;
- Typical cost of standard network equipment such as power transformers, lines and cables at MV level.
Scalability in density
- Amount/volume of connected DER and loads per grid section
- Different DER and load connections

Functional Scalability in size
- Number of grid nodes
- Number of connected loads and RES
- Number of connected DER
- Number of switches for reconfigurations

Component layer

We identify as critical one of the key functions (MV Load Allocation) and two other components (AMI head end and the Meter Data Management Database, MDMD). The MV Load Allocation server may receive many requests which might affect its performance and response time. Since the communication architecture used is an Advance Metering Infrastructure, the AMI head end and the Meter Data Management Database can affect scalability if they are not able to adapt correctly when scaled.

ICT Communication & Information layers

Over the communication and information layers, no critical data sources or possible constraints have been found. Protocols as well as data formats are compliant with scalability since they are industry standard operating procedure. Nevertheless, it is worth to point out that from the security point of view, the File Transfer Protocol (FTP) can become a constraint if the system scales (as it can limit the file size and there is no data protection).

The HLUC01 solution has the following requirements to perform adequately:
- Historical data from the grid to be controlled
- Weather measurements for the controlled time horizon (temperature, irradiance, etc.)
- Detailed grid topology
- Network technical constraints limits (voltage, branch flows limits) fixed by existing regulation.
- Available flexibilities and associated costs
- SCADA measurements definition
- ICT minimum requirements for real time (RT) control.

Replicability

The replicability will be tested according to the following factors:
- Grid topology (radial/mesh)
- DER types and location
- Location of loads
- Different RES and loads profiles (to illustrate seasonality)
- Availability and location of real-time measurements/forecasts/historical data that may affect the MV
allocator/load and RES DSO forecasting tools (affecting also the scalability in size).

**Replicability intranational**

To assess the intranational replicability, a matching between the above general replicability aspects and the particularities of the considered regions will help to assess the replicability in those regions. In terms of the ICT, it will address the minimum capacity requirements (bandwidth) to allow basic communications and RT control.

In addition, other qualitative aspects such as local regulation or stakeholder acceptance and involvement may also be considered.

The countries initially considered for the functional SRA will be those involved in the demonstration: Portugal and Slovenia. Other possible countries could also be Spain, the Netherlands and Austria, attending to the origin of the consortium participants (to be decided).

A matching between the above general replicability aspects and the particularities of the considered regions will help to assess the replicability in those countries.

Regarding the ICT, there is different network architecture approach between the Portuguese demo (leader) and the Slovenian demo (learner). Whereas in the Portuguese demo, the SCADA has embedded the MV load Allocation in addition to the MPOPFO into one server, in the Slovenian demo, they are separate servers.

In addition, other qualitative aspects such as national regulation (tariffs, RES incentives, data protection regulation, etc.) or stakeholder (regulator, TSO and DSO, etc) acceptance and involvement may also be considered.

**Tools to perform a SRA**

HLUC01 tools (forecast, load allocation and OPF modules), being the MV multi-period OPF the one that provides the HLUC output.

A network planning tool to analyse the costs to solve the problems in the baseline networks if HLUC01 would not be applied.

**KPIs**

- Time performance
- Total costs (from the OPF and for the economic analysis)
- Energy losses
- Voltage deviations from nominal set points and voltage variability (losses minimization should tend to reduce voltage deviations).
- Avoided overvoltage’s/overloads: this may be rather difficult to estimate unless the baseline (see below) allows for this type of problems. Otherwise, overvoltage’s/overloads would probably never happen, since the planning module will not allow them. However, avoiding them will be done with solutions with different cost, depending on the flexibilities used in each case (and its costs), which could be the KPI to be considered.
- RES hosting capacity, RES curtailment and load shedding can also be analysed, although they are not objectives by themselves.
Therefore, their behaviour may lead to unexpected results under several scenarios, and total cost analysis may be required to understand the solution performance.

- Estimation errors of the MV load allocator and forecasting tools due to the availability of historical data and/or SCADA measurements. Errors impact on the MV planning may be very complex to assess. A possible approach could be to compare the performance of the plan obtained with real measurements (i.e. perfect information) with the plan obtained from operating scenarios with forecast/allocation errors.

If possible, the simulations should produce outputs for each of the above KPIs, and both in magnitude and associated cost (when available).

The baseline should be the “standard” network planning”:

- When available, the standard DSO operating planning practices will be selected as baseline - Normal/scheduled programming for capacitor banks, voltage regulation bandwidths/set-points for OLTCs and also other resources that DSO use to avoid/solve the technical constraints.
- Otherwise, the baseline will try to replicate these standard practices, for example, limiting the flexibility usage (such as using only DSO assets) and running the HLUC01 tools for this scenario. In some cases, the baseline may consist in the result of a simple Power flow execution without allowing any flexibility usage.

For a set of selected simulation scenarios, the MV planning from perfect forecasts/allocations (i.e. real-time measurements) should be obtained and compared to the performance of the planning strategies resulting from forecast/allocation errors. However, a systematic approach for this testing may be difficult to design and very time consuming, and will have to be limited to a few case studies.

Table 5 summarizes the information provided in this section. It describes the KPI that should be evaluated in each scenario for the different tools belonging to HLUC01, given a set of input factors with impact on the SRA. However, it is important to highlight, as already mentioned, that the SRA analysis will be performed at the HLUC level. Therefore, the impact of the different scenarios should be observed, if possible, at the HLUC output. As an example, for the SCADA measurements availability/location, its impact on the estimation error should be evaluated in terms of the avoided problems that MV OPF achieve using different inputs (i.e. network snapshots with different estimation errors caused by diverse SCADA measurements availability/location). This is also valid for the remaining HLUC assessment.
### Table 5: Main factors for SRA analysis of HLUC01

<table>
<thead>
<tr>
<th>Tools/Factors</th>
<th>Number of nodes /TSS</th>
<th>Grid Type: Radial/meshed /YR</th>
<th>DER type/amount /localization (including switches reconfig.) /TESDSSR</th>
<th>RES type/amount /localization/profiles /TESDSSR</th>
<th>SCADA measur. availability/ location /YR</th>
<th>Historical Data availability/ location /YR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forecasting tool</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Forecast error</td>
</tr>
<tr>
<td><strong>MV Load allocation</strong></td>
<td>Time performance</td>
<td>Estimation error</td>
<td>-</td>
<td>Estimation error</td>
<td>Estimation error</td>
<td>Estimation error</td>
</tr>
<tr>
<td><strong>Multi-period Optimal Power Flow</strong></td>
<td>Time performance</td>
<td>Time performance</td>
<td>Avoided problems Voltage deviations Total costs Energy losses RES hosting</td>
<td>Avoided problems Voltage deviations Total costs Energy losses RES hosting</td>
<td>Avoided problems Voltage deviations Total costs Energy losses RES hosting (planning impact)</td>
<td>Avoided problems Voltage deviations Total costs Energy losses RES hosting (planning impact)</td>
</tr>
</tbody>
</table>

T=technical, E=economical, SS=scalability in size, SD=scalability in density, R=replicability

The functionality-oriented analysis will be performed in order to evaluate the three smart grid functions developed for the specificities of this HLUC. Portugal and Slovenia will be considered for the analysis, as the HLUC is implemented in both demos and data should be available to perform the simulations. The ICT-architecture presents challenges from the integration perspective so the replicability will consider both countries as well.
3.2. HLUC02  Pre-evaluation  (Distributed monitoring and control of LV network using available flexibilities)

A schematic approach of the tools and functionalities involved in the HLUC02 is shown in Figure 8.

Figure 8: Tools chain for the LV control system (HLUC02)

The module for load and renewable generation estimation and the module for the LV grid state estimation provide both data to the LV control module.

All the tools associated with this HLUC can also be separately used, therefore providing their own results, which could be used by a wide range of services. Nevertheless, the LV control is the tool that provides the outcome of HLUC02. Since the SRA analysis is being performed at the HLUC level, the accuracy of the other tools will be indirectly analysed by looking at its impact in the output of the LV control.

The LV control has two different modes of operation:

1. **Predictive management of the grid using load and DRES forecasts**: a predictive plan for grid management is performed based on load and RES forecasts, by defining future set-points for DSO and DRES flexibility resources (Energy Storage, HEMS, OLTC transformers, FACTS). The process is performed as follows:

   - A ratio analysis between demand and generation in each phase is performed to identify scenarios where voltage violations or overloads are most likely to occur (although overloads are less frequent since the networks are usually oversized, and since solving voltages deviations also tends to avoid overloads).
   - For each of the scenarios identified as potentially problematic, the initial time frame of the voltage violation or overload is determined. This is performed by recursively running a three-phase unbalanced power flow algorithm for the previous time frame, until the time frame when the problem starts is identified, and therefore the total time range of the deviation.
• For this time range the Control Actions Management Module is applied.

• A control action plan to address the problem is determined according to the established merit order (e.g., prioritizing the DSO’s recourses, such as OLTC transformers and Energy Storage systems over HEMS flexibility use), the resource availability, the connection phase and the resource’s proximity to the problem.

• The outcome of the predictive management module is a control action plan with the future set-points for the selected resources, which are then considered to be pre-booked.

2. Real time control:

• Using the current state of operation of the network (obtained from real time measurements when available, or LV estimations when not) and the most recent forecasts, the predictive plan is evaluated (i.e. new power flow simulation is run) to verify the adequacy of the predictive management’s control action to address the problem. All nodes voltages are required, either measured or estimated. Estimations are therefore made whenever just a few RT measurements are available.

• If the forecasted state is similar to the current state, the previously defined control action, with the selected flexibility resources set-points, is sent to the DSO for validation and then executed. If not, new control actions, based on the most recent data available, are determined and then sent to the DSO for validation and execution.

• If unforeseen voltage problems arise, the Control Actions Management Module is also applied to define a new control action with the available flexible resources to address the problem.

• The probabilistic nature of the LV state estimator allows the control tool to express the risk exposure of the operation to voltage violations. This is accomplished by defining thresholds for probabilistic voltages that will trigger the process of adjusting the control actions (e.g. overvoltage at a given node is estimated to occur with 20% certainty and it is within the threshold to activate the voltage control).

Given the large number of variables involved in this analysis, and subsequent large amount of simulation scenarios that derive from it, a methodology has to be established in order to limit the number of scenarios under evaluation, while still properly evaluating the HLUC SRA under realistic conditions. Therefore, as previously stated, the general approach is to focus on worst case scenarios, i.e. scenarios that could impact the grid’s controllability, the tool’s time performance, number of avoided problems or the grid’s RES hosting capacity. Other, more specific factors can also be analysed, if considered relevant to the tool’s performance.

In the scope of the InteGrid project, innovative solar photovoltaics and storage inverters will be developed up to the certification stage. DNV GL in its Flexible Power Grid Laboratory will carry a full-converter test and validation stage. In addition, INESC TEC will also validate the
communication interfaces between these grid-connected converters (single-phase) with the HEMS. The operation of these inverters is directly associated with both the LV control (HLUC02) and the HEMS (HLUC09) depending on how the PV and energy storage systems are controlled (i.e. only through the HEMS or separately), but since they are essential part of the LV control, it was decided to include their SRA analysis in this section.

Regarding the ICT architecture supporting the HLUC implementation in the Portuguese demo, the Load/RES Forecasting function is located at the operation-distribution levels. The LVC and the LV state estimator are coupled in one device, at the Distribution Transformer Controller (DTC), which is located at station-distribution level.

For the predive LV grid management the communication path goes as follows. The DMS pushes the network topology and the current state of network equipment to the DTC. The DTC retrieves the necessary SM measurements from the low voltage. The Load and RES forecasting systems and the HEMS (through the gm-hub) share the Load/RES forecast for each node and the available flexibilities respectively. From there, the control set points are forwarded to the operator.

For the real-time control the data flow towards the DTC goes as follows. The DMS sends the network topology and the current state of network equipment to the DTC. The gm-Hub sends the available flexibilities to the DTC. Moreover, the AMI head end provides the DTC with historical data (P, V, RTU ID) and with real data (P, V, RTY ID). From the DTC two connections are established: the first one to the operator (HMI) to carry the information regarding the control send points and the second one to the DER (MV and LV) aggregator (RTU).

<table>
<thead>
<tr>
<th>Topic</th>
<th>Evaluation</th>
</tr>
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<tbody>
<tr>
<td>Objectives of the</td>
<td>The objectives of the current HLUC are:</td>
</tr>
<tr>
<td>HLUC</td>
<td>1. Define predictive control action plans to address foreseen voltage and</td>
</tr>
<tr>
<td></td>
<td>overload problems.</td>
</tr>
<tr>
<td></td>
<td>2. Monitor the LV network and its assets in (or close to) real time.</td>
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<tr>
<td></td>
<td>3. Manage the available flexibilities to avoid technical violations that</td>
</tr>
<tr>
<td></td>
<td>may occur (voltage limits or branch overload).</td>
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<tr>
<td>SRA methodology</td>
<td>The quantitative SRA will be based on a set of selected simulations to</td>
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<tr>
<td></td>
<td>assess the main scalability and replicability aspects, focusing on worst-case</td>
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<tr>
<td></td>
<td>scenarios.</td>
</tr>
<tr>
<td></td>
<td>The following assumptions are made in HLUC02:</td>
</tr>
<tr>
<td></td>
<td>• Only networks with voltage or overload problems will be considered, since</td>
</tr>
<tr>
<td></td>
<td>otherwise the LV control module will not perform any action (since most</td>
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<tr>
<td></td>
<td>historical data corresponds to normal operation conditions, even if situations</td>
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<tr>
<td></td>
<td>concerning technical violations can also be covered by the train data,</td>
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<tr>
<td></td>
<td>train data will mainly correspond to normal operation, and therefore a</td>
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<td></td>
<td>negative impact in the state estimator performance in these scenarios could</td>
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<td></td>
<td>be expected).</td>
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<tr>
<td></td>
<td>The economic analysis will be based on the control of three monetizable</td>
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<tr>
<td></td>
<td>KPI’s:</td>
</tr>
<tr>
<td></td>
<td>• Value of losses (as compared to a baseline).</td>
</tr>
<tr>
<td></td>
<td>• Avoided RES trips (also as compared to base line).</td>
</tr>
</tbody>
</table>
Avoided investment in the grid (also as compared to base cases and focused on the scalability in density analysis – high RES/load volumes).

Therefore, the economic analysis will require the following data:

- Cost of losses for DSO at LV level (€/MWh) in each country.
- Cost of CO₂ in each country (present and future projection).
- Average CO₂ emissions per MWh of generated electricity in each country.
- Price of energy sold at LV level by RES (€/MWh).
- Typical cost of standard network equipment such as power transformers, lines and cables at LMV level.

Scalability in density will be evaluated through the following factors:

- **Amount/volume and location of connected DER and loads per grid section and flexibility availability** – the location and concentration of DERs and loads relatively to voltage problem sources, as well as their availability at the control action implementation period, has an impact in the management of the problems.

- **Amount/volume and location of connected RES and load/generation profiles.** The location and concentration of RES in different points of the grid will impact the grid’s controllability in different ways. Furthermore, scenarios with different load and generation profiles - illustrating seasonality - will also be tested to evaluate the tool’s performance under these conditions.

- **HEMS and other DER activation:** the response of the LVC under non-activation of particular resources should be tested.

Scalability in size will be evaluated according to the following factors:

- **Number of grid nodes** – starting from a typical network, the tool’s performance will be assessed for grids with different number of nodes by homogeneously scaling the number of grid nodes – e.g. increasing the number of nodes to the worst cases observed or predicted - with the main objective of evaluating the tool’s time performance under these conditions.

- **Number of connected loads, RES and DER** – different scenarios, with different power levels of loads, RES and DER will be evaluated with the objective of assessing the tool’s performance by using the KPIs defined below in this table.

Regarding the inverters operation: **Different power levels of variable PV panels’ integration** will be considered.
Two components are considered as critical for this HLUC: the DTC, due to its critical importance since it englobes two functions (LVC and LV state estimator), and the AMI head end, since data process time can be affected by scaling.

**Communication and Information layers**

From the protocols and communication technologies perspective, Modbus is the only protocol to be considered as critical. It can only address a limited number of devices (254). In addition, it does not provide cyber-security by its mere implementation, hence, additional has to be provided.

The HLUC02 solution has the following requirements (essential for its replicability) to perform adequately:

- Only radial networks are considered in the LV control module since this type of topology is the most typical in LV networks.
- Historical data from the grid to be controlled
- Weather measurements for the controlled time horizon (temperature, irradiance, etc.)
- Detailed grid topology
- Network technical constraints (voltage limits, flows limits) fixed by existing regulation
- Available flexibilities and associated costs (indirectly established through the merit order).

**Replicability will be tested according to the following factors:**

- Grid characteristics: The Low Voltage Control (LVC) performance may be influenced by the characteristic impedance of the network (rural networks are typically resistive, urban networks are typically more inductive), which can influence the active power based droop control from the HEMS
- DER types and location
- Location of loads
- RES types and load/RES profiles – assess the tool’s performance for different RES types and energy generation and consumption profiles, illustrating seasonality and different geographies
- Rules for HEMS controllability (according to the existing regulation that may limit DSO controllability of HEMS) – task for the regulatory SRA.
- Amount and location of SM (RT measurements and historical data): all nodes voltages are needed for the LV control. At least one RT measurement per phase and feeder is required to ensure the estimation feasibility. Therefore, the availability of historical data and/or the existence/location of RT measurements may affect the quality of the final control (affecting also the scalability in size).
- Amount and location of load and RES historical records (affecting also the scalability in size)
- Overvoltage time range (affecting also the scalability), due to the computational burden of identify this time period.
Regarding the inverters operation:
- Grid codes compliance: compliance with specific aspects of local regulatory framework (e.g., VDE Testing and Certification in Germany)
- Different grid conditions (e.g., voltage dips, harmonic interference or faults, at real voltage and power levels)
- Different operation conditions (i.e. normal and emergency)
- Different operating temperatures (there are two operating bands, a larger and a more restricted)

### Replicability intranational

A matching between the above general replicability aspects and the particularities of the considered regions will be performed to assess the replicability in those regions.

In addition, other qualitative aspects such as local regulation or stakeholder acceptance and involvement may also be considered.

Considering the Portuguese demo is the only demo implementing this HLUC and given there is only one DSO in Portugal, from an intranational perspective, the only reasons for intranational study would be security (DSO premises) and address the minimum capacity requirements (bandwidth) to allow basic communications and RT control.

### Replicability international

The countries initially considered will be those involved in the demonstration: Portugal, Slovenia and Sweden. Other possible countries could also be Spain, the Netherlands and Austria, attending to the origin of the consortium participants (to be decided).

A matching between the above general replicability aspects and the particularities of the considered countries will be performed to assess the international replicability in those countries.

In addition, other qualitative aspects such as national regulation (tariffs, RES incentives, data protection regulation, etc.) or stakeholder (regulator, TSO and DSO, etc.) acceptance and involvement may also be considered.

Concerning the ICT, Portugal demo will be studied for migration into the Slovenian demo. Moreover, for this HLUC, the ICT shall focus on testing interoperability and interchangeability regarding the inverters over the interconnection with other systems besides the HEMS using standard communications (e.g., Modbus RTU-TCP/IP).

### Tools to perform a SRA

HLUC02 tools (load and RES DSO forecast system, LV state estimation and LV control module), being LV control module the one that provides the HLUC output.

### KPIs

The KPI have been interpreted as absolute measurements of the solutions performance. The improvement or deterioration of this performance is evaluated by comparing the computed KPI among different scenarios.

- (Computational) time performance.
- Power quality and quality of supply, in terms of reduction of voltages and overloads limits deviations, and voltages phases’ imbalances. This may be rather difficult to estimate unless the baseline (see below) allows for this type of problems. Otherwise, overvoltage’s/overloads would probably never happen, since the planning module will not allow them.
• Estimation errors of the state estimator and forecasting tools due to the availability of historical data and/or RT measurements. Errors impact on the LV control may be very complex to assess. A possible approach could be to compare the performance of the plan obtained with real measurements (i.e. perfect information) with the control obtained from scenarios with forecast/state estimation errors.

• RES hosting capacity: although not being the main objective, the exploitation of the added flexibility is expected to have a positive impact in the LV network RES hosting capacity. However, this analysis may be difficult to perform, due to the large number of new simulations. The chosen approach is based in the RES/DER Enhanced Hosting Capacity KPI, proposed by the European Electricity Grids Initiative (EEGI), which measures the additional RES that can be connected to the grid above the BAU scenario. This methodology may be fulfilled by determining the grid’s hosting capacity for both scenarios by installing a generator at the highest voltage node and increasing its power until any of the grid’s nodes reaches its maximum admissible value.

The following comments should be considered regarding other potential KPI:

• Total costs: there is neither a cost reduction objective nor a total cost measure, even if a merit order is established among the possible flexibilities to be activated. Therefore, the total cost may not make sense as a KPI unless meaningful costs are established for network performance and flexibilities usages (possibly in the CBA).

• Energy losses: its reduction is not an objective of the use case, and keeping voltages and line flows inside their limits could decrease or increase losses. However, the performance on this KPI may be tested under different scenarios.

• Load shedding: as for losses, it is not a specific objective although its performance could be analysed under different scenarios.

The simulations should produce outputs for each of the selected KPIs, and, if possible, both in magnitude and associated cost (if and when available).

The baseline to be considered is:

• For overvoltage or line overloads, no RT action is taken, only recording to help in future decisions making on reinforcements.

• In extreme situations protections could trip and disconnect parts of the network.

Since there is no explicit cost objective for this HLUC, the SRA will focus on the number and magnitude of the avoided voltage/overload violations. For a set of selected simulation scenarios, the LV control using real time measurements should be obtained and compared to the performance of the control strategies resulting from forecast/state estimation with associated errors. However, a systematic approach for this testing may be difficult to design and very time consuming, and will have to be limited to a few case studies.
Regarding the inverters operation, the baseline should be compliant with the relevant standards for the inverter components development (e.g., IEC 60904) and for the integration with utility systems (e.g., IEC 61727, IEC 62116, IEC 62910). Additionally, it should also be compliant with relevant testing standards in order to ensure the safe operation of inverters (e.g., IEC 61739, IEC 62109). The baseline grid conditions should refer to the ones available in the countries of the demonstration sites (at least).

The following table illustrates the main factors that will be considered in the definition of scenarios, as well as the associated KPIs and targeted tools.

**Table 6: Main factors for SRA analysis of HLUC02**

<table>
<thead>
<tr>
<th>Tool/ Factors</th>
<th>Number of nodes</th>
<th>Grid Type: Only rural/ Only urban/ (redundant)</th>
<th>DER type: amount / location</th>
<th>RES type/ amount/ localization/ profiles</th>
<th>IM availability / location</th>
<th>Historical Data availability / location</th>
<th>Correct HEMS/ DER flexibility activation</th>
<th>Overvoltage time range</th>
<th>HEMS controllability rules</th>
<th>Standardization Compliance Grid code compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load and RES forecasting system</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Forecast error</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LV State Estimator</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Estimation error</td>
<td>Estimation error</td>
<td>Estimation error</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LV control</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Avoided problems Voltage deviations Total Costs Energy losses RES hosting</td>
<td>Avoided problems Voltage deviations Total Costs Energy losses RES hosting</td>
<td>Avoided problems Voltage deviations Total Costs Energy losses RES hosting</td>
<td>Avoided problems Voltage deviations Total Costs Energy losses (planning impact)</td>
<td>Feasibility of the control Network operation improvement</td>
<td>Time performance</td>
<td>Controllability Regulatory analysis</td>
</tr>
<tr>
<td>Inverters</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Standardization Compliance Grid code compliance analysis</td>
</tr>
</tbody>
</table>

T=technical, E=economical, SS=scalability in size, SD=scalability in density, R=replicability

Since several smart grid functions are (only) implemented in this HLUC, the functional-oriented analysis shall be performed. Given the importance of LV data for the simulations, Portugal only will be considered for the replicability study. In case Slovenia provides LV network data (which seems unlikely), specific scenarios could be created to perform a replicability study. The ICT-oriented and the economic-oriented analysis will be focused on Portugal as well.
3.3. HLUC03 Pre-evaluation (Perform health diagnostics and preventive maintenance planning of distribution network assets)

This Use Case aims at using data analytics to improve the distribution-grid reliability and to reduce its maintenance costs. In order to evaluate the health conditions of secondary substations transformers, vital information is collected by the DSO using the advanced metering infrastructure (AMI). This information is processed by analytical tools operated by the DSO, able to diagnose and assess the current health conditions of the transformers. The function performing this diagnosis is depicted in Figure 9 below. The main output is a Health Index, used by the DSO to identify the investments and maintenance costs and to create a management plan of the transformers for different time horizons.

![Figure 9: Tools chain for the Health Diagnostic (HLUC03)](image)

The functional analysis will solely focus on the Health Diagnostic function, the process deployed by the DSO to use the Health Index is out-of-scope. The economic benefits arising from the asset management plan will only be considered in the economic analysis.

It is important to note that at the time of writing this document, there is a significant lack of information related to this HLUC, particularly concerning the requirements, the ICT architecture and the specifications of the Health Diagnostic function which impacts the development of the SRA methodology. Therefore, the pre-evaluation presented hereinafter is likely to change during the proceedings of the analysis, and therefore the simulation scenarios will be created in the future awaiting additional information.
### Objectives of the HLUC

The objectives of the HLUC are the following:

- To perform health diagnosis of secondary substations equipment based on information remotely collected by off-the-shelf sensors mounted in substations.
- To identify investments or maintenance actions for end-of-life assets considering the consequences of their outages.
- To select the cost-effective investment or maintenance plan for end-of-life assets considering the prioritization guidelines issued by business analysts.

The analysis carried out for the Scalability and Replicability will exclusively focus on the first objective of the HLUC, which is the health diagnosis of power equipment.

### SRA methodology

Although one of the main objectives of this HLUC is to improve the distribution network reliability, the functional analysis will not consist in any reliability assessment. Instead, the analysis will be narrowed to secondary substation transformers.

The functional-oriented and ICT-oriented SRA will be performed on the Health Diagnostic function while the economic and regulatory analysis will be extended to the asset management plan in order to monetize the benefits of the solution.

From an economic perspective the SRA will consider essentially the costs of the monitoring equipment, associated communication and IT systems. The benefits will be evaluated from two perspectives:

- Decrease in maintenance costs (since no time-based maintenance will be realized);
- Decrease in failure costs. We will assume that no unexpected failures happen with the HLUC in place.

Therefore, the economic analysis will require the following data:

- Costs of sensors, communication equipment and associated IT systems to support the functionalities.
- Failure rates of transformers in secondary substations. Cost of new MV/LV transformers, including transport and installation.

### Functional

Given that Health Diagnostics will be created on a daily or weekly basis, the (computational) performance of the algorithm is not critical. Therefore, the scalability will not be considered from the functional perspective.

### Scalability

Since the fully integration of the secondary substation into the SCADA system is still under development, the purposed ICT architecture may vary. Nonetheless, for the purposed one:

#### Component layer

From the component layer perspective; smart meters (sensors) are critical devices for measurements for primary and secondary substations and their proper integration with
the SCADA system is crucial. Scaling up their number can provoke performance issues at the AMI Head end.

**Communication and Information layers**
The protocols are industry best practices; therefore, they should not be a constraint for the scalability. Nevertheless, data availability and quality (frequency) from secondary substations are critical for the system as they may compromise the functional layer.

**Conclusion**
For this HLUC, the ICT architecture of the Swedish demo is to be considered for further analysis due to possibility of analysing an interesting ICT which supports an innovative function. However, the scalability analysis should bear in mind the concerns regarding the components to be implemented as they may affect the analysis.

<table>
<thead>
<tr>
<th>Replicability</th>
<th>The main requirements of the Health Diagnostic function are the followings:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Historical data of interventions</td>
</tr>
<tr>
<td></td>
<td>• Outages statistics</td>
</tr>
<tr>
<td></td>
<td>• Sensor data (P, V and I with min, max and mean values for 15 minutes intervals)</td>
</tr>
<tr>
<td>Replicability</td>
<td>The replicability will be tested according to the following factors:</td>
</tr>
<tr>
<td>intranational</td>
<td>• Availability of the measurements</td>
</tr>
<tr>
<td></td>
<td>• ICT min requirements to enable functions and interfaces</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Replicability</th>
<th>The assessment of the intranational replicability is done by evaluating the functional and ICT requirements for solution deployment in another area of the same country.</th>
</tr>
</thead>
<tbody>
<tr>
<td>international</td>
<td>Functional-oriented analysis will be only considered in Sweden, since the analysis will be likely performed in the scope of the demonstration.</td>
</tr>
<tr>
<td></td>
<td>Economic analysis can be extended to other countries of the consortium such as Spain and Portugal.</td>
</tr>
<tr>
<td></td>
<td>Regulatory analysis will be considered</td>
</tr>
</tbody>
</table>

| Tools to | The Health Diagnostic tool will be used in order to evaluate its performance.                                                |
| perform a SRA |                                                                                                                            |

<table>
<thead>
<tr>
<th>KPIs</th>
<th>The following KPIs are considered for the analysis:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Reliability index of the power equipment (e.g. MTBF) to evaluate the effect of the predictive maintenance</td>
</tr>
<tr>
<td></td>
<td>• Accuracy of the health diagnostics: the accuracy of the algorithm is affected by the availability and the quality of the input data required, therefore it is considered in the replicability analysis</td>
</tr>
<tr>
<td></td>
<td>• Reduced maintenance costs achieved by the implementation of the Health Diagnosis function and the asset management plan: this KPI</td>
</tr>
</tbody>
</table>
is relevant for the economic analysis only and it should be obtained from the demo analysis.

Baseline

The baseline is business as usual, where only preventive maintenance planning of distribution network assets can be performed, considering for instance the degradation of the components and of the oil.

A commercial tool from SAP, the Predictive Maintenance and Service (PdMS) product, will be used and adapted to the needs of the InteGrid project. The objective is to produce a Health Index for primary substations distribution transformers. From the functional perspective (in particular the replicability), the Health Diagnostic function seems promising. Concerning the ICT-oriented SRA, this HLUC is very specific to the Swedish demo and the integration in other DSO systems is not foreseen. The fact that this is a commercial tool also makes it less attractive from the ICT-replicability perspective. The economic analysis appears to have a good potential as well. Given the difficulty to obtain the cost data, it will be performed in Sweden only.
3.4. HLUC04 Pre-evaluation (Define optimal repair actions for unplanned outages based on sensor data, historical information and remote equipment diagnostic)

This HLUC aims at reducing the restoration time of unplanned outages, based on the use of a fault-detection function and a Workforce Management (WFM) process, which aims at maximizing the performance levels in the organization.

The global procedure of HLUC04 (depicted in Figure 10) is described in the following points:

- At first, the Distribution Management System (DMS) detects an outage by crossing the information from multiple indicators and it informs the operators about the fault.
- From the data gathered before and after the event and the network topology, an analysis is performed to circumscribe the outage area and to locate the fault (this is performed by the Smart Grid function ‘Locate MV fault’).
- The equipment responsible for the fault is identified and a set of actions to isolate the fault and to restore the service is defined. In this last step, the intervention teams are selected and deployed by the Workforce Management System.
A similar remark as for HLUC03 is valid: at the time of writing this document, there is a significant lack of information (e.g. the ICT architecture for fault detectors integration is not yet finalized and the data models are not clearly defined). This impacts the development of the SRA methodology for all areas. Therefore, the pre-evaluation presented hereinafter is likely to change during the proceedings of the analysis and the scenarios will be created in the future awaiting additional information.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives of the HLUC</td>
<td>The main objective of this HLUC is to develop a process to optimize restoration and repair actions of unplanned outages based on pre-fault data collected from sensors, on remote equipment diagnostics, and on historical data collected from smart secondary substations.</td>
</tr>
<tr>
<td>SRA methodology</td>
<td>The functional and ICT-oriented SRA will focus only on the Smart Grid function named ‘Locate MV fault’, since the Workforce Management System (WFM) only consists in a set of procedures, which makes it difficult to evaluate from the technical perspective. Nevertheless, the economic analysis can consider both the MV fault location detection function and the WFM.</td>
</tr>
<tr>
<td>Functional</td>
<td>The functional scalability is focused on the MV fault location function for the reason stated above.</td>
</tr>
<tr>
<td>Density</td>
<td>A very important aspect to consider is the time criticality, since the main objective is to reduce the time to locate the fault. The scalability in density will be analysed by varying the number of fault-indicators in the network, in case increasing the quantity of fault-indicators can affect the computational performance of the function and the data flow.</td>
</tr>
<tr>
<td>Size</td>
<td>The number of fault-indicators will be varied as well. The size of the network can be considered if it has an impact on the fault detection time. Then, the economic analysis will consider the benefits for the DSO to implement this system at a larger scale.</td>
</tr>
<tr>
<td>Scalability</td>
<td>An increasing number of fault-indicators devices may affect the ICT infrastructure purposed by the Swedish demo. Additionally, the integration of additional sensors for further monitoring should be explored.</td>
</tr>
<tr>
<td>Component layer</td>
<td>Communication and Information layers</td>
</tr>
<tr>
<td>ICT</td>
<td>Wireless communication technologies can become a constraint due to limited bandwidth. Additionally, disruption of communication channels may lead to ‘emergent properties’ which bias the corrective actions, especially if this occurs in grid low-use hours, when customer calls are less frequent.</td>
</tr>
</tbody>
</table>
The following sources of data are needed in order to locate the faults:

- Historical data on outages location and causes
- Fault-indicators (devices mounted on the network, communicating with the SCADA system).

**Replicability**

The functional-oriented replicability analysis could be performed by making sensitivity analysis according to these factors, for instance by varying the number and location of fault-indicators in the network.

ICT analysis would consider the minimum requirements (not yet available) for its domestic replication.

**Replicability intranational**

The ICT-oriented SRA will consider how the MV fault location function can be replicated in the other demonstration countries (Slovenia and Portugal).

The regulatory analysis will be extended to other countries of the consortium that have been considered in the WP1 analysis, and eventually extended to a few other countries.

**Replicability international**

The fault detection function can be used to evaluate its performance.

The results arising from the WFM implementation will be obtained from the demonstrators.

**Tools to perform a SRA**

The following KPIs will be produced or measured:

- **SAIFI and SAIDI**: the improvement of these reliability indexes will be either produced via simulations, or measured and extrapolated from the demonstrator
- **Time to identify the failure**: this parameter is used to evaluate the performance of the fault-detection function. It is considered in the functionality-oriented SRA and mainly affected by the number of sensors available.
- **Time performance of the tool**: considering the computational performance of the function as well as the time inherent to the ICT architecture
- **OPEX and CAPEX**: of the components / ICT architecture needed to perform the function

**KPIs**

The baseline is business as usual where the information of an outage is received automatically without exact location of the fault and additionally by customers calling in to report an outage.

The repair actions are performed by the field-team by identifying the fault location based on the available information (and own experience).

**Baseline**

From the functional perspective, the interest of this HLUC lies in the Fault-location function. At this stage, it is not decided whether new (smart) features will be added to this function in the continuity of the project. Similar functions are also widely deployed and used by the DSOs, therefore the functionality-oriented scalability and replicability doesn’t present any significant interest nor potential. Similar observations can be made concerning the ICT-oriented SRA, which will not be considered. Finally, the economic benefits of the HLUC seem difficult to capture so the economic-oriented SRA will not be applied.
3.5. HLUC05 Pre-evaluation (Manage the impact of flexibility activation from resources connected to the distribution network)

In the context of this HLUC, the TSO is contracting flexibility products on the balancing market for Replacement Reserve (mFRR). These flexibilities, provided by resources connected on the distribution grid and operated by a Flexibility Operator (e.g. a Virtual Power Plant operator or an aggregator), can affect the distribution network state (and potentially create violations such as overloading or over voltage).

The Traffic Light System is the Smart Grid function used to perform the evaluation and the validation of the schedule prepared by the Flexibility Operator (FO). Several Smart Grid functions (shown in Figure 11 below) are used by the Traffic Light System, most of them described in the HLUC01:

- Load/RES forecasting DSO system for MV networks
- Multi-Period Optimal Power Flow (OPF) for MV networks

![Figure 11: Schematic view of the Traffic Light System](image)

A Power Flow calculation is performed to detect eventual constraints due to activation of the flexibility programs sent by the Flexibility Operator. The OPF is used in a similar way as in HLUC01, although additional inputs are needed to consider the Flexibility Programs.
The Grid-Market Hub is used in HLUC05 with the main objective to communicate and exchange the flexibility bids and the Traffic Light evaluation between the Flexibility Operator (in most cases the commercial VPP) and the DSO.

The Traffic Light System (TLS) is used in two different time frames:

1. **Ex-ante evaluation**: the TLS evaluates the flexibility programs (schedules) composing mFRR bids before the TSO activation.
   - Flexibility Operators (FOs) communicate the mFRR bids (and the flexibility programs composing them) to the gm-Hub and the TLS gets them every 15 minutes.
   - The TLS gets the Load/RES forecasts from the forecasting function mentioned in HLUC01 and it also prepares the network model to include the most recent topology changes.
   - The TLS evaluates the impact of activating the flexibility programs. All the bids submitted on the mFRR market and the flexibility programs composing them are considered in this step, which corresponds to the worst-case scenario. A Power-Flow (PF) calculation is performed to detect potential network violations. In that case, an OPF calculation is performed to calculate the maximum volume of flexibility allowed (according the bid energy price).
   - The results of the evaluation are communicated to the flexibility operators via the gmHub.

2. **Post-activation evaluation**: it is performed in close-to-real time after the activation of the mFRR bids by the TSO.
   - The TSO calculates the volume of mFRR reserve needed and he selects the bids according to the merit order curve. Activation schedules for the selected bids are sent to the gm-Hub and transferred to the TLS;
   - The TLS gets the Load and RES forecast for each MV node, with a time horizon of one hour. The latest status of the network state is also obtained in this step.
   - The OPF evaluates the impact of the flexibility programs composing the activated bids. The programs which are problematic are curtailed according to the bids energy price.
   - The FO request the evaluation results via the gm-Hub and he activates the resources according to the amount of reserve activated and the TLS results. The activation status is reported to TSO and the TLS.
### Evaluation

The objectives of this HLUC are the following:

- To ensure a non-discriminatory access to the mFRR markets for all actors.
- To enable the TSO to use the flexibility from the distribution grid for balancing reserves, while the DSO guarantees the safe operation of the distribution grid in line with the quality standard (e.g. voltage quality and interruption times).
- To help to a safe operation of the transmission grid.

### SRA methodology

The main objective is the increase of the volume of available flexibility and the limitation of the risk of constraints on the distribution network.

The performance of the Traffic Light System, relies mostly on the functions used by the Traffic Light System (Forecast, OPF/power flow and Traffic Light System algorithm) which are already considered in the HLUC01. Some specific scenarios will be evaluated to account for specificities introduced by the Traffic Light system (e.g. new variables are introduced like the flexibility programs and the flexibility bids, increasing the complexity and the flows), however a significant part of the results of the functional-oriented SRA of HLUC01 will be extrapolated for the HLUC05 functional-oriented SRA.

Similarly, the ICT-oriented SRA can consider in addition to HLUC05, HLUC06 (gm-Hub) and HLUC01 due to their functionality wise link.

From an economic perspective, the analysis will consider:

- The benefits to the owners of the assets of being able to participate in the mFRR market in a safe way, and therefore make additional revenue.
- The economic benefit of increasing the competition in the mFRR market

The costs associated to the systems required to put it in place.

---

### Density

From the functional perspective, the increase of resources in density or size affects the different Smart Grid functions present in this HLUC. In addition to HLUC01, other attributes will affect the performance of the TLS. The impact of scaling variables will be very limited on the Power Flow due to the robustness of the tool.

An increased number of participants in the same grid area can affect the computation time of the OPF and the time for data acquisition and processing. The scalability in density will be evaluated by varying the following factors:

- Number of flexibility sources and number of flexibility operators

### Size

The TLS core algorithm (for data management) could become difficult to handle as the number of FO increase when the area gets larger.
Although the number of flexibility sources and programs has an effect on the power flow and OPF module, the scalability of these tools is already covered in the scope of HLUC01.

**Component layer**

Along with the critical devices highlighted in HLUC01 (i.e. the AMI head end and the MDMD (are affected by the increase of measuring points from real time and MV/LV substations)), the gm-Hub has a key role for the multiple possible actors’ integration.

**ICT Communication and information layer**

The possible increase in requests over the “OPF module” can downgrade its performance as the flow data rate is scaled up. Its communication and data handling will be assessed. In addition, data frequency increase, can provoke bottlenecks over the data collectors and the AMI-head-end data process. Formats supported by the MDMD should also be addressed due to its connections to numerous components.

| Replicability | The following aspects are required for HLUC05 (in addition to HLUC01):
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>• Flexibility bids and programs as well as communication infrastructure requirement to exchange information between the TLS and the FOs shall be provided.</td>
</tr>
<tr>
<td></td>
<td>• Internet connection between stakeholders and gm-hub;</td>
</tr>
<tr>
<td></td>
<td>• The needed tools for the SRA, listed above, require connection to external sources (metering data; CRM);</td>
</tr>
</tbody>
</table>

**Replicability intranational**

In some network areas, the activation of flexibility programs might not create any constraint on the distribution network, if the network is over-dimensioned or if low volumes of flexibilities are activated, which makes the deployment of the TLS unnecessary. Hence, the potential of the TLS in other network areas (of the same DSO or from other DSOs) within the same regulatory framework will be assessed. Not only the topological and electrical characteristics of the network will be considered but also the diversity of resources connected to it (size, type).

**Replicability international**

The regulatory framework will strongly affect the replicability of HLUC05 since the current TLS is designed for the Portuguese and Slovenian markets. Therefore, the particularities of other countries (of the consortium) will be considered as well.

As for the intranational replicability, the evaluation of the TLS will be tested with different network characteristics (voltage levels, DER types and levels, topologies, etc.). From the ICT perspective, the Slovenian will seek replication into the Portuguese demo through the analysis interchangeability (different components) and interoperability (data exchanges).

**KPIs**

- Time performance: it is critical for the “Post-activation evaluation” because this process is done in close-to-real time and can affect the balance of the power system. The time performance is mainly affected by the computation time of the different functions used
within the TLS (in particular by the Multi-Period OPF), but also by the time necessary for the data acquisition and treatment. These two aspects will be considered in the scalability and replicability analysis. The modularity of the system will also be analysed as it impacts the ability of the system to scale up.

- Power quality and quality of supply, in terms of voltage limits and loading limit of network elements. The ability of the Traffic Light System to avoid constraints caused by the activation of flexibility programs inherently depends on the performance of the OPF, which is assessed in in the scope of HLUC01.
- The amount of positive and negative flexibility that can be activated without violating grid constraints and without curtailing flexibilities

The simulations should produce outputs for each of the selected KPIs, and, if possible, both in magnitude and associated cost (when available).

<table>
<thead>
<tr>
<th>Tools to perform a SRA</th>
<th>The function used within the TLS are used for this purpose: Power flow, OPF, Forecasting and TLS algorithm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>The choice of the baseline will depend on the KPIs to be calculated. We propose the two following options:</td>
</tr>
<tr>
<td></td>
<td>- In the first baseline, the TLS is blocking the activation of the flexibility programs leading to violations. This allows the computation of the reduction of the curtailed energy</td>
</tr>
<tr>
<td></td>
<td>- In the second baseline, there is no TLS so all the flexibility programs are activated, leading to constraints in the network: this allows the computation of the avoided constraints.</td>
</tr>
</tbody>
</table>

Concerning the functionality-oriented SRA, most of the smart grid functions will be analysed thoroughly in the scope of HLUC01. However, an analysis will be performed on the Traffic Light System core functions to evaluate the benefit of the impact on the distribution network and the mFRR market when deployed at a large scale. Given that the TLS is demonstrated both in Slovenia and Portugal, we propose the perform the functionality-oriented analysis in both countries. The economic-SRA will be performed as well and it will mainly consist in quantifying the economic benefit of the TLS (e.g. on the mFRR reserve market); both countries will be considered as well. The ICT SRA is partially covered in HLUC01 and HLUC12, given that HLUC05 is very inter-related with the formers.
3.6. HLUC06 Pre-evaluation (Provide data management and exchange between DSO and stakeholders)

The Grid and Market Hub (gm-Hub) is a cloud-based neutral data proxy among stakeholders (consumers, DSO, TSO and additional third parties). The platform validates authorizations, creates appropriate data flows between parties and offers the services depicted in Figure 12.

![Grid and Market Hub Diagram]

Figure 12: Gm-hub-related services covered in HLUC06

The services “Traffic Light System”, “Gather consumption profile” and “Residential Energy Resources Sizing” have not been considered here. The first is covered within HLUC05 and the last two are external services, i.e. their provider only use the gm-Hub’s infrastructure to advertise these services to the consumers. The SRA will not assess specific services therein developed and/or implemented but it will focus on the platform itself.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives of the HLUC</td>
<td>The following objectives were identified to the present HLUC:</td>
</tr>
<tr>
<td></td>
<td>• To successfully collect customers’ metering data;</td>
</tr>
<tr>
<td></td>
<td>• To successfully reply to all customers’ metering data requests;</td>
</tr>
<tr>
<td></td>
<td>• To represent the requested data in a clear and transparent way in the gm-hub;</td>
</tr>
<tr>
<td></td>
<td>• To support the respect of the legal obligations (customers’ consents, contractual relationships and privacy and security constraints);</td>
</tr>
<tr>
<td></td>
<td>• To boost, and maintain, the registration of external stakeholders in the gm-hub;</td>
</tr>
<tr>
<td></td>
<td>• To foster, and maintain, the provision of new data driven services that grow around the gm-hub;</td>
</tr>
</tbody>
</table>
• To promote, and maintain, the number of subscribers of the services offered in the gm-hub.

Given the intrinsic characteristics of this HLUC, which is an “enabler”, it is only sensible to perform the SRA from an ICT and regulatory perspective. Concerning the latter, a qualitative analysis will be performed by inferring what would be the implications of replicating the gm-hub in another EU country, by studying its energy-related legal framework.

SRA methodology
In order to be performed adequately, the following requirements must be complied:
• Cloud based system implementing Grid and Market-Hub (gm-hub);
• Internet connection between stakeholders and gm-hub;
• The needed tools for the SRA, listed below, requires connection to external sources (metering data; CRM)

This HLUC will strongly depend on gm-hub technical specifications. Therefore, only ICT-oriented is considered.

Component layer
The increasing number of users/clients of the platform (customers point, DSO, TSO and possible third parties) can decrease the system performance. Therefore, for this HLUC the technical specifications from the components need to be tested in scenarios as follow,
• Computational time to perform VEE (data processing – inner function), considering an increasing refresh rate of the existing smart meters sending upstream consumption data;
• Gm-hub response time to consumers’ queries (data processing – inner function) facing a growing number of interaction of the existing subscribers
• Gm-hub security levels, considering a growing number of queries from the existing clients.

Communication and Information layers
There are no constraints foreseen within these two layers as no internal information about the data models or the communication are provided at the time of the pre-evaluation.

The replicability analysis for this HLUC will be assessed from the ICT-oriented and Regulatory-oriented points of view.

From the ICT perspective, the analysis will be both quantitative (based in the security) and qualitative (based on interoperability and standardization).

The regulatory SRA will be fully qualitative, assessing what would be the legal openness to the implementation of the gm-hub and its envisioned
services in other countries, identifying the barriers (if any) and ways to overcome them.

In order to be performed adequately, the following requirements must be complied:

- Cloud based system implementing Grid and Market-Hub (gm-hub);
- Internet connection between stakeholders and gm-hub;
- The needed tools for the SRA, listed below, requires connection to external sources (metering data; CRM), which can be simulated through virtual machines;
- Access to legal framework regarding the energy sector of other EU countries.

<table>
<thead>
<tr>
<th>Replicability intranational</th>
<th>Intranational replicability will be tested according to the following factors:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Security requirements for the gm-hub system migration into other platforms;</td>
</tr>
<tr>
<td></td>
<td>• Interoperability of the User interfaces (UI)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Replicability international</th>
<th>International replicability will be tested according to the following factors:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• ICT wise, to provide requirements for system migration regarding components (data bases, servers, etc.), communications and information specifications (data needed, standards used to enable interchangeability, etc.).</td>
</tr>
<tr>
<td></td>
<td>• Regulatory wise, to analyse country specific regulation in order to assess if the gm-hub concept and the services that are intended to be provided therein comply with the legal framework.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tools to perform a SRA</th>
<th>To perform the SRA, the following tools are required:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Access to the gm-hub platform, based on virtual machines system, implementing all/several services from gm-hub, enabling to estimate data processing capabilities and standardisation and interoperability impacts under different conditions. The Human-Machine Interface (HMI) is a web page which can be placed in same server as gm-hub system or not. Third parties’ services can also be simulated in virtual machines;</td>
</tr>
<tr>
<td></td>
<td>These systems shall be simulated in pre-production environment.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KPIs</th>
<th>The SRA should produce outputs of the following KPIs:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Successfully reply rate: number of queries replied, by the CRM, without an error/Number of queries received by the CRM;</td>
</tr>
<tr>
<td></td>
<td>• System up-time level (ICT reliability)- non-functional requirement;</td>
</tr>
<tr>
<td></td>
<td>• Response time: time needed to send the information requested by one customer, through the gm-hub.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Baseline</th>
<th>N/A</th>
</tr>
</thead>
</table>

InteGrid WP08
Given that the Scalability of cloud systems is guaranteed, the analysis could only focus on the Replicability. Since the HLUC is demonstrated in the three countries with similar interfaces, the interest is very limited, so no ICT-oriented SRA will be performed.

<table>
<thead>
<tr>
<th>Tools/Factors</th>
<th>Number of subscribers → TSS</th>
<th>Number of provided services → TSS</th>
<th>User interface design → TR</th>
<th>Database location → TR</th>
<th>Legal framework (Regulatory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-sized gm-hub</td>
<td>Storing capacity</td>
<td>Storing capacity</td>
<td>Users’ acceptance</td>
<td></td>
<td>Feasibility (of some services, at least)</td>
</tr>
<tr>
<td>Validation, Estimation and Editing</td>
<td>Time performance</td>
<td>Time performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety and security assessment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Employed methodology</td>
<td>-</td>
</tr>
</tbody>
</table>
3.7. HLUC07 Pre-evaluation (Procure and manage regulated flexibilities from DER to optimize operation costs)

HLUC07 presents the procedures to be followed by the DSO to pre-qualify potential flexibility providers/operators and to activate their resources when previously contracted in order to solve potential network constraints. Therefore, this HLUC is divided into these two procedures: the flexibility provider pre-qualification and the flexibility resource activation (that have been pre-booked by the DSO in HLUC01).

The pre-qualification process is composed of four sub-steps, as described below:

1. Calculate flexibility needs: through network analysis, the DSO calculates the expected flexibility needed to solve potential problems in its distribution grid, and submits this information to the grid-market hub.

2. Pre-qualification of flexibility operators: Flexibility operators submit pre-qualification requests to the grid-market hub. The DSO then assesses the compliance of the flexibility provider and registers the pre-qualification information to the grid-market hub.

3. Obtain available flexibility: the flexibility provider sees DSO’s needs, calculates internal flexibility and submits this information to the grid-market hub, along with the corresponding activation cost.

4. Contract flexibilities: the DSO, as distribution constraints market officer, contracts or pre-books flexibility from pre-qualified flexibility operators that have declared their available flexibilities in order to meet the previously quantified flexibility needs.

In the activation of the contracted flexibility, the DSO as distribution constraints market officer, activates flexibilities previously contracted with flexibility operators in order to solve potential network constraints of the DSO distribution network, following the commands of the distribution system optimizer. This step involves identifying the need to activate flexibilities and sending the activation requests to parties. The activation request may happen ex-ante (day-head or intraday activation) or in the real-time. Finally, the activation data has to be registered in the grid-market-hub.
Figure 13 below summarizes the HLUC07:

![Pre-qualification and activation of flexibility](image)

**Figure 13: Illustration of the different procedures (HLUC07)**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives of the HLUC</td>
<td>The main objectives are:</td>
</tr>
<tr>
<td></td>
<td>• Pre-qualify potential flexibility providers at distribution level.</td>
</tr>
<tr>
<td></td>
<td>• Collect information on available flexibilities and their updates.</td>
</tr>
<tr>
<td></td>
<td>• Define, sign and manage flexibility contracts with providers.</td>
</tr>
<tr>
<td></td>
<td>Manage the exchange of information between the DSO and other stakeholders for the provision of non-frequency ancillary services at distribution level.</td>
</tr>
<tr>
<td>SRA methodology</td>
<td>The HLUC07 sets procedures for the DSO, and therefore a technical/economic scalability analysis seems not suitable for this HLUC.</td>
</tr>
<tr>
<td></td>
<td>The HLUC takes place exclusively inside the DSOs premises, and sets a technical procedure for the DSO to follow when pre-qualifying and activating the flexibility offered by DER connected to the distribution level.</td>
</tr>
<tr>
<td></td>
<td>In this context, the performance of the procedure should not be impacted by the number of pre-qualification requests or by the number of activations made by the DSO. For these reasons, a functional SRA is not considered appropriate for this HLUC.</td>
</tr>
<tr>
<td></td>
<td>On the replicability side, a regulatory analysis will be conducted, mainly for international replicability.</td>
</tr>
<tr>
<td></td>
<td>The DSO should be able to incorporate the gm-hub in its internal ICT structure to properly carry out the procedures described in the HLUC07, since the information flow happens in the gm-Hub. This is already covered in HLUC06.</td>
</tr>
</tbody>
</table>
Besides the manual input at the gm-Hub, the information is treated internally by the DSO and the DER, and no tool is specified for these treatments.

<table>
<thead>
<tr>
<th>Scalability</th>
<th>The scope of the HLUC07 is mainly a procedure to be implemented by the DSO, and therefore a technical scalability analysis does not seem to be necessary.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicability</td>
<td>The replicability will be analysed for regulatory barrier, mainly for international replicability.</td>
</tr>
<tr>
<td>Replicability intranational</td>
<td>Not applicable, since DSOs in the same country are subject to the same set of legislations and regulations, on both grid operation and market design. Therefore, the procedure for qualification and activation of flexibility provided by DER should find no barriers to be implemented in different parts of one country.</td>
</tr>
<tr>
<td>Replicability international</td>
<td>A regulatory assessment is necessary in order to identify drivers and barriers for the implementation of the procedures proposed in HLUC07 to different countries.</td>
</tr>
<tr>
<td>Tools to perform a SRA</td>
<td>No tool is needed since the SRA will by only regulatory-based</td>
</tr>
<tr>
<td>KPIs</td>
<td>Neither a technical nor an economic analysis is performed in the scope of this HLUC. For the regulatory analysis, a qualitative analysis will be performed, and therefore no KPIs are suitable either.</td>
</tr>
<tr>
<td>Baseline</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

The HLUC07 implements sets procedures for the DSO to pre-qualify and activate flexibilities, so neither a technical nor an economic SRA can be performed in this case. The analysis of this HLUC will only be regulatory-based.
3.8. HLUC08 Pre-evaluation (Manage internal processes’ flexibility to minimize energy costs according to market-driven mechanisms and system operators’ requests)

The objective of this HLUC is to analyse the energy-intensive processes of wastewater systems, identify and model the flexibility potential of each process. These objectives are the following:

1) Minimizing the energy cost by considering processes flexibility to minimize (optimize) electrical energy consumption.
2) Providing part of this flexibility to the DSO (and TSO) for grid constraints management, and reducing the total energy consumption cost through remuneration of this system service.

Wastewater treatment systems are based on a series of physical, chemical and/or biological processes interconnected, where intermediate reservoirs may be needed. The sources of potential flexibility are being investigated through a flexibility audit to the internal processes of AdTA wastewater systems. Although in an early phase of the evaluation, it can be expected that a major part of the flexibility will arise from minimizing the energy consumption for specific parts of the processes, especially when pump units are involved. At this stage, the optimized control of the variable-speed water pumps, at the elevation stations of the wastewater treatment facility, appears as a clear way to optimize the energy consumption, provided the levels of the water reservoir remain inside the operational range. Large reservoirs, as it is the case of water supply systems, may provide daily load shifting response capabilities, while smaller reservoirs as it is the case in wastewater treatment systems, may only be able to provide short-term flexibility. Nevertheless, after the energy audit, other processes may become eligible for a SRA analysis.

As an example, Figure 14 shows the block diagram of a water reservoir with a nominal range level of [3m, 8m]. Online measurements and forecasts of the wastewater intake rate are used by an advanced control system to maintain the water level inside the nominal range while minimizing the total energy consumption (and therefore the cost). The control is predictive, since it relies in the forecasted information to anticipate periods of high water intake rate and increase the wastewater level buffer to accommodate it. This control methodology is implemented with a data-driven learning algorithm.
Figure 14: Example of wastewater reservoir control

<table>
<thead>
<tr>
<th>Topic</th>
<th>Evaluation</th>
</tr>
</thead>
</table>
| Objectives of the HLUC | 1. Minimization of the energy cost by minimizing electrical energy consumption.  
2. Provision of flexibility services to DSO (and TSO) for grid constraints management and reduce the total energy consumption cost through remuneration of this system service.                                                                                     |
| SRA methodology     | Size or density do not seem very relevant variables for the SRA, apart from the fact that different sizes may have different impact on the total electricity cost reduction. Therefore, the SRA should mainly focus on the replicability analysis. In addition, since different plants configurations may be found, replicability may require a detailed analysis for each, so only general guidelines can be provided at this phase.  
Depending on the possibility of identifying common sub-processes it might be possible to establish a battery of sub-processes with parametrized flexibility availability for energy savings and flexibility provision. This could help for a rapid quantification of the potential savings of other plants.  
From an economic perspective, the analysis will evaluate the following points:  
- Evaluation of the energy saving cost due to optimized consumption.  
- Evaluation of the benefits associated to the provision of flexibilities such as peak demand reduction. |
Investment cost related to the implementation of the control system will be used. Moreover, historical data of the energy consumption of the wastewater plant before the system is implemented is needed.

| Scalability | Functional | Plant and components sizes may be relevant to assess the available flexibility of some processes. Some possible factors to consider, depending on the type of plants identified, could be:
|             |            | • Maximum pumping capacity of the plant (in relation to the average and maximum wastewater intake rate measured)
|             | Reservoir sizes | These factors would normally impact on the total cost savings and available flexibility. Moreover, they can help to distinguish processes eligible for short-term or long-term provision of flexibility.

| Component layer | The component layer should not be critical in terms of impact on the scalability.

| ICT | Communication and information layers | State of the art communication technologies (Lora, TCP/IP, ethernet, etc.) and protocols (DLMS/COSEM, Restful, IP, etc.) are implemented on the ICT architecture, therefore they should not be a constraint when scaling-up.

| Replicability | The HLUC08 solution has the following requirements (essential for its replicability) to perform adequately:
| Plant characteristics
| Monitoring and control automation capabilities (access to SCADA database) and devices required for data acquisition.
| Data availability for forecasting models fitting
| Potential for flexibility provision: time shifting or interruption features of plant sub-processes
| Regulation allowing providing services to TSO and/or DSO

| Replicability | Replicability can be tested according to the following factors:
| Available measurements (mentioned in the previous paragraphs), affecting the process observability and controllability
| Amount of historical data, affecting forecasting models’ errors (e.g. forecast of the wastewater intake).
| Level of wastewater intake. Different zones, different climatological conditions, different behavioural patterns, may affect significantly the amounts of flows to be processed or the plant stresses, impacting on the potential flexibility available.
| Characteristics of the wastewater pumps (variable speed guarantees better optimization potential vs fixed speed that makes control less flexible)
| Pump’s power level and nominal range of the reservoir level.
| Type of flexibility requests (power and duration, etc.).

| Replicability intranational | For wastewater facilities in the same country the above factors can be tested and mirroring the ICT architecture purposed in the Portuguese demo.
For similar industries in the other countries the above factors can be tested. In addition, regulation should be analysed since it may impose additional constraints or may contribute to flexibility offering.

<table>
<thead>
<tr>
<th>Tools to perform a SRA</th>
<th>Data-driven plant simulation model and optimal control method</th>
</tr>
</thead>
</table>

**KPIs**

- Energy savings
- Energy cost savings
- Flexibility potential (power, direction and duration), including peak load reduction.
- Process constraints violations (reservoirs levels range and possible overflows, flow ranges, etc.) that depend on the type of process, and that could entail partial flexibilities activation or activation failures (and the corresponding penalties).

**Baseline**

Control rules currently in place and with energy consumption “performance” available in the historical dataset. For example, in the particular case of wastewater elevation stations, the baseline would correspond to the current control level without an explicit energy cost optimization objective.

The following table illustrates the main factors that will be considered in the definition of scenarios, as well as the associated KPIs and targeted tools.

<table>
<thead>
<tr>
<th>Process/Factors</th>
<th>Size (pumping capacity and reservoir sizes) → TESS</th>
<th>Number of processes → TS</th>
<th>Available measurements → TR</th>
<th>Historical data → TR</th>
<th>Water intakes (affected by climate, behavioral patterns, etc) → TER</th>
<th>Pumps power and reservoir levels → TER</th>
<th>Process type and components → TER</th>
<th>Tariffs → ER</th>
<th>Type of flex offered → TER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant</strong></td>
<td>Energy and cost savings Flex potential violations Time perfm.</td>
<td>Energy and cost savings Flex potential violations</td>
<td>Energy and cost savings Flex potential violations</td>
<td>Energy and cost savings Flex potential violations</td>
<td>Energy and cost savings Flex potential violations</td>
<td>Energy and cost savings Flex potential violations</td>
<td>Energy and cost savings Flex potential violations</td>
<td>Energy and cost savings Flex potential violations</td>
<td>Energy and cost savings Flex potential violations</td>
</tr>
</tbody>
</table>

The complexity of the control system implemented in the wastewater treatment plant makes the functional-analysis challenging, and significant efforts would be needed to comprehend the different processes and the interactions between them. Given the novelty of the control algorithm developed and the high-potential of this solution, a functional-oriented SRA and an economic-SRA will be performed. This HLUC will only be demonstrated in Portugal and no other wastewater treatments companies are part of the project, so the analysis will be bounded to the demo country. Although the system integration may result in a challenge, the ICT-oriented analysis will not be performed, given the specificity of this HLUC which is only demonstrated in Portugal.
3.9. HLUC09 Pre-evaluation (Home Energy Management System)

A schematic approach of HEMS functionalities is shown in Figure 15.

The HEMS produce an optimal appliances schedule (e.g., for PV panels, energy storage systems) whose as main objectives are the minimization of the energy cost for the end-user and the maximization of self-consumption. In addition, the HEMS also facilitates the participation of consumers in demand response services. To do so, it uses the following main data as inputs:

- User comfort definitions
- Configuration preferences of participating appliances and systems (for example to avoid inconvenient manual actions)
- Data about domestic electricity consumption, electricity tariffs and PV forecasts (the HEMS may also include some forecasting algorithms to supply non-available data)
- Selected optimization criteria: although the main objective should be the minimization of the energy cost, this could also be combined with additional objectives. However, complex objective functions (OF) may require complex optimization algorithms and could slow down HEMS planning process to unacceptable speeds, being simple OF with linear problem formulations preferable. Suboptimal solutions with low errors (5% or 10%) may be totally acceptable in real environments to avoid too slow planning processes.

After collecting these inputs, the following actions are performed by the HEMS:

- It publishes the proposed schedule on the user interface for either manual or automatic validation (appliances and systems are considered for activation for the next day/hours). The approved plan is stored in a local DB
- It directly activates automated appliances and notify the user of manual activations (if the end-user has previously validated the schedule).
- It retrieves data from the appliances regarding their effective activation (e.g., time of activation, energy consumed).
• When needed, the HEMS could use remote computational resources for inference algorithms in order to detect the activation of appliances (not directly monitored). These algorithms would take advantage from the consumptions measurements recorded.

• It estimates the available flexibility to provide demand response services (e.g., voltage support), which would be managed by an aggregator. A possibility is to represent the existing flexibility with a virtual battery so as to use standard battery parameters to evaluate and operate it (either for self-consumption or provision of flexibility to the grid). This solution could prevent the aggregator from needing additional details on the customer appliances (ensuring privacy).

<table>
<thead>
<tr>
<th>Topic</th>
<th>Evaluation</th>
</tr>
</thead>
</table>
| Objectives of the HLUC | 1. According to the existing dynamic tariffs, minimize energy cost to the end user.  
2. Improve self-consumption from PV.  
3. Flexibility computation to facilitate participation in demand response programs (e.g., for voltage support). |
| SRA methodology | The quantitative SRA will be based on a set of selected simulations to assess the main quantitative scalability and replicability aspects, trying to focus on worst cases so as to limit the number of scenarios.  
The economic SRA will consist in the evaluation of the following parameters:  
- Economic gain by the end-users associated with the provision of flexibility (e.g. for voltage support).  
- Energy saving costs due to the implementation of the HEMS (to be compared with the historical data of the household).  
- Benefits for the DSO associated with the provision of services  
Cost data on the HEMS shall be provided for the economic analysis. |
| Scalability | The HEMS from the ICT point of view must be analysed as a mere component integrated into the overall ICT architecture (externally) and as an aggregation of appliances inside a house (internally).  
Component layer  
- Internally: All devices/appliances connected into the HEMS central system have to be considered as critical devices since they can be scaled up and performance of the HEMS be diminished.  
- Externally: The HEMS is to be considered a field component that can be scaled. Its connections and system integration shall be studied due to the lack of an AMI architecture at its end.  
Communication and information layers  
- Internally: The demo implementation needs to provide additional technical details for further assessment. Nevertheless, the Portuguese demo over HLUC08 has implemented state of the art communication technologies and protocols so no scalability constraints are foreseen in these layers. |
Externally: more information regarding the communication technology and the data is being transmitted into the cloud services “Energy service platform”.

The HLUC09 solution has the following requirements to perform adequately:

- Engagement/acceptance to participate of consumers/prosumers
- Communication between Market hub and HEMS need to be defined.
- Controllable devices (automated and non-automated)

Replicability will be tested according to the following factors:

- Type of appliances - Generation resources (e.g. PV), EV, energy storage systems.
- Type of controllability (inflexible, shiftable or thermal)
- Qualitative assessment of the economic benefits of controlling new appliances (task for the Economic SRA)
- Climatological conditions (affecting potential energy saving, for example considering different heating needs among countries)
- Local regulatory framework (tariffs structure, such as TOU or hourly discrimination)
- Optimization criteria (processing time vs planning approximation errors, different economic benefits, flexibility provision benefits)
- Customer engagement aspects:
  - Comfort preferences modification
  - Planned schedule fulfilment
  - Number of accepted optimal solutions

About the ICT-oriented the system should consider,

- Data required for the different type of appliances - Generation resources (e.g. PV), EV, energy storage systems.
- Supported appliances internally by the HEMS in terms of, interfaces (API compatibility), open-source software, etc.
- HEMS compatibility with existing metering and controlling infrastructure protocols.

Replicability intranational

To assess the intranational replicability, a matching between the above general replicability aspects and the particularities of the considered regions will help to assess the replicability in those regions.

Replicability international

The countries initially considered will be those involved in the demonstration: Portugal, Slovenia and Sweden. Other possible countries could also be Spain, the Netherlands and Austria, attending to the origin of the consortium participants (to be decided).

Regarding the ICT-oriented analysis, it will be only performed for Portugal (demo leader) and Sweden (demo learner).

To assess the international replicability, a matching between the above general replicability aspects and the particularities of the considered countries will help to assess the replicability in those countries.
The KPI have been interpreted as absolute measurements of the solutions performance. The improvement or deterioration of this performance is evaluated by comparing the computed KPI among different scenarios.

- Peak demand, and ratio between minimum and maximum load within a day
- Energy costs (including the provision of demand response services and potential contracted power reduction)
- Schedule computation time
- RES hosting capacity

The baseline to be considered is the original historic consumption profiles before HEMS installation (considering seasonality), to take their energy costs as reference.

A functionality-oriented SRA will be performed on this HLUC. Portugal and Sweden will be considered for the replicability analysis, since a commercial HEMS is also implemented in the Swedish demo. The economic-oriented SRA will focus on the energy savings costs and the benefits associated to the HEMS. The ICT-oriented SRA presents interesting characteristics given that it can be approached from the external and internal side.

The following table illustrates the main factors that will be considered in the definition of scenarios, as well as the associated KPIs and targeted tools.

<table>
<thead>
<tr>
<th>Table 9: Main factors for SRA analysis of HLUC09</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools/Factors</td>
</tr>
</tbody>
</table>

T=technical, E=economical, SS=scalability in size, SD=scalability in density, R=replicability.
3.10. HLUC10 Pre-evaluation (Aggregate and communicate multi-period behind-the-meter flexibility from MV and LV consumers)

The present HLUC invokes a set of tools, which are represented, along with their interactions and simplified exchanged information, in Figure 16:

- **Intraday Market Participation Assessment**: assessment that concludes about intraday energy market participation or use of available flexibility for different purpose (internal balancing or ancillary services provision); a **Price Forecasting function** is used to generate intraday market prices;
- **Ancillary Services Market Participation Assessment**: assessment on the activation of flexibility for further provision of ancillary services;
- **Flexibility Activation Assessment**: infers about the most profitable way of using the available flexibility: for portfolio internal balancing, within ancillary services market or both.

The Flexibility Operator, depicted here by the Energy Services Platform, receives the individual values of flexibility from the on-premises installed HEMS and, after performing their aggregation, run an assessment tool that outputs the most favourable way of optimizing its portfolio: either by bidding in the intraday energy market or by activating its available aggregated flexibility. If the tool highlights the second option as the one that brings more benefits, a second assessment tool is employed – **Flexibility Activation Assessment**, which evaluates if it is more profitable to use the flexibility for portfolio internal balancing and/or within the Ancillary Services Market, as a balancing product.

The ICT structure purposed for such functionalities is based on a star topology. The key functions, Intraday market platform, Ancillary Services platform, Gm-Hub, Aggregation platform and Forecast system for intraday market (price prediction) have direct connections to the central function, the Energy services platform. From the data acquisition point of view the metering is done at smart meter level, then gathered at the BMS premises. From there is routed to via an RTU to the Aggregation platform to its database.
Figure 16 does not depict the **Ancillary Services Market Participation Assessment**, since the figure provides the tool chain applicable when the first assessment tool is the one deeming the intraday market. Nevertheless, if the Flexibility Operator starts with the tool regarding the ancillary services participation, the concept would be the same: after the **Ancillary Services Market Participation Assessment**, the Flexibility Operator would perform the **Flexibility Activation Assessment**, assessing, at this stage, the use of flexibility within the intraday market.

### Objectives of the HLUC

The objectives of the current HLUC are the following:

- Enables fully use of consumers’ flexibility;
- Aggregates and communicates consumers’ flexibility to the Grid-Market Hub;
- Intraday perspective: use of consumers’ flexibility to reduce the deviation between the energy consumption forecast and real value, improving benefit for both customers and Retailer, by minimizing costs/improving profits.
- Ancillary services perspective: use the flexibility to provide some ancillary services (reduce the variation between real and forecast generation, provide balancing capacity, etc.), resulting in profit for both Retailer and end-users and improving grid operation performance.

### SRA methodology

While the quantitative SRA (related with scalability and some points of intranational replicability) should be performed through a set of simulations,
the qualitative SRA (related with the international replicability) should be based in a market study of a specific group of countries which have already been addressed in D1.3 (Spain, Portugal, Slovenia and Sweden).

This HLUC has both scalability and replicability factors whose change should result in different outputs and viability of the solution therein presented. Therefore, both analysis can be conducted, both from a qualitative (from a regulatory point of view) and quantitative perspective (technical and also regulatory).

The technical SRA will be based in the conditions that a flexibility provider will face (e.g. minimum and maximum size of its pool of customer, number of customers, market competitors, type of clients, etc.), while the regulatory will look into the market regulation and design of Slovenia, Sweden and Spain.

From an economic perspective, the analysis will be focused on evaluating the costs and earnings for the aggregator (its business model must be defined), the earnings and costs for customers (again depends on how the aggregator services will be charged). Benefits for society in general will be approached qualitatively.

<table>
<thead>
<tr>
<th>Scalability</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scalability in density will be tested according to the following factor:</td>
</tr>
<tr>
<td></td>
<td>• Minimum and maximum size of the pool of flexibility providers (in terms of kW, kWh, € and technical limitations).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Functional</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scalability in size will be tested according to the following factors:</td>
</tr>
<tr>
<td></td>
<td>• Number of customers providing flexibility.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Communication and information layer</th>
<th>ICT</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV and MV smart meters as well as HEMS are to be considered the main critical devices when scaling-up. They might contribute to process bottlenecks and architecture misbehaviour. They have a direct impact on the BMS which falls into the category of critical devices, since the data acquisition is done at the BMS premise but gathers the data from the HEMS and smart meters.</td>
<td>Communication and Information layers</td>
</tr>
<tr>
<td>Adding more aggregators when scaled-up may become a constraint since request will increase and performance must be maintained. Therefore, its connections to the Energy service must be further analysed. Additionally, the connection from the BMS to the aggregator side shall be analysed too. In this case, not only from the performance point (additional...</td>
<td></td>
</tr>
</tbody>
</table>
components are connected to the system) but also, from the security side (Denial of Services Attacks (DDOs)). This connection might be the most probable attack entry point into the ICT architecture. Regarding the other connections established into the Energy service platform, their communication technology (yet to be decided) must ensure a fast connection for adequate data exchange avoiding timing issues.

The following requirements must be complied:

- FO complies with the minimum bid size that enables its market participation;
- Availability of flexibility providers (and their consumption baselines);
- Households/industries/commercial facilities equipped with HEMS/BMS;
- Flexibility offer considered as reliable balancing product by the TSO or NRA.

For the ICT, the main point to analyse will be focus on the interfaces interoperability for integration of different HEMS/BMS available at the demo country side, Portugal.

Intranational replicability will be tested according to the following factors:

- Type of flexibility providers (residential, commercial and/or industrial);
- Type of flexibility providers’ equipment/business/industry (can influence customers’ flexibility delivery time).

The ICT will extend the analysis to the other connections to the Energy service platform since their interoperability can mean enabling international replication from an ICT point of view.

To internationally replicate this HLUC, which will be demonstrated in Portugal, one should analyse the specific market regulation and design that is applied in that country (e.g.: NordPool). Some notes are already available in D1.3. The following factors, among others, could impact the replication of the present use case:

- Minimum Activation time of the flexibility.
- Bid size and resolution (e.g. minimum bid is 5 MW, increment in impartible 1 MW blocks).
- Accepted entities to provide balancing services, and the requirements that they must comply with.
- Remuneration framework.

The impact of other factors on the Intraday market prices forecasting function will be assessed (e.g. the availability of historical data or the weather predictions in the covered country).

To perform a SRA, the smart grid function “Intraday market Price forecasts” is needed.

In addition, the following tool can be used to assess their performance:

Intraday market Price forecasts
- Intraday market participation assessment.
- Flexibility activation assessment.
- Ancillary services market participation assessment.

The simulations should produce outputs of the following KPIs:

- Price forecasting accuracy: measures the accuracy of the price forecasting tool under different boundary conditions (related with replicability – since some countries may not have the same level of access to historical and weather predictions).
- Amount of provided flexibility by the aggregated consumers.
- Reduction of the imbalance in the balancing area of the BRP by using flexibility.

The baselines will be the following:

- Amount of load participating in Demand Response, of the customers already engaged in this process, before the entrance in this business model.
- Historical data on the imbalances attained by the market player (BRP), seasonably compared.

The following table illustrates the main factors that will be considered in the definition of scenarios, as well as the associated KPIs and targeted tools.

**Table 10: Main factors for SRA analysis of HLUC10**

<table>
<thead>
<tr>
<th>Tools/Factors</th>
<th>Historical and weather data availability</th>
<th>Minimum and maximum size of flexibility providers' pool</th>
<th>Number of customers providing flexibility</th>
<th>Number of aggregators competing in the same market</th>
<th>Legal framework (Regulatory)</th>
<th>Level of customer engagement in DR schemes</th>
<th>Type of flexibility providers (residential, commercial or industrial)</th>
<th>Type of flexibility providers' equipment/business/industry</th>
<th>Assessment output (curtailments can be prioritized according to client's requirements)</th>
<th>Time required for flexibility activation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price forecasting algorithm</td>
<td>Accuracy</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Intraday market participation assessment</td>
<td>Accuracy</td>
<td>Technical constraints compliance</td>
<td>Time performance and employed methodology</td>
<td>Client churning rate</td>
<td>Assessment accuracy</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ancillary services market participation assessment</td>
<td>Accuracy</td>
<td>Technical constraints compliance</td>
<td>Time performance and employed methodology</td>
<td>Client churning rate</td>
<td>Feasibility</td>
<td>Assessment accuracy</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flexibility activation assessment</td>
<td>Accuracy</td>
<td>Technical constraints compliance</td>
<td>Time performance and employed methodology</td>
<td>Client churning rate</td>
<td>Feasibility</td>
<td>Assessment accuracy</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The functionality-oriented SRA will be performed on this HLUC, mainly focusing on the smart grid function "Intraday market prices forecast". Currently, the analysis potential of the tools used for the activation or participation assessment is not clear, since they are still under specification in HLUC10. The functionality-oriented SRA will be performed in Portugal and it could be extended to another country (most probably Slovenia), in order to assess the performance of the smart grid function on different markets. The economic-oriented SRA will be mainly focused in Portugal (and could be extended to Slovenia as well). With respect to ICT, the scalability analysis will evaluate the performance of the BMS and the energy service platform. Replicability analysis will be limited to the intra-national aspects.
3.11. HLUC11 Pre-evaluation (Engage consumers in demand-side management programs feedback mechanisms)

In the context of this HLUC, feedback-based demand-side interventions strategies are applied at residential level. Two different mechanisms are used by the DSO/Retailer to increase residential awareness and engagement in demand side management (DSM) programs:

- The first mechanism consists is improving the household comfort in smart homes equipped with sub-metering, smart appliances and actuators (compared to HLUC09, the level of automation is higher). Non-economic (environmental signals)\(^4\), based on the forecasted generation mix are used to induce automatic demand-side adjustments. The user interacts with the feedback mechanism for comfort or energy related purpose.
- The second mechanism is to improve the local life by providing a local social network to increase social cohesion. A price and/or environmental forecasting signal is created based on planned generation/grid mix and the feedback is presented in a local social network.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Evaluation</th>
</tr>
</thead>
</table>
| **Objectives of the HLUC** | The objectives of the Use Case are:  
- To influence residential attitudes, interactions, and behaviours related to energy.  
- To increase demand flexibility considering price and/or environmental signals.  
- To reduce overall electricity use, or in other words, boost energy efficiency through feedback mechanisms about energy consumption. |
| **SRA methodology** | The HLUC11 does not rely on the development on smart grid functions, so the SRA should be a combination of a qualitative analysis and a quantitative analysis based on demo results. The objectives of the HLUC are achieved by two different mechanisms, therefore the SRA should be done separately for each of them. |
The first mechanism will be focus on the SRA for the households equipped with HEMS (i.e. the Smart Homes). It should measure the effect of scaling-up the mechanism on the provision of flexibility and the benefits for the customers (i.e. more customers equipped with HEMS). The replication will mainly assess the engagement of the customer in different environments. It shall take into consideration the cost of deployment and lifetime of the equipment and their possible installation in customer premises (submeters for internal appliances).

As for the second mechanism based on the Local Life social network, the SRA will only focus on the evaluation of the consumer engagement to further improve the functionalities provided by the social network. Feedback provided by the customers shall be not taken for granted as it may solve the question of how to increase demand flexibility and opinion regard the system interface.

### Scalability

#### Density

The scalability in density of the system will be assessed by:

- Number of flexibilities offered within the HEMS.
- Number of smart appliances connected. A smart appliance can be connected but not offered as a flexibility.
- Impact on the distribution network (grid section affected), via the coincidence factor, protection, etc...

#### Functional

- Impact on the distribution network (grid section affected), via the coincidence factor, protection, etc...

#### Size

The scalability in size of the system will be assessed by:

- Number of customers offering flexibilities.
- Number of active social life user.

### ICT

#### Component layer

Number of users are identified as the main scalable component to may produce constraints over the ICT system implanted at the demo leader side, Sweden. Their increase might affect the customer service integrated into the system via Human Machine Interface (HMI).

#### Communication and Information layers

The demo has already implanted scalable solution regarding the communication choices, by choosing Simple Object Access Protocol (SOAP) to their critical point, connections to third parties into the Local life platform.

### Replicability intranational

Degree of automation over the process for feedback customer response shall be addressed.

Concerning the ICT study, the main focus shall be the interface connection between the Energy database and the DSO to analyse interoperability. Although a standard protocol is used for the connection (such as Simple Mail
Transfer Protocol (SMTP)), the data format involved for the data exchange is clearly a constraint for replication since it is DSO dependent.

Replicability

DSM potential, language and habits, feedback mechanism will be topics to be further analysed.

Intranational

In this HLUC the ICT is directly impacted by the regulation constraints at the demo side for data collection and use. The EGreement Platform could be constrained by the local regulations.

Tools to perform a SRA

- Economical model of user engagement with focus on the value when flexibilities are increased.
- User’s model engagement for a certain amount of load shit (%).
- Engagement/acceptance to participate of consumers/prosumers.
- Household comfort questionnaires’.
- Increase awareness of customers questionnaire to identify and address household needs.
- Identification of the available flexibilities.
- Implementation of the Local social network and communication channels with customers.
- Communication with sub meters for interruptible loads.

KPIs

- Available flexibility (MWh, Pmin, Pmax) for normal case, and reduction peaks of 6% and 4%.
- Number of customers engaged.
- Cost/benefit ratio regarding the costs for flexibility increase (€/MWh) when additional equipment is necessary and the monetization of the flexibility over a certain time period.
- Energy use, before and after the demo in order to evaluate result of residential awareness programs.

Baseline

Due to the stage of development and implementation and certain open concerns yet to be discussed the baseline cannot be defined at the moment.

Given the singularity of this HLUC, which targets end-user’s customer engagement through two different approaches, a functionality-oriented SRA will be applied. From the ICT perspective, the architecture does not seem to present challenges with respect to scalability. International standards are widely used so the interest of the replicability analysis is also limited. This HLUC will also be assess economically to quantify the benefits of both solution.
3.12. HLUC12 Pre-evaluation (Aggregate geographically distributed third-party (multi-client) resources to offer ancillary services to TSO (frequency) and DSO (non-frequency))

Consumers and third-party distributed energy resources (DER) which have ability to change their consumption/generation for short time could be aggregated, and their flexibility offered as ancillary service to TSO, or be used by the DSO for its own grid management. In this context, HLUC12 describes how resources can be aggregated into two types of Virtual Power Plants (VPPs): commercial and technical VPPs. Commercial will provide balancing services to the TSO, whereas technical will provide flexibility for the DSO to manage the constraints of its distribution grid.

For commercial purposes, the flexibility operator offers balancing services to the TSO through a pool of resources. This commercial Virtual Power Plant (cVPP) communicates the flexibilities to the gm-Hub for validation, so that the activation of the flexibility does not compromise the DSO grid operation.

On the other hand, the same flexibility sources could be offered to the DSO for grid planning and operation purpose (for instance, to solve local congestions and voltage problems). The technical Virtual Power Plant (tVPP) is the actor who aggregates the resources and make them available with to the DSO.

Figure 17 exemplifies the concept of the HLUC12:
The objectives of the HLUC are:

- To supply reliable and efficient (technically and competitively priced) flexibility to TSO or DSO from geographically distributed third-party energy resources.
- To demonstrate the concept of the commercial VPP, in which DER can provide mFRR to the TSO.
- To demonstrate the concept of the technical VPP, in which DER flexibility can be activated to fulfil the DSO’s needs (solving local congestion or voltage problems).

A quantitative SRA should be performed through a set of simulations, considering a higher density of prosumers, several aggregators and larger areas covered by the VPPs. A qualitative SRA (related with the international replicability) will be based in analysing the possible regulatory barriers for replicability in different countries.

Considering the specificities of the commercial VPP and the technical VPP, the SRA can be firstly done separately for the two cases, and then combined.
The SRA focused commercial VPP should analyse how scalability in size and density impacts the total cost of balancing services provision, given the reliability level provided by the VPP and considering that the balancing needs of the TSO are the same with and without the VPP.

The SRA for the technical VPP will focus on the reduction of problems in the distributions network, and possibly the gains from differed investments.

The two cases can then be combined to account for the impact that one VPP type has on the other. Simulations will be carried to determine if the cost reduction achieved by the commercial VPP is higher than the opportunity cost of using that grid capacity for other purposes.

### Requirements to perform a SRA

- The OPF must be used in order to identify the flexibilities to use through the tVPP;
- A Secured Constrained Economic Dispatch model (specified in section “tools”) must be available to compute the day-ahead and the real-time dispatch
- Availability of data on the DERs and VPPs (typical size, typical ratio of industrial/residential DERs) from demos.
- Availability of network data (either real or simulated);
- Availability of information on the current balancing market in the chosen countries for the SRA (mix of generation participating, typical prices in the balancing markets etc).

### Density

Related to the availability and size of prosumer’s resources in the given areas.

Scalability in density will be tested according to the following factors:

- Minimum and maximum size of DERs providing flexibility to the VPP (in terms of kW, kWh, € and technical limitations).

Minimum and maximum size of the pool of flexibility providers participating in the VPP (in terms of kW, kWh, € and technical limitations).

### Functional

Scalability in size is linked to the capacity of the VPPs to aggregate players’ without compromising the quality of supply, and considering the reliability of the VPP for commercial and technical purposes. The bigger the VPP, the higher is the expected reliability, due to portfolio effect.

Scalability in size will be tested according to the following factors: Number of customers providing flexibility;
• Number and size of VPPs competing in the same market;
• Reliability factor of the scaled up VPP;
• Ratio of type of customer in the VPP (industrial/residential).

Network characteristics (meshed vs. radial; number of nodes).

Component layer:
For the Slovenian demo (leader), the first constraint comes when the number of customers (to be connected into the services of either the tVPP or cVPP) expands out of DSO’s reach. This means that not only when scaling, smart meters are implemented but also RTU to route the information to the DSO via GRPS. Additionally, since it is requirement, the smart meters have to be technically able to provide 1 min (real time) metering data to the VPP.

Communication and Information layers
Although it has been stated they implement different interfaces, regarding the other factors which affect the communication and information layer are,
• Data flow availability must be provided with low error connections, therefore, the communication technologies implemented throughout the entire ICT architecture shall be addressed.
• Data quality and resolution of the meters must be properly structured when pushed up to the system. Global data size due to granularity of 1 min for measurements will require high data-process actions. Asynchronous communication over the architecture has to be considered as, due to scaling, data process is decreased. It can create bottlenecks and even provoke functions to misbehave.

Replicability
Concerning the tVPP, the load density, voltage levels, DER penetration and participation, type of DER, and the topology of the network will have an influence, therefore the influence of these parameters will be considered. Replicability depends on existing resources and regulatory normative in the local areas/countries not only for distributed generation and energy storage but also for market participation. This analysis is related to the technical VPP.

The commercial VPP should not be impacted by this factor, as the rules for the TSO are expected to be the same for a whole country.

From the point of view of the ICT, technical and commercial VPPs must be targeted separately as they implement different interfaces among their connections.
• **Commercial VPP interfaces**: the interfaces to be analyzed concern the gm-hub, the MDM and the TSO connections.
• **Technical VPP central unit interfaces**: the interfaces to be analyzed concern the gm-hub and the MDM connections.

<table>
<thead>
<tr>
<th>Replicability international</th>
</tr>
</thead>
</table>
| The mix of generation technologies providing balancing services for the TSO will be evaluated, as it has a direct influence on the cVPP. Regulatory analysis of barriers that may be present in other countries regarding the implementation of the commercial and technical VPP concepts. This involves market design and operation rules.

The international replicability analysis is especially relevant for the commercial VPP, as rules for balancing markets vary from country to country. Product definition, technical rules and pricing for mFRR/RR may be different and may be a barrier for international replicability.

<table>
<thead>
<tr>
<th>Tools to perform a SRA</th>
</tr>
</thead>
</table>
| • Optimal Power Flow: for the analysis of the technical VPP.  
• Secure Constrained Economic Dispatch model: for the commercial VPP is important to model the day-ahead dispatch and the real-time economic dispatch considering the grid. Therefore, the use of a model like the ROM model is proposed\(^5\).  
• Models of the Technical VPP (aggregation and bidding)  
• Models of the Commercial VPP (aggregation and bidding) |

<table>
<thead>
<tr>
<th>KPIs</th>
</tr>
</thead>
</table>
| • Cost reduction in mFRR/RR activation achieved by the cVPP;  
• Availability of VPPs for commercial and technical purposes: as VPPs get bigger, it is expected that their availability to provide services may decrease (more activation blocked by the TLS, for instance), since a larger impact on the grid is expected. This KPI aims at quantifying this effect. This can also be interpreted as the critical volume of the VPP (cVPP and tVPP).  
• Expected deviation factor of VPPs (compared to the committed reserves and/or schedules): reliability measure of the VPP. It is expected that a bigger VPP will have a higher reliability level considering that the portfolio effect can offset deviations. We define here the reliability KPI as the expected deviations (cVPP and tVPP).  
• Reduction in the number of voltage problem events in the DSO area (tVPP);  
• Reduction in the number of network constrained events (tVPP).  
• Monetization of the reduction in network constrain events (tVPP).  
• Difference in price of flexibility: difference in the price of flexibility from different sources (e.g., HEMS from HLUC10 and waste water management from HLUC08) (cVPP and tVPP). |
For the cVPP: the baseline will consider the absence of cVPP, allowing the computation of the average price of mFRR/RR on each region and the current status of the balancing market (mix of generators participating as of today);
For the tVPP: the baseline will consider the network state before the implementation of the tVPP. This would allow the calculation of the required investment (e.g. in reactive compensation / voltage control) in the absence of the tech VPP.

Both, the tVPP and the cVPP will be analysed from a functional, ICT and economic perspective. For the analysis of the tVPP, network simulations will be performed to assess the impact of the different factors identified in the pre-evaluation. For the cVPP, most of the analysis will be focused on the economic domain, as the functional-oriented SRA of this use case is partly covered in HLUC (Traffic Light System). The ICT meanwhile will analyse their expansion with respect of an increase of devices and data flow; and the different interfaces used for each VPP. The tVPP and cVPP will be tested in both Slovenia and Portugal, therefore the analysis will embrace both countries from the functional whereas the ICT perspective will assess scalability in Slovenia and its possible replication into Portugal.

The following table illustrates the main factors that will be considered in the definition of scenarios, as well as the associated KPIs and targeted tools.

<table>
<thead>
<tr>
<th>Tools/Factors</th>
<th>Size of the DER flex. providers in the VPPs → TESDR</th>
<th>Number of DER flex. Providers in the VPPs → TESSR</th>
<th>Size of the VPPs → TESDR</th>
<th>Number of VPPs → TESSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secured Constrained Economic Dispatch Commercial VPP</td>
<td>• Cost reduction in mFRR activation • Availability and reliability of the VPP for commercial and technical purposes</td>
<td>• Cost reduction in mFRR activation • Availability and reliability of the VPP for commercial and technical purposes</td>
<td>• Cost reduction in mFRR activation • Availability and reliability of the VPP for commercial and technical purposes</td>
<td>• Cost reduction in mFRR activation • Availability and reliability of the VPP for commercial and technical purposes</td>
</tr>
<tr>
<td>Optimal Power Flow Technical VPP</td>
<td>• Reduction in the number of network constrained / voltage problem events; • Monetization of the reduction in network constrain events • Availability and reliability of the VPP for commercial and technical purposes</td>
<td>• Reduction in the number of network constrained / voltage problem events; • Monetization of the reduction in network constrain events • Availability and reliability of the VPP for commercial and technical purposes</td>
<td>• Reduction in the number of network constrained / voltage problem events; • Monetization of the reduction in network constrain events • Availability and reliability of the VPP for commercial and technical purposes</td>
<td>• Reduction in the number of network constrained / voltage problem events; • Monetization of the reduction in network constrain events • Availability and reliability of the VPP for commercial and technical purposes</td>
</tr>
</tbody>
</table>

T=technical, E=economical, SS=scalability in size, SD=scalability in density, R=replicability
4. Definition of scenarios for the functionality oriented-SRA

The scenarios and boundary conditions listed in this section used for the Scalability and Replicability Analysis (SRA) are based on the different output analyses performed in WP7 which are inputs for WP8.

Additionally, we need to consider that the following scenarios are high dependent of the available grid data which can may affect the description of the scenarios or their adjustment to align with the available data at the time of the WP8 redaction.

The idea of this scenarios is to provide the necessary scenarios to test the demo network scaling.
4.1. HLUC01

The Scalability and Replicability Analysis for the HLUC01 is based on evaluating the technical and computational performance of the involved tools by comparing a set of extreme operational scenarios with a baseline scenario with perfect information. This pragmatic analysis intends to test and demonstrate the potential provided by the HLUC01 tools for solving network technical problems.

The assessment on the HLUC01 comprehends three different tools: load and RES DSO forecasting system, MV load allocator, and multi-temporal optimal power flow.

4.1.1. Scalability in size

Ten distinct scenarios are devised to evaluate the impact of scaling-up in size the HLUC01 baseline. These scenarios intend to assess the optimal power flow module predictive and real-time performance according to different number of nodes of MV distribution networks, limited amount of metering data and load and generation forecasting errors.

The SRA for the HLUC01 takes base on the specification of a set of network operational scenarios, derived from an urban MV distribution network with synthetic data based on typical equipment parameters and load and generation profiles. The network comprises 52 nodes, 4 primary substations and 52 secondary substations (loads). Each primary substation accounts for an HV/MV power transformer with on-load tap changers. From the HV side the network is supplied through 4 network equivalents, each connected to a different primary substation. The distribution network comprises 64 transmission lines, 4 capacitor banks and 4 distributed...
generation units (2 wind parks and 2 solar PV plants). The network loads are homogenously distributed, and all the flexibility assets are available for exploitation by the multi-period optimal power flow module. The network is operating with a radial topology – light blue lines represent open/not energized transmission lines and dark lines represent closed/energized transmission lines.

Two baselines are devised, according to different time horizons: the real-time operation and the predictive operation.

The real-time operation baseline assumes a perfect knowledge of the networks’ operating point considering the availability of perfect real-time metering data. Therefore, it allows assessing the multi-temporal optimal power flow without the influence of the MV load allocator module, respectively.

The predictive operation baseline assumes a perfect knowledge of the networks’ operating point for a given number of hours ahead, and so, it considers the availability of a perfect metering data historic. Such baseline allows the assessment of the multi-temporal optimal power flow without the influence of the load and generation forecasting module and without the influence of the MV load allocator.

Departing from such baseline, a set of scenarios is constructed. Forecasting errors and the unavailability of metering data are accounted for some of the defined scenarios. For the MV load allocator minimum performance, at least metering data at the network primary substations must be available.

For evaluating the impact of the actual network dimensions on the multi-temporal optimization module performance, two cases are considered for the number of elements present in the original network: (i) scaled-up to 5 times; (ii) scaled-up to 50 times. Such dimensions are chosen, since the defined scenarios intend to be representative and not exhaustive samples. The main point here is to provide an assessment of the tools’ performance given a set of arbitrary network dimensions, which account for a modest and an extreme increase on the number of elements. In terms of scenario definition, the scale-up corresponds to an increase of 5 and 50 times the number of network nodes, transmission lines, primary substations and the total number of loads and distributed generators (while keeping the generation-to-load ratio).

The real-time operation analysis considers the following scenarios,

**Scenario #1** (real-time baseline scenario)

- **Objective** Evaluate the real-time multi-temporal optimization module without the influence of the MV load allocator.
- **Additional comments**: access to perfect metering data exists

**Scenario #2**

- **Scaling dimension**: Nodes, loads & generation.
- **Scaling range**: 5 times its initial value
- **Objective**: Evaluate the real-time multi-temporal optimization module without the influence of the MV load allocator.
- **Baseline**: Scenario #1
Scenario #3
- **Scaling dimension:** Nodes, loads & generation.
- **Scaling range:** 50 times its initial value
- **Objective:** Evaluate the real-time multi-temporal optimization module without the influence of the MV load allocator.
- **Baseline:** Scenario #1

Scenario #4
- **Scaling dimension:** Primary substation data & forecasts
- **Scaling range:** Data available for primary substations but not for forecasts
- **Objective:** Evaluation and influence of MV load allocator without forecasting on the real-time multi-temporal optimization module.
- **Baseline:** Scenario #1

Scenario #5
- **Scaling dimension:** Primary substation data & forecasts.
- **Scaling range:** Data available for primary substations but not for forecasts.
- **Objective:** Evaluation and influence of MV load allocator without forecasting on the real-time multi-temporal optimization module.
- **Baseline:** Scenario #2

*The predictive operation analysis considers the following scenarios,*

Scenario #6 predictive baseline scenario
- **Objective:** Evaluate the predictive multi-temporal optimization module without the influence of the Forecasting or the MV load allocator.
- **Additional comments:** metering data for future operating points is known and perfect (so no forecasts or MV load allocation error exist).

Scenario #7
- **Scaling dimension:** Nodes, loads & generation
- **Scaling range:** 5 times its initial value.
- **Objective:** Evaluate the predictive multi-temporal optimization module without the influence of the Forecasting or the MV load allocator.
- **Baseline:** Scenario #6

Scenario #8
- **Scaling dimension:** Nodes, loads & generation.
- **Scaling range:** 50 times its initial value
- **Objective:** Evaluate the predictive multi-temporal optimization module without the influence of the Forecasting or the MV load allocator.
- **Baseline:** Scenario #6

Scenario #9
• **Scaling dimension:** Nodes, loads & generation.
• **Scaling range:** 5 times its initial value
• **Objective:** Evaluate real-time multi-temporal optimization module without the influence of the mv load allocator.
• **Baseline:** Scenario #6

**Scenario #10**

• **Scaling dimension:** Nodes, loads & generation.
• **Scaling range:** 50 times its initial value
• **Objective:** Evaluate real-time multi-temporal optimization module without the influence of the mv load allocator.
• **Baseline:** Scenario #6
4.1.2. Scalability in density

A set of scenarios is derived from the previous real-time and predictive operational baselines so as to assess the impact of scaling-up in density. These scenarios intend to account for extreme operational situations (worst cases) for which the load and generation are increased twofold (from the previously defined baseline scenarios). The devised scenarios assume perfect real-time and historical metering data (for a perfect forecast). This approach aims to push the network to an extreme operating point that will likely result in the violation of the networks’ technical constraints, to evaluate the optimal power flow module performance for solving such technical problems. In addition, two other scenarios for each operation mode are also considered for assessing the performance of the MV Load allocator module and the forecasting module, and their impact on the multi-temporal optimization module.

The real-time operation considers the following scenarios,

Scenario #11

- **Scaling dimension:** Load consumption.
- **Scaling range:** 2 times its initial value
- **Objective:** Evaluate the real-time multi-temporal optimization module for solving violations on the network technical constraints (without the influence of the MV load allocator or the load and RES DSO forecasting).
- **Baseline:** Scenario #1.

Scenario #12

- **Scaling dimension:** Distributed generation
- **Scaling range:** 2 times its initial value
- **Objective:** Evaluate MV load allocator, without the forecasting, and its influence on the real-time multi-temporal optimization module for solving violations on the network technical constraints.
- **Baseline:** Scenario #1.

Scenario #13

- **Scaling dimension:** Distributed generation.
- **Scaling range:** 2 times its initial value
- **Objective:** Evaluate the MV load allocator, without the forecasting, and its influence on the real-time multi-temporal optimization module for solving violations on the network technical constraints.
- **Baseline:** Scenario #4.
The predictive operation considers the following scenarios,

**Scenario #14**

- **Scaling dimension:** Load consumption.
- **Scaling range:** 2 times its initial value
- **Objective:** Evaluate the predictive multi-temporal optimization module for solving violations on the network technical constraints (without the influence of the MV load allocator or the Forecasting).
- **Baseline:** Scenario #6.

**Scenario #15**

- **Scaling dimension:** Distributed generation.
- **Scaling range:** 2 times its initial value.
- **Objective:** Evaluate the MV load allocator with the forecasting, and its influence on the predictive multi-temporal optimization module for solving violations on the network technical constraints.
- **Baseline:** Scenario #6

**Scenario #16**

- **Scaling dimension:** Distributed generation.
- **Scaling range:** 2 times its initial value.
- **Objective:** Evaluate the MV load allocator, with the forecasting, and their influence on the predictive multi-temporal optimization module for solving violations on the network technical constraints.
- **Baseline:** Scenario #9
4.1.3. Replicability

The HLUC01 replicability analysis intends to evaluate the module performance according to factors that may differ for intra-national networks and/or networks from differences countries. The devised scenarios are constructed from some of the previously defined scenarios and aim to account for missing historical data for the Forecasting and for differences regarding the available flexible resources types between networks.

The real-time operation considers the following scenarios,

Scenario #17
- **Attributes**: Consider only OLTCs and Capacitor Banks as available flexibility resources.
- **Objective**: Evaluate the real-time multi-temporal optimization module by changing the available flexibility resources types.
- **Baseline**: Scenario #11.

Scenario #18
- **Attributes**: Consider only Demand Response and RES as available flexibility resources.
- **Objective**: Evaluate the real-time multi-temporal optimization module by changing the available flexibility resources types.
- **Baseline**: Scenario #11.

Scenario #19
- **Attributes**: Consider only OLTCs and Capacitor Banks as available flexibility resources.
- **Objective**: Evaluate the real-time multi-temporal optimization module by changing the available flexibility resources types.
- **Baseline**: Scenario #12.

Scenario #20
- **Attributes**: Consider only Demand Response and RES as available flexibility resources.
- **Objective**: Evaluate the real-time multi-temporal optimization module by changing the available flexibility resources types.
- **Baseline**: Scenario #12.
The predictive operation considers the following scenarios,

Scenario #21
- **Attributes**: Consider only that 1 month of historical data is available.
- **Objective**: Evaluate the Forecasting, and its influence on the predictive multi-temporal optimization module.
- **Baseline**: Scenario #6.

Scenario #22
- **Attributes**: Consider the 3 months of historical data with randomly missing values.
- **Objective**: Evaluate the Forecasting, and its influence on the predictive multi-temporal optimization module.
- **Baseline**: Scenario #6.

Scenario #23
- **Attributes**: Consider that 80% (16 units) of the distributed generation is wind generation and the remaining 20% (4 units) is solar PV generation.
- **Objective**: Evaluate the Forecasting, and its influence on the predictive multi-temporal optimization module.
- **Baseline**: Scenario #7.

Scenario #24
- **Attributes**: Consider considering that 80% (16 units) of the distributed generation is solar PV generation and the remaining 20% (4 units) is wind generation.
- **Objective**: Evaluate the Forecasting, and its influence on the predictive multi-temporal optimization module.
- **Baseline**: Scenario #7.
Table 12: HLUC01 simulation scenarios guidelines HLUC01

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Target Evaluation Tool</th>
<th>Node Number</th>
<th>Load &amp; RES Historical Data</th>
<th>MV Load Allocator</th>
<th>Load and Generation Profiles</th>
<th>Available Flexibility</th>
<th>Main KPI</th>
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<tr>
<td>1</td>
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<td>52</td>
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<td>Real-time Baseline</td>
<td>All</td>
<td>Time Performance Solved technical problems</td>
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<tr>
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<td>All</td>
<td>Time Performance</td>
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<td>All</td>
<td>Time Performance</td>
</tr>
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<td>4</td>
<td>Real-time optimization module (MV Load Allocator)</td>
<td>52</td>
<td>-</td>
<td>Metering for primary substations</td>
<td>Real-time Baseline</td>
<td>All</td>
<td>Load Allocation Error Solved technical problems</td>
</tr>
<tr>
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<td>Metering for primary substations</td>
<td>Real-time Baseline</td>
<td>All</td>
<td>Load Allocation Error Time performance Solved technical problems</td>
</tr>
<tr>
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<td>All metering data available</td>
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<td>All</td>
<td>Time Performance Solved technical problems</td>
</tr>
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<td>Time Performance</td>
</tr>
<tr>
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<td>All</td>
<td>Time Performance</td>
</tr>
<tr>
<td>9</td>
<td>Predictive optimization module (MV Load Allocator and Forecasting)</td>
<td>52</td>
<td>12 months</td>
<td>Metering for primary substations</td>
<td>Predictive Baseline</td>
<td>All</td>
<td>Load Allocation and Forecasting Errors Solved technical problems</td>
</tr>
<tr>
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<td>Metering for primary substations</td>
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<td>All</td>
<td>Load Allocation and Forecasting Errors Solved technical problems Time performance</td>
</tr>
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<td>-</td>
<td>All metering data available</td>
<td>2 Times Baseline Load Power Rate</td>
<td>All</td>
<td>Solved Technical Problems</td>
</tr>
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Scalability in Size
<table>
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<tr>
<th>No.</th>
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<th>Period</th>
<th>Metering Data</th>
<th>Generation</th>
<th>Replicability</th>
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<tr>
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<td>All</td>
<td>2 Times Baseline</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Generation</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>13</td>
<td>Real-time optimization module (MV Load Allocator)</td>
<td>52</td>
<td>-</td>
<td>Metering for primary substations</td>
<td>2 Times Baseline Generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>14</td>
<td>Predictive optimization module</td>
<td>52</td>
<td>12 months</td>
<td>All metering data available</td>
<td>2 Times Baseline Load Power Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>All</td>
</tr>
<tr>
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<td>Predictive optimization module</td>
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<td>All metering data available</td>
<td>2 Times Baseline Generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>16</td>
<td>Predictive optimization module (MV Load Allocator)</td>
<td>52</td>
<td>12 months</td>
<td>Metering for primary substations</td>
<td>2 Times Baseline Generation</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>17</td>
<td>Real-time optimization module</td>
<td>52</td>
<td>-</td>
<td>All metering data available</td>
<td>2 Times Baseline Load Power Rate</td>
</tr>
<tr>
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<td></td>
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<td>OLTCs and Capacitor Banks</td>
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<tr>
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<td>-</td>
<td>All metering data available</td>
<td>2 Times Baseline Load Power Rate</td>
</tr>
<tr>
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<td>Demand Response and RES</td>
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<td>-</td>
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<td>2 Times Baseline Generation</td>
</tr>
<tr>
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<td>OLTCs and Capacitor Banks</td>
</tr>
<tr>
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<td>Real-time optimization module</td>
<td>52</td>
<td>-</td>
<td>All metering data available</td>
<td>2 Times Baseline Generation</td>
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<td>Demand Response and RES</td>
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<tr>
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<td>1 month</td>
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<tr>
<td></td>
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<td></td>
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<td>All</td>
</tr>
<tr>
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<td>Predictive optimization module (Forecasting)</td>
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<td>3 months with missing values</td>
<td>All metering data available</td>
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<tr>
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<td></td>
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<td></td>
<td>All</td>
</tr>
<tr>
<td>23</td>
<td>Predictive optimization module (Forecasting)</td>
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<td>12 months</td>
<td>All metering data available</td>
<td>80% Wind, 20% Solar PV</td>
</tr>
<tr>
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<td></td>
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</tr>
<tr>
<td>24</td>
<td>Predictive optimization module (Forecasting)</td>
<td>260</td>
<td>12 months</td>
<td>All metering data available</td>
<td>20% Wind, 80% Solar PV</td>
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<td>All</td>
</tr>
</tbody>
</table>
4.2. HLUC02

As previously described, given the large number of variables and simulation scenarios involved in this type of analysis, an adequate methodology for the selection of a representative set of scenarios has to be established in order to be able to evaluate the performance of the HLUC under a set of different, realistic conditions. Given this, the adopted methodology is focused on analysing worst-case scenarios, i.e. scenarios that could have an impact on the normal operation of the LV grid, the computational performance of the involved tools and the number of avoided voltage problems. In this document, a set of simulation guidelines is proposed to conduct the SRA analysis for the HLUC02. It must be stressed that the full evaluation of the HLUC02 involves three different tools: state estimation, forecasting and voltage control.

4.2.1. Scalability in size

Regarding scalability in size, the HLUC02 will be evaluated through a total of nine different scenarios, which intend to assess the predictive and real-time performance of the LVC module for LV grids. These scenarios consider number of nodes, load and RES forecasting errors and SM real-time measurements errors/unavailability. Therefore, the impact of the state estimation and forecasting tools for the HLUC02 output is also analysed.

The baseline uses a typical Portuguese network based on a real grid (Barbeiro, Moreira, Soares & Rocha Almeida, 2010), with around 30 nodes and a rather low X/R ratio. The load is assumed to be homogeneously distributed with at least three load profiles reflecting different consumption patterns so as to deal with the existing diversity, provided that representative profiles are available or can be easily estimated. RES levels and DER types and resources will be synthetically designed and dimensioned so that the scenarios pose a real challenge to the control tools under test. It is also assumed that all resources are available at the set-point implementation period. From this baseline the performance of the real-time mode (resp. predictive) can be analysed by assuming perfect forecasts (resp. perfect estimation of the operating grid conditions) and generating different scenarios by varying the number of nodes (maintaining the microgeneration-to-loads ratio) and introducing SM measurements unavailability (resp. forecast errors). Finally, a particular scenario where a large share of smart inverters are present in the grid will also be considered since the smart inverters used in this project curtail the active power injection to the grid under overvoltage situations. This last scenario is focused on the predictive control module since a negative impact on the forecast tool is expected.

It is important to note that these new grids, while based on a real grid, are synthetically generated so that the performance of the HLUC can be tested for the selected input factors values. The nine proposed scenarios can be summarized as follows,
Scenario #1: (real-time baseline scenario)
  - Additional comments: A typical Portuguese network, with around 30 homogeneously distributed nodes, low X/R ratio, access to perfect SM information

Scenario #2
  - Scaling dimension: Number of nodes.
  - Scaling range: Homogeneously up to 150 nodes (5 times baseline value).
  - Objective: Evaluate the real-time control without the influence of the state estimator.
  - Baseline: Scenario #1.

Scenario #3
  - Scaling dimension: real-time SM readings unavailability.
  - Scaling range: Around 50% of meters besides the minimum requirements of one SM per feeder and phase, and 12 months of historical data.
  - Objective: state estimation (considering uncertainty) and its influence on the real-time control.
  - Additional comments: different levels of risk exposure are considered (minimum of 30%, 40% and 50% probability of occurring overvoltage/under voltage).
  - Baseline: Scenario #1.

Scenario #4
  - Scaling dimension: real-time SM readings unavailability.
  - Scaling range: Around 50% of meters besides the minimum requirements of one SM per feeder and phase, and 12 months of historical data.
  - Objective: Evaluate state estimation and its influence on the real-time control.
  - Baseline: Scenario #2.

Scenario #5: predictive baseline scenario
  - Objective: Evaluate the predictive control without the influence of the forecasting.
  - Additional comments: A typical Portuguese network, with around 30 homogeneously distributed nodes, low X/R ratio, access to perfect renewable generation and load forecasts.

Scenario #6
  - Scaling dimension: number of nodes.
  - Scaling range: Homogeneously up to 150 nodes (5 times baseline value).
  - Objective: Evaluate the predictive control without the influence of the forecasting.
  - Baseline: Scenario #5.
Scenario #7

- **Scaling dimension**: Forecast errors introduced.
- **Scaling range**: historical data of 12 months.
- **Objective** Evaluate forecasting and its influence on the **predictive control**.
- **Baseline**: Scenario #5.

Scenario #8:

- **Scaling dimension**: Forecast errors are introduced.
- **Scaling range**: historical data of 12 months.
- **Objective** Evaluate forecasting and its influence on the **predictive control**.
- **Baseline**: Scenario #6.

Scenario #9:

- **Scaling dimension**: High smart inverters.
- **Scaling range**: high integration (HEMS).
- **Objective** Evaluate forecasting and its influence on the predictive control (interdependency with HLUC09).
- **Baseline**: Scenario #1.
4.2.2. Scalability in density

Scalability in density will be assessed through three different scenarios. Starting from the mentioned typical network, two of the proposed scenarios are related with the heterogeneous increase of loads and microgeneration – i.e. increase the number of RES and DER at the end of the feeder, where more problems are susceptible to happen (extreme situation, corresponding to a worst case). In one of these scenarios it is considered that the SM readings in real-time are all available, and in the other one state estimation errors are considered. In the remaining scenario, the influence of the resources’ availability at the set-point implementation period will be assessed (i.e. inability of a resource to comply with the defined set-point). The three proposed scenarios can be summarized as:

Scenario #10
- **Scaling dimension** RES and DER concentrated at the end of the feeder.
- **Objective:** Evaluate the real-time control without the influence of the state estimator.
- **Baseline:** Scenario #1.

Scenario #11
- **Scaling dimension** but with RES and DER concentrated at the end of the feeder.
- **Objective:** Evaluate state estimation (considering uncertainty) and its influence on the real-time control.
- **Baseline:** Scenario #3.

Scenario #12
- **Scaling dimension:** rate of failure in implementing the flexibility activation
- **Scaling range:** of around 50%.
- **Objective:** Evaluate the impact of partial flexibility activation (interdependency with HLUC09) in the real-time control.
- **Baseline:** Scenario #1.

4.2.3. Replicability

Replicability will be assessed through nine new scenarios. The first scenario corresponds to a different grid type, i.e. a grid that has a higher X/R ratio than that of the base scenario (Scenario #1). In another scenario, different RES and DER types will be considered to address the possible realities of other countries. Three scenarios correspond specifically to the assessment of the state estimation error in the real-time control module – i.e. a scenario with the minimum SM information required is considered; one with 50% of real-time SM measurements and 1 month of historical values; and one considering 50% of real-time SM measurements and 12 months of historical values with missing data (randomly generated). The following two scenarios are focused on the predictive control module. In these scenarios, the impact of the load and RES
forecast error on the predictive control module’s performance will be assessed. In the first of these scenarios, it is considered that only 3 months of data (with different types of days such as sunny, partially cloudy or totally cloudy to account for diversity) is available while in the second one it is considered that 12 months of data (ideal amount) is available, but with missing values. Finally, in the last two scenarios, different levels of integration of DSO resources and controllable DER are considered. In the first of these scenarios it is considered that there is a large integration of renewable generation under the form of self-consumption and low integration of DSO resources (i.e. energy storage devices and OLTC transformers). In the second scenario it is considered that there is a low number of controllable DER in the grid, the voltage control being made mostly through DSO resources, i.e. OLTC transformers and energy storage devices. The objective of these two scenarios is to evaluate the tool’s capability of addressing voltage deviation situations under these extreme conditions. The nine proposed scenarios can be summarized as:

**Scenario #13**

- **Scaling dimension**: Consider a grid with a different characteristic impedance (i.e. higher X/R ratio).
- **Objective**: Evaluate the quality of the control and its impact on the real-time control.
- **Baseline**: similar conditions to Scenario #1.

**Scenario #14**

- **Scaling dimension**: Consider that only the minimum required conditions for the LV State Estimation module are met (i.e. 1 real-time SM per phase and feeder).
- **Objective** of evaluating state estimation and its influence on the real-time control.
- **Baseline**: Scenario #3.

**Scenario #15**

- **Scaling dimension**: Consider that only 1 month of historical data is available.
- **Objective**: Evaluate state estimation and its influence on the real-time control.
- **Baseline**: Scenario #3.

**Scenario #16**

- **Scaling dimension** Consider the 12 months of historical data with missing values.
- **Objective** of evaluating state estimation and its influence on the real-time control.
- **Baseline**: Scenario #3.

**Scenario #17**:

- **Scaling dimension**: Consider a large integration of DRES in the form of self-consumption and low integration of DSO resources (absence of OLTC transformers and low integration of energy storage devices).
- **Objective**: of evaluating the quality of the control and its impact on the real-time control.
- **Baseline**: Scenario #1.
Scenario #18
- **Scaling dimension**: Consider a large integration of DRES, in the presence of DSO resources (OLTC transformers and/or energy storage devices).
- **Objective**: Evaluate the quality of the control and its impact on the real-time control.
- **Baseline**: Scenario #1.

Scenario #19 –
- **Scaling dimension**: Consider different RES and DER types (such as micro wind turbines, storage devices or other DSO resources).
- **Objective**: Evaluate the predictive control without the influence of the forecasting.
- **Baseline**: Scenario #5.

Scenario #20
- **Scaling dimension**: Consider only 3 months of historical data.
- **Objective**: Evaluate forecasting and its influence on the predictive control.
- **Baseline**: Scenario #7.

Scenario #21
- **Scaling dimension** Consider the 12 months of historical data with missing values.
- **Objective**: Evaluate forecasting and its influence on the predictive control.
- **Baseline**: Scenario #7.

All of the considered scenarios are summarized in Table 13.
### Table 13: Simulation scenarios guidelines HLUC02

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Target Evaluation Tool</th>
<th>Node N*</th>
<th>Load &amp; RES Forecasting</th>
<th>Load &amp; RES H.R.</th>
<th>LV State Estimator</th>
<th>Grid H.R.</th>
<th>Resources Location</th>
<th>Flexibility Availability</th>
<th>Grid Type</th>
<th>RES Type</th>
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<tbody>
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<td>1</td>
<td>Real-time Control module</td>
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<td>Solar PV</td>
<td>Avoided problems Time performance</td>
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<td>Time performance</td>
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<td>Estimation errors, 50% real-time SM measurements available</td>
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<td>Estimation errors, 50% real-time SM measurements available</td>
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<td>Homogeneous distribution</td>
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<td>Solar PV</td>
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<td>Forecasting</td>
<td>Load and RES Forecasting</td>
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<td>X/R</td>
<td>RES type</td>
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<td>Real-time Control module</td>
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<td>Low X/R</td>
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<td>19</td>
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<td>Homogeneous distribution</td>
<td>100%</td>
<td>Low X/R</td>
<td>Different RES type (e.g., micro WT)</td>
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<tr>
<td>20</td>
<td>Predictive Control module (Load and RES Forecasting)</td>
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<td>Forecasting errors 3 months</td>
<td>-</td>
<td>-</td>
<td>Homogeneous distribution</td>
<td>100%</td>
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<td>Avoided problems Forecast errors</td>
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<td>Predictive Control module (Load and RES Forecasting)</td>
<td>~ 30</td>
<td>Forecasting errors 12 months (missing data)</td>
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<td>-</td>
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<td>100%</td>
<td>Low X/R</td>
<td>Solar PV</td>
<td>Avoided problems Forecast errors</td>
<td></td>
</tr>
</tbody>
</table>

H.R. = Historical data
4.3. HLUC05

4.3.1. Scalability in size

Scenario #1: Baseline scenario

- **Objective**: reference model based on the Portuguese demo or Slovenian demo since both are going to be providing their grid topology.

Scenario #2

- **Scaling dimension**: Number of nodes
- **Scaling range**: x5
- **Objective**: Impact on the OPF module and test its endurance.
- **Baseline**: Scenario #1

Scenario #3

- **Scaling dimension**: Sources generation & consumption.
- **Scaling range**: x50.
- **Objective**: Impact on the OPF module and test its endurance (How much flexibilities is able to handle the TLS).
- **Baseline**: Scenario #1.

4.3.2. Scalability in density

Scenario #4

- **Scaling dimension**: Number of flexibility operators.
- **Scaling range**: To be defined at a later stage.
- **Objective**: Impact on the time performance of the TLS validation process (time for data acquisition and processing).
- **Additional comments**: Neither generation nor consumption is changed. What changes are the number of bid which corresponds to a flexibility operator.
- **Baseline**: Scenario #1

Scenario #5

- **Scaling dimension**: Number of DSOs.
- **Scaling range**: 2...5 times its initial value.
- **Objective**: Evaluate multi DSO operation in the TLS process and decision taking implemented for DSO.
- **Additional comments**: Portugal demo has 1 DSO.
- **Baseline**: Scenario #1
Scenario #6

- **Scaling dimension:** Flexible sources.
- **Scaling range:** x5 times its initial value.
- **Objective:** Evaluate computation time for the MP-OPF module and power quality provided.
- **Additional comments:** There is no increment in their number, only in their upward or downward offer.
- **Baseline:** Scenario #1

### 4.3.3. Replicability

Scenario #7

- **Attribute:** Grid topology.
- **Objective:** Test the TLS in a different topology.
- **Additional comments:** Maintain simplicity of the baseline.
  **Baseline:** scenario #1.

Scenario #8

- **Attribute:** Stakeholders- gmHub interconnection.
- **Objective:** Evaluate the performance of the TLS when different actors are involved.
- **Additional comments:** Maintain simplicity of the baseline.
  **Baseline:** Scenario #1.
### Table 14: Simulation scenarios guidelines HLUC05

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Target Evaluation Tool</th>
<th>Node Number</th>
<th>Load and RES Forecasting</th>
<th>Load and RES Historical Records</th>
<th>LV State Estimator</th>
<th>Grid Historical Records</th>
<th>Resources Location</th>
<th>Flexibility Availability</th>
<th>Main KPI</th>
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<tbody>
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<td>TLS- Baseline</td>
<td>-α</td>
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<td>Time performance, Power quality</td>
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<td>-</td>
<td>-</td>
<td>-Grid model</td>
<td>tbc</td>
<td>Time performance</td>
<td></td>
</tr>
</tbody>
</table>
| Replicability | 7 | TLS | ~? | - | - | - | - | - | - | New model/Topology | tbc | Time Performance  
|              |   |     |    |   |   |   |   |   |   | Power quality      |
|              | 8 | GmHub | ~? | - | - | - | - | - | - | - | Grid model         | tbc | Time performance  
|              |   |       |    |   |   |   |   |   |   | Power quality      
|              |   |       |    |   |   |   |   |   |   | Flexibility activation |
4.4. HLUC06

4.4.1. Scalability in size

Scenario #1
- **Scaling dimension:** 200% of X clients; Y update rate.
- **Scaling range:** 100-200%, with discrete increases of 50%.
- **Objective:** assess the impact of a growing number of clients (scalability in size) in the data processing and security levels of the gm-hub.
- **Baseline:** X clients and Y devices retrieving information to the gm-hub.

Scenario #2
- **Scaling dimension:** 1000% of X clients; Y update rate.
- **Scaling range:** 200-1000%, with discrete increases of 100%.
- **Objective:** assess the impact of a growing number of clients (scalability in size) in the data processing and security levels of the gm-hub.
- **Baseline:** X clients and Y devices retrieving information to the gm-hub.

Scenario #3
- **Scaling dimension:** 10000% of X clients; Y update rate.
- **Scaling range:** 1000-10000%, with discrete increases of 1000%.
- **Objective:** assess the impact of a growing number of clients (scalability in size) in the data processing and security levels of the gm-hub.
- **Baseline:** X clients and Y devices retrieving information to the gm-hub.

4.4.2. Scalability in density

Scenario #4
- **Scaling dimension:** number of gm-hub clients’ (henceforth depicted by “X”) equal to the one presented in the baseline scenario; 200% of the update rate presented in the baseline scenario (henceforth named “Y”).
- **Scaling range:** 100-200%, with discrete increases of 50%.
- **Objective:** assess the impact of the increased update rate (scalability in density) in the data processing and security levels of the gm-hub.
- **Baseline:** X clients and Y devices retrieving information to the gm-hub.

Scenario #5
- **Scaling dimension:** X clients; 1000% of Y.
- **Scaling range:** 200-1000%, with discrete increases of 100%.
• **Objective:** assess the impact of the increased update rate (scalability in density) in the data processing and security levels of the gm-hub.
• **Baseline:** X clients and Y devices retrieving information to the gm-hub.

Scenario #6

• **Scaling dimension:** X clients; 10000% of Y.
• **Scaling range:** 1000-10000%, with discrete increases of 1000%.
• **Objective:** assess the impact of the increased update rate (scalability in density) in the data processing and security levels of the gm-hub.
• **Baseline:** X clients and Y devices retrieving information to the gm-hub.

4.4.3. Replication international

Scenario #7

• **Replication location:** Sweden.
• **Objective:** assess the replication potential of the gm-hub in Sweden.
• **Baseline:** N/A.

Scenario #8

• **Replication location:** Spain.
• **Objective:** assess the replication potential of the gm-hub in Spain.
• **Baseline:** N/A.

4.4.4. Replication intranational

Scenario #9

• **Replication location:** platform A.
• **Objective:** assess the impacts that stem from the migration of the gm-hub to platform A, evaluating them in terms of standardisation and interoperability and achieved security levels.
• **Baseline:** Gm-hub standardisation and interoperability and security levels in Portugal.

Scenario #10

• **Replication location:** platform B.
• **Objective:** assess the impacts that stem from the migration of the gm-hub to platform B, evaluating them in terms of standardisation and interoperability and achieved security levels.
• **Baseline:** Gm-hub standardisation and interoperability and security levels in Portugal.
Table 15: Simulation scenarios guidelines HLUC06

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Target Evaluation Tool</th>
<th>Gm-Hub Clients</th>
<th>Update Rate</th>
<th>Range Increases</th>
<th>Location</th>
<th>Main KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gm-hub</td>
<td>200% of X</td>
<td>Y</td>
<td>50%</td>
<td>Portugal</td>
<td>Data processing &amp; Security levels</td>
</tr>
<tr>
<td>2</td>
<td>Gm-hub</td>
<td>1000 of X</td>
<td>Y</td>
<td>100%</td>
<td>Portugal</td>
<td>Data processing &amp; Security levels</td>
</tr>
<tr>
<td>3</td>
<td>Gm-hub</td>
<td>10000% of X</td>
<td>Y</td>
<td>1000%</td>
<td>Portugal</td>
<td>Data processing &amp; Security levels</td>
</tr>
<tr>
<td>4</td>
<td>Gm-hub</td>
<td>X</td>
<td>Y</td>
<td>50%</td>
<td>Portugal</td>
<td>Data processing &amp; Security levels</td>
</tr>
<tr>
<td>5</td>
<td>Gm-hub</td>
<td>X</td>
<td>1000% of Y</td>
<td>1000%</td>
<td>Portugal</td>
<td>Data processing &amp; Security levels</td>
</tr>
<tr>
<td>6</td>
<td>Gm-hub</td>
<td>X</td>
<td>10000 of Y</td>
<td>10000%</td>
<td>Portugal</td>
<td>Data processing &amp; Security levels</td>
</tr>
<tr>
<td>Replicability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>---</td>
<td>---</td>
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</tr>
<tr>
<td>International</td>
<td>7</td>
<td>Gm-hub</td>
<td>X</td>
<td>Y</td>
<td>-</td>
<td>Sweden</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Gm-hub</td>
<td>X</td>
<td>Y</td>
<td>-</td>
<td>Spain</td>
</tr>
<tr>
<td>Intranational</td>
<td>9</td>
<td>Gm-hub</td>
<td>X</td>
<td>Y</td>
<td>-</td>
<td>Portugal (Platform A)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Gm-hub</td>
<td>X</td>
<td>Y</td>
<td>-</td>
<td>Portugal (Platform B)</td>
</tr>
</tbody>
</table>
4.5. HLUC09

The adopted methodology described in this section is focused on analysing worst-case scenarios that could have an impact on the normal operation of the HEMS, and on the factors, that can influence its computational performance and controllability.

4.5.1. Scalability

As mentioned in Section 3.9, distinguishing between scalability in size or in density does not seem to be meaningful for this use case. Therefore, it will be approached as a unique scalability concept, which will be tested according the following scenarios.

The defined baseline assumes the consumption of a typical house without any PV installation, considering Portugal average climatological conditions and a dynamic tariff scheme. For simulation purposes two appliances are considered (one thermal and one shiftable). To characterize the behaviour of residential thermostatically controlled loads, physically-based load models are used and two representative types have been considered: air conditioner and electric water heater. The necessary parameters to model these household appliances are based on standard values from public datasets. The models of shiftable appliances are based on historical data retrieved from the house, or on default consumption patterns. From the baseline scenario, different scenarios will be generated in order to test the impact of increasing the number of appliances to be controlled (or varying other factors) for the HEMS performance.

It is important to highlight that these scenarios will be synthetically generated if no real data are available. The proposed scenarios can be summarized as follows:

Scenario #1 (baseline scenario)

- **Description**: The normal operating conditions of a daily operation of the appliances (their activation) in a so-called typical day. If no real data is available for simulation purposes it will be considered one shiftable appliance - washing machine (WM); and one thermal - electric water heater (EWH). No controllability and no optimization are considered for this scenario. A dynamic tariff scheme is employed, which will allow the comparison with the following scenarios.
- **Objective**: Collect real-time (or generate in a synthetic way) monitoring data for comparison.

Scenario #2

- **Description**: An optimized scenario for the house (described in Scenario #1) considering dynamic tariffs. A Spanish dynamic tariff (“Precio Voluntario para el Pequeño Consumidor”) will be used for simulation purposes.
- **Objective**: Evaluate the time performance and reduction of energy costs.
Scenario #3

- **Description**: An optimized scenario for the house (described in Scenario #1) considering dynamic tariffs and with the number of appliances scaled to 3 thermal appliances and 3 shiftable appliances (three shiftable appliances: washing machine (WM), dishwasher (DW), and Clothes Dryer (CD); and three thermal: Air Conditioner based on Heat Pump (AC), electric water heater (EWH), and Water heater based on Heat Pump (HP)).

- **Objective**: Evaluate the time performance and reduction of energy costs.

Scenario #4

- **Description**: Consider all appliances “smart” instead of using smart plugs (smart appliances are in general more efficient than conventional appliances with smart plugs), i.e. they can be remotely controlled without having to use a smart plug.

- **Objective**: Evaluate the added value of a fully automated household in achieving higher savings.

- **Baseline**: Scenario #3.

4.5.2. Replicability

Regarding replicability, the HLUC09 solution must perform adequately concerning the engagement/acceptance of the consumers/prosumers, the communication between gm-hub and HEMS, compatibility with the (automated and non-automated) devices, as well as the performance of the software with different inputs from the region/country.

Replicability will therefore be assessed through the following six scenarios considering different climatological conditions, regulatory framework, controlling infrastructures protocols and end users’ preferences.

Scenario #5

- **Attributes**: Use weather and water temperature data to simulate three different cases of climate temperature conditions in Europe:

  - **Subsets**:
    - **Scenario #5.1** – Warm Mediterranean climate (southern Europe).
    - **Scenario #5.2** – Temperate Oceanic climate (western Europe).
    - **Scenario #5.3** – Cool Continental climate (eastern Europe).

- **Objective**: Evaluate how energy costs are reduced for different climatological conditions corresponding to different regions (international replicability).

- **Baseline**: Scenario #3.

Scenario #6

- **Attributes**: similar conditions from scenario #3 but adding limitation to the instantaneous power that can be drawn from the grid (contracted power).
• **Additional comments:** For simulation purposes, the Portuguese contracted power tariffs will be initially used,
  o **Scenario #6.1** – 4.6 KVA.
  o **Scenario #6.2** – 6.9 KVA.
  o **Additional scenario:** (to be defined) to account for very large consumption households.
• **Objective** of evaluate the algorithm time performance, the reduction of energy costs and peak demand reduction, considering countries with and without power limitation (international replicability).
• **Baseline:** Scenario #3.

**Scenario #7**

• **Attributes:** similar conditions from scenario#3 but considering the Spanish TOU tariff “Plan Elige 8 Horas”, and the Portuguese tariff “bi-horária” as simulation examples of hourly price discrimination,
  o **Scenario #7.1** – TOU tariff (“Plan Elige 8 Horas”)
  o **Scenario #7.2** – TOU tariff (“Bi-Horária”)
• **Objective** Evaluate the algorithm time performance and the reduction of energy costs with different energy retailing prices (intranational/international replicability).
• **Baseline:** Scenario #3.

**Scenario #8**

• **Attributes:** PV integration optimization.
• **Additional comments:** Assess the capability of optimizing energy consumption for PV self-consumption schemes (or generation to the grid). Due to the optimization criteria followed, this scenario is independent from the tariff scheme used.
• **Objective** Evaluate the RES hosting capacity increase with PV optimization for self-consumption.
• **Baseline:** Scenario #3.

**Scenario #9**

• **Attributes:** PV integration.
• **Additional comments:** Assess the capability of optimizing energy consumption for both dynamic tariffs and PV self-consumption (multiple optimization criteria).
• **Objective** Evaluate the reduction of energy costs with multiple criteria optimization and different local regulatory framework.
• **Baseline:** Scenario #3.

**Scenario #10**

• **Attributes:** Two shiftable appliances and different preferences from the end user.
• **Additional comments:** For shiftable appliances the user has the possibility to choose one or more deadlines (depending how many times the appliance is going to work that day) with a maximum operation span of 24h.
- **Objective**: of evaluating how the algorithm behaves with end user restrictions and how these different end user preferences can affect the reduction of the energy costs.
- **Baseline**: Scenario #2.
Table 16: Simulation scenarios guidelines HLUC09

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Number of Appliances</th>
<th>Type of appliances</th>
<th>Type of controllability</th>
<th>Climatological conditions*</th>
<th>Optimization criteria</th>
<th>Local Regulatory Framework</th>
<th>Consumer restrictions</th>
<th>Main KPI</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1 thermal and 1 shiftable</td>
<td>-</td>
<td>-</td>
<td>Dynamic tariff</td>
<td>-</td>
<td>Energy costs Schedule computation time Peak demand RES hosting capacity</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>1 thermal and 1 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>smart appliances</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>5.1</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>Warm Mediterranean climate</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>5.2</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>Temperate Oceanic climate</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>5.3</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>Cool Continental climate</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.1</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff and Power limitation (4.6 KVA)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.2</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff and Power limitation (6.9 KVA)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>TOU (Spanish)</td>
<td>-</td>
<td>Energy costs Schedule computation time</td>
</tr>
<tr>
<td>---</td>
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<td>----------------------------------------</td>
</tr>
<tr>
<td>7.1</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>TOU (Portuguese)</td>
<td>-</td>
<td>Energy costs Schedule computation time</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>PV self-consumption</td>
<td>Scenario independent from the tariff scheme</td>
<td>-</td>
<td>RES hosting capacity</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>3 thermal and 3 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs and PV self-consumption</td>
<td>Dynamic tariff</td>
<td>-</td>
<td>Energy costs RES hosting capacity</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>2 shiftable</td>
<td>non-automated appliances controlled by a smart plug</td>
<td>-</td>
<td>Reduce energy costs</td>
<td>Dynamic tariff</td>
<td>one deadline per appliance</td>
<td>Energy costs</td>
</tr>
</tbody>
</table>

* The climatological conditions in every scenario excepting for 5.1, 5.2 and 5.3 intend to illustrate the Portuguese average ones
4.6. HLUC10

4.6.1. Scalability in size

Scenario #1
- **Scaling dimension**: 200 % of the number of flexibility providers (henceforth depicted by “Z”) equal to the one presented in the baseline scenario.
- **Scaling range**: 100-200%, with discrete increases of 50%.
- **Objective**: assess the impact of an increasing number of flexibility providers (scalability in size) in the achieved deviation reductions.
- **Baseline**: Z flexibility providers.

Scenario #2
- **Scaling dimension**: 1000 % Z.
- **Scaling range**: 200-1000%, with discrete increases of 100%.
- **Objective**: assess the impact of an increasing number of flexibility providers (scalability in size) in the achieved deviation reductions.
- **Baseline**: Z flexibility providers.

Scenario #3
- **Scaling dimension**: 10000 % Z.
- **Scaling range**: 1000-100000%, with discrete increases of 1000%.
- **Objective**: assess the impact of an increasing number of flexibility providers (scalability in size) in the achieved deviation reductions.
- **Baseline**: Z flexibility providers.

Scenario #4
- **Scaling dimension**: 200 % of the number of flexibility providers competing in the same market (henceforth depicted by “A”) equal to the one presented in the baseline scenario.
- **Scaling range**: 100-200%, with discrete increases of 50%.
- **Objective**: assess the impact of an increasing number of flexibility providers competing in the same market (scalability in size) in the achieved deviation reductions.
- **Baseline**: A flexibility providers competing in the same market.

Scenario #5
- **Scaling dimension**: 10000 % of A;
- **Scaling range**: 200-100000%, with discrete increases of 200%.
- **Objective**: assess the impact of an increasing number of flexibility providers competing in the same market (scalability in size) in the achieved deviation reductions.
- **Baseline**: A flexibility providers competing in the same market.
4.6.2. Scalability in density

Scenario #6

- **Scaling dimension**: 200 % of the minimum size (kW or kWh, depending on the remunerating scheme of the simulated market) of flexibility providers’ pool (henceforth depicted by “X”) equal to the one presented in the baseline scenario, maintaining the maximum size stable.
- **Scaling range**: 100-200%, with discrete increases of 50%.
- **Objective**: assess the impact of the increased size of the minimum flexibility providers’ pool (scalability in density) in the achieved deviation reductions.
- **Baseline**: X flexibility providers.

Scenario #7

- **Scaling dimension**: 1000 % of X, maintaining the maximum size stable.
- **Scaling range**: 200-1000%, with discrete increases of 100%.
- **Objective**: assess the impact of the increased size of the minimum flexibility providers’ pool (scalability in density) in the achieved deviation reductions.
- **Baseline**: X flexibility providers.

Scenario #8

- **Scaling dimension**: 10000 % X, maintaining the maximum size stable.
- **Scaling range**: 1000-10000%, with discrete increases of 1000%.
- **Objective**: assess the impact of the increased size of the minimum flexibility providers’ pool (scalability in density) in the achieved deviation reductions.
- **Baseline**: X flexibility providers.

Scenario #9

- **Scaling dimension**: 200 % of the maximum size of flexibility providers’ pool (henceforth depicted by “Y”) equal to the one presented in the baseline scenario, maintaining the minimum size stable.
- **Scaling range**: 100-200%, with discrete increases of 50%.
- **Objective**: assess the impact of the increased size of the maximum flexibility providers’ pool (scalability in density) in the achieved deviation reductions.
- **Baseline**: Y flexibility providers.

Scenario #10

- **Scaling dimension**: 1000 % of Y, maintaining the minimum size stable.
- **Scaling range**: 200-1000%, with discrete increases of 100%.
- **Objective**: assess the impact of the increased size of the maximum flexibility providers’ pool (scalability in density) in the achieved deviation reductions.
- **Baseline**: Y flexibility providers.

Scenario #11
• **Scaling dimension**: 10000 % of Y, maintaining the minimum size stable.
• **Scaling range**: 1000–10000%, with discrete increases of 100%.
• **Objective**: assess the impact of the increased size of the maximum flexibility providers’ pool (scalability in density) in the achieved deviation reductions.
• **Baseline**: Y flexibility providers.

### 4.6.3. Replicability intranational

**Scenario #12**

• **Replication changed factor**: only residential flexibility providers considered, maintaining all the other factors unchanged.
• **Objective**: assess the intranational replication potential of HLUC10, evaluating the achieved deviation reductions.
• **Baseline**: real aggregated clients’ types division within HLUC10.

**Scenario #13**

• **Replication changed factor**: only commercial flexibility providers considered, maintaining all the other factors unchanged.
• **Objective**: assess the intranational replication potential of HLUC10, evaluating the achieved deviation reductions.
• **Baseline**: real aggregated clients’ types division within HLUC10.

**Scenario #14**

• **Replication changed factor**: only industrial flexibility providers considered, maintaining all the other factors unchanged.
• **Objective**: assess the intranational replication potential of HLUC10, evaluating the achieved deviation reductions.
• **Baseline**: real aggregated clients’ types division within HLUC10.

**Scenario #15**

• **Replication changed factor**: flexibility delivery achieved time.
• **Replication range**: 100–500% of the baseline delivery time.
• **Objective**: assess the intranational replication potential of HLUC10, evaluating the achieved deviation reductions.
• **Baseline**: 15 minutes (maximum time length that a replacement reserve can start to actuate in the Portuguese ancillary services market).
4.6.4. Replicability international

Scenario #16

- **Replication location**: Slovenia.
- **Objective**: assess the impacts in the attained deviation reductions of employing the available flexibility offers features (achieved in HLUC10 demonstration) in Slovenian markets’ framework.
- **Baseline**: Results achieved (through simulation or demonstration) in Portugal.

Scenario #17

- **Replication location**: Sweden.
- **Objective**: assess the impacts in the attained deviation reductions of employing the available flexibility offers features (achieved in HLUC10 demonstration) in Swedish markets’ framework.
- **Baseline**: Results achieved (through simulation or demonstration) in Portugal.

Scenario #18

- **Replication location**: Spain.
- **Objective**: assess the impacts in the attained deviation reductions of employing the available flexibility offers features (achieved in HLUC10 demonstration) in Spanish markets’ framework.
- **Baseline**: Results achieved (through simulation or demonstration) in Portugal.

Scenario #19

- **Replication location**: Slovenia.
- **Objective**: assess the impacts in the attained price forecasting tool of the historical data weather predictions available in Slovenia.
- **Baseline**: Level of historical data and weather predictions available in Portugal.

Scenario #20

- **Replication location**: Sweden.
- **Objective**: assess the impacts in the attained price forecasting tool of the historical data weather predictions available in Sweden.
- **Baseline**: Level of historical data and weather predictions available in Portugal.

Scenario #21

- **Replication location**: Spain.
- **Objective**: assess the impacts in the attained price forecasting tool of the historical data weather predictions available in Spain.
- **Baseline**: Level of historical data and weather predictions available in Portugal.
### Table 17: Simulation scenarios guidelines HLUC10

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Target Evaluation Tool</th>
<th>Flexibility providers</th>
<th>Min. Size of F.P. ‘s pool</th>
<th>Max. Size of F.P. ‘s</th>
<th>F.P. in the same Market</th>
<th>Increments</th>
<th>Range</th>
<th>Replication Factor changed</th>
<th>Location</th>
<th>Main KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intraday M.P. Assessment</td>
<td>Z</td>
<td>Y</td>
<td>X</td>
<td>A</td>
<td>50%?</td>
<td>100-200%</td>
<td>-</td>
<td>-</td>
<td>Deviation Reductions</td>
</tr>
<tr>
<td></td>
<td>Ancillary Services M.P. Assessment</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Flexibility Activation Assessment</td>
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<td></td>
</tr>
<tr>
<td>2</td>
<td>Intraday M.P. Assessment</td>
<td>1000% Z</td>
<td>Y</td>
<td>X</td>
<td>A</td>
<td>100%?</td>
<td>200-1000%</td>
<td>-</td>
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<td></td>
<td>Ancillary Services M.P. Assessment</td>
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<tr>
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<td>Flexibility Activation Assessment</td>
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4.7. HLUC12

4.7.1. Scalability in size

Scenario #1

- **Scaling dimension**: Number of DER in each VPP.
- **Scaling range**: To be defined in a later stage (e.g. Increase 5 and 20 times the number of DERs, compared to baseline.)
- **Objective**: Test the critical volume of the VPPs
- **Additional comments**: Separate test for commercial and for technical VPP.
- **Baseline**: For Commercial VPPs: amount and average price of mFRR on each region, considering the current status of the balancing market (mix of generators participating as of today); For Tech VPPs: required investment in reactive compensation / voltage control in the absence of the tech VPP.

Scenario #2

- **Scaling dimension**: Number of DER in each VPP.
- **Scaling range**: To be defined in a later stage (e.g. Increase 5 and 20 times the number of DERs, compared to baseline).
- **Objective**: Test the critical volume of the VPPs, but considering both commercial and technical VPP at the same time.
- **Additional comments**: Considering both tech VPP and commercial VPP jointly. The objective is to verify the impact of one over the other under scalability. The total cost reduction (from both VPPs) can be compared with the baseline.
- **Baseline**: A combined baseline for both commercial and technical VPPs. It may be the current balancing market in a given region and the necessary investment to relieve voltage problems in a given grid.

Scenario #3

- **Scaling dimension**: Number of VPPs.
- **Scaling range**: To be defined in a later stage (e.g. Increase n times the number of VPPs, compared to baseline).
- **Objective**: Test the grid behaviour under the presence of a high number of VPPs (therefore DERs). Also test the economic viability. For that, the total system benefits can be compared against the baseline.
- **Additional comments**: Considering both tech VPP and commercial VPP jointly. The objective is to verify the impact of one over the other under scalability. The total cost reduction (from both VPPs) can be compared with the baseline.
- **Baseline**: For Commercial VPPs: amount and average price of mFRR on each region, taking into account the current status of the balancing market (mix of generators participating as of today); For Tech VPPs: required investment in reactive compensation / voltage control in the absence of the tech VPP.
Scenario #4

- **Scaling dimension**: Number of VPPs
- **Scaling range**: To be defined in a later stage (e.g. Increase n times the number of VPPs, compared to baseline).
- **Objective**: Test the grid behaviour under the presence of a high number of VPPs (therefore DERs). Also test the economic viability. For that, the total system benefits can be compared against the baseline., but considering both commercial and technical VPP at the same time.
- **Additional comments**: Considering both tech VPP and commercial VPP jointly. The objective is to verify the impact of one over the other under scalability. The total cost reduction (from both VPPs) can be compared with the baseline.
- **Baseline**: A combined baseline for both commercial and technical VPPs. It may be the current balancing market in a given region and the necessary investment to relieve voltage problems in a given grid.

Scenario #5

- **Scaling dimension**: VPP flexibility
- **Scaling range**: To be defined at a later stage (Can use outputs form other scenarios, e.g., when ramping up the number of DERs within a VPP)
- **Objective**: measure the reliability factor (ratio between agreed delivered flexibility volume and real delivered flexibility volume)
- **Baseline**: Demo configuration.

Scenario #6

- **Scaling dimension**: Number of customers
- **Scaling range**: To be defined at a later stage (Increase flexibility offered by tweaking load consumption, generation...).
- **Objective**: Measure the impact of the user ratio, ratio user= industrial/residential, in a defined grid topology.
- **Baseline**: Demo configuration.

Scenario #7

- **Scaling dimension**: Number of nodes, interconnections
- **Scaling range**: To be defined at a later stage
- **Objective**: resilience and performance of different network types (network characteristics).
- **Baseline**: Demos grid topology

Scenario #8 (number of customers providing flexibility)

- **Scaling dimension**: Number of customers providing flexibility (industrial and residential)
- **Scaling range**: To be defined at a later stage (applying same factor to both.)
- **Objective**: Impact on the network and performance of the technical VPP when customer number increases.
- **Baseline**: demo definition/configuration (how it set up at the beginning) for each demo

### 4.7.2. Scalability in density

#### Scenario #9
- **Scaling dimension**: DER size for each VPP.
- **Scaling range**: To be defined in a later stage (e.g., Double and triple the maximum size of DERs compared to baseline).
- **Objective**: Test the behaviour of expected deviation factor of VPPs.
- **Additional comments**: Separate test for commercial and for technical VPP.
- **Baseline**: For Commercial VPPs: amount and average price of mFRR on each region, considering the current status of the balancing market (mix of generators participating as of today); For Tech VPPs: required investment in reactive compensation / voltage control in the absence of the tech VPP.

#### Scenario #10
- **Scaling dimension**: DER size for each VPP.
- **Scaling range**: To be defined in a later stage (e.g., Double and triple the maximum size of DERs compared to baseline).
- **Objective**: Test the behaviour of expected deviation factor of VPPs, but considering both commercial and technical VPP at the same time.
- **Additional comments**: Considering both tech VPP and commercial VPP jointly. The objective is to verify the impact of one over the other under scalability. The total cost reduction (from both VPPs) can be compared with the baseline.
- **Baseline**: A combined baseline for both commercial and technical VPPs. It may be the current balancing market in a given region and the necessary investment to relieve voltage problems in a given grid.

#### Scenario #11
- **Scaling dimension**: Size of VPPs
- **Scaling range**: To be defined in a later stage (e.g. Double and triple the maximum size of DERs, compared to baseline).
- **Objective**: Test the critical volume of the VPPs.
- **Additional comments**: Separate test for commercial and for technical VPP.
- **Baseline**: For Commercial VPPs: amount and average price of mFRR on each region, considering the current status of the balancing market (mix of generators participating as of today); For Tech VPPs: required investment in reactive compensation / voltage control in the absence of the tech VPP.

#### Scenario #12
- **Scaling dimension**: Size of VPPs.
• **Scaling range:** To be defined in a later stage (e.g. Double and triple the maximum size of DERs, compared to baseline).
• **Objective:** Test the critical volume of the VPPs, but considering both commercial and technical VPP at the same time.
• **Additional comments:** Considering both tech VPP and commercial VPP jointly. The objective is to verify the impact of one over the other under scalability. The total cost reduction (from both VPPs) can be compared with the baseline.
• **Baseline:** A combined baseline for both commercial and technical VPPs. It may be the current balancing market in a given region and the necessary investment to relieve voltage problems in a given grid.

### 4.7.3. Replicability

**Scenario #13**

- **Replicability characteristics:** Demand / DER mix characteristics.
- **Objective:** Test the replicability to areas/countries with a different characteristic of demand and the DER (e.g., Industrial/residential flexibility providers, RES connected to distribution, difference of the mix for different voltage levels, etc).
- **Additional comments:** For the new mix characteristics, different countries can be used as example (e.g. high penetration of solar as in Germany).
- **Baseline:** As baseline, the characteristics found in the demos can be considered.

**Scenario #14**

- **Replicability characteristics:** Design of balancing products.
- **Objective:** Balancing products may vary from country to country. The objective of this scenario is to test performance under the different balancing products found in different countries.
- **Additional comments:** Focused on the commercial VPP.
- **Baseline:** As baseline, the product design found in the demos can be considered.

**Scenario #15**

- **Replicability characteristics:** Voltage drop rules.
- **Objective:** Countries may have different voltage drop rules, influencing the activation of DER for technical purposes. The objective of this scenario is to verify how voltage drop rules change the activation and economic benefits for VPPs.
- **Additional comments:** Focused on the technical VPP.
- **Baseline:** As baseline, the voltage-drop rules found in the demos can be considered.
### Table 18: Simulation scenarios guidelines HLUC12.

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Scaling dimension</th>
<th>Testy Type</th>
<th>Range</th>
<th>Replicability attribute</th>
<th>Main KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scalability in size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>DER number ∀ VPP</td>
<td>TVPP &amp; CVPP individual</td>
<td>TBD</td>
<td>-</td>
<td>Critical Volume</td>
</tr>
<tr>
<td>2</td>
<td>DER number ∀ VPP</td>
<td>TVPP &amp; CVPP at same time</td>
<td>TBD</td>
<td>-</td>
<td>Critical Volume</td>
</tr>
<tr>
<td>3</td>
<td>VPP number</td>
<td>TVPP &amp; CVPP individual</td>
<td>TBD</td>
<td>-</td>
<td>Cost reduction in mFRR/RR</td>
</tr>
<tr>
<td>4</td>
<td>VPP number</td>
<td>TVPP &amp; CVPP at same time</td>
<td>TBD</td>
<td>-</td>
<td>Cost reduction in mFRR/RR</td>
</tr>
<tr>
<td>5</td>
<td>VPP Flexibility</td>
<td>TBD</td>
<td>TBD</td>
<td>-</td>
<td>Reliability factor</td>
</tr>
<tr>
<td>6</td>
<td>Number of customers</td>
<td>TBD</td>
<td>TBD</td>
<td>-</td>
<td>Price difference (industrial/commercial)</td>
</tr>
<tr>
<td><strong>Scalability in density</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Nodes/Interconnections</td>
<td>TBD</td>
<td>TBD</td>
<td>-</td>
<td>Reduction in the number of Voltage problems Reduction in the number of network constraints</td>
</tr>
<tr>
<td>8</td>
<td>Customers providing Flex.</td>
<td>TBD</td>
<td>TBD</td>
<td>-</td>
<td>Reduction in the number of Voltage problems Reduction in the number of network constraints</td>
</tr>
<tr>
<td>9</td>
<td>DER size ∀ VPP</td>
<td>TVPP &amp; CVPP individual</td>
<td>TBD</td>
<td>-</td>
<td>Cost reduction in mFRR/RR Expected deviation factor of VPPs</td>
</tr>
<tr>
<td>10</td>
<td>DER size ∀ VPP</td>
<td>TVPP &amp; CVPP at same time</td>
<td>TBD</td>
<td>-</td>
<td>Expected deviation factor of VPPs</td>
</tr>
<tr>
<td>11</td>
<td>Size of VPP</td>
<td>TVPP &amp; CVPP at same time</td>
<td>TBD</td>
<td>-</td>
<td>Critical Volume</td>
</tr>
<tr>
<td>12</td>
<td>Size of VPP</td>
<td>TVPP &amp; CVPP individual</td>
<td>TBD</td>
<td>-</td>
<td>Critical Volume</td>
</tr>
<tr>
<td><strong>Replicability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>13</td>
<td>-</td>
<td>TBD</td>
<td>TBD</td>
<td>Demand/DER mix characteristics.</td>
<td>Price difference (industrial/commercial) Cost reduction in mFRR/RR</td>
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<td>TBD</td>
<td>-</td>
<td>Design of balancing products</td>
<td>Price difference (industrial/commercial) Cost reduction in mFRR/RR</td>
</tr>
<tr>
<td>15</td>
<td>-</td>
<td>TBD</td>
<td>-</td>
<td>Voltage drop rules</td>
<td>Reduction in the number of Voltage problems</td>
</tr>
</tbody>
</table>
5. Conclusions and next steps

In the context of this report, a literature review on the Scalability and Replicability analysis has been performed. For each relevant domain, a specific methodology has been designed, to consider the specificities of the ICT, functional, economic and regulatory aspects. The SRA will be performed at the HLUC, focusing on the business view point.

Concerning the functionality-oriented SRA, the methodology used in InteGrid is using the framework developed in the Grid4EU project. The analysis will be quantitative-based and the results (technical KPIs) will be obtained by simulating the smart grid functions and tools developed in the context of the project. The ICT-oriented SRA will assess modularity, interoperability as well as interchangeability. The analysis will be mostly qualitative-based, given the difficulty to simulate ICT-systems. The economic analysis will strive to deliver as much quantitative results and it will use inputs from the technical analysis. Finally, the regulatory-oriented SRA will explore the factors identified in a previous task.

Considering the number and the diversity of HLUCs (and the associated PUCs), we have identified the most promising solutions, so as to reduce the potential number of simulations and as to concentrate the available resources on the most relevant business. Therefore, prior to the definition of scenarios for the technical, economic and regulatory analysis, a qualitative analysis for each HLUC (called pre-evaluation) has been performed as part of the proposed methodology. The results of the pre-evaluation are presented in the table below:

<table>
<thead>
<tr>
<th>Functional-oriented</th>
<th>ICT-oriented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Future evaluation</td>
</tr>
<tr>
<td>HLUC01</td>
<td>Yes</td>
</tr>
<tr>
<td>HLUC02</td>
<td>Yes</td>
</tr>
<tr>
<td>HLUC03</td>
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<td>HLUC04</td>
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<td>HLUC05</td>
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<td>HLUC09</td>
<td>Yes</td>
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<td>HLUC11</td>
<td>Yes</td>
</tr>
<tr>
<td>HLUC12</td>
<td>Yes</td>
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</tbody>
</table>
Regarding the functionality-oriented SRA, the main criteria for selecting a HLUC is the existence of smart grid functions. As for the ICT-oriented SRA, selecting a HLUC has been a pragmatic choice considering the limited amount of resources available compared to the functionality-oriented SRA. The HLUCs showing challenges in terms of implementation have been selected in priority.

Unlike the technical analysis, the regulatory analysis will not be bounded to the three demo countries, but it will be extended to Spain and Austria, two countries members of the consortium. The economic SRA has not been illustrated in the table neither as a different approach, consisting in evaluating the HLUCs in sets, will be used.
References

InteGrid Documents

[REF GA] InteGrid’s Grant Agreement
[REF CA] InteGrid’s Consortium Agreement
[REF D9.1] InteGrid’s Dissemination Plan

External Documents

