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

Deliverable: D10.2

Methodology and scenarios for the EUniversal Scalability and Replicability Analysis

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Acronyms and abbreviations

AP	Active Power
BUC	Business Use Case
DE	Germany
DER	Distributed Energy Resource
DG	Distributed Generator
DoA	Description of the Action
DLR	Dynamic Line Rating
DNR	Distribution network reconfiguration
DSO	Distribution System Operator
FSP	Flexibility Service Provider
HV	High Voltage
IAB	International Advisory Board
KPI	Key Performance Indicator
LV	Low Voltage
MO	Market Operator
MV	Medium Voltage
OLTC	On-load tap changer
PL	Poland
PT	Portugal
PTDF	Power transfer distribution factor
RNM	Reference Network Model
RP	Reactive Power
SGAM	Smart Grid Architecture Model
SOC	Second order cone programming
SRA	Scalability and Replicability Analysis
TSO	Transmission System Operator
UMEI	Universal Market Enabling Interface

Executive Summary

The EUniversal project comprises three different demonstrators located in Germany, Poland, and Portugal, in which ten Business Use Cases (BUCs) will be tested on real distribution networks at different locations. The majority of the BUCs implement local flexibility markets for the procurement of flexibility by Distribution System Operators (DSOs) in the short-term and long-term timelines. In addition, they are concentrated on the delivery of congestion management or voltage control services through active and/or reactive power.

The results obtained from the demonstrators will provide helpful information on the impact of the BUC solutions. However, these results will be subject to the boundary conditions of each location, such as technical, regulatory, environmental, and social contexts. Therefore, it is necessary to perform a Scalability and Replicability Analysis (SRA) to understand the effects of implementing similar solutions under different boundary conditions that may affect the outcomes expected from the EUniversal project.

The scalability part of the analysis aims to determine the ability of a process, system, or network to increase in size or range to meet a growth in demand correctly. On the other hand, the replicability part of the analysis aims to determine how the modification of the boundary conditions affects the conclusions extracted from the use case with the objective of applying it in other regions, whether intranational or international.

In this context, the main objective of this deliverable is to describe the methodology and scenarios to carry out the SRA of the EUniversal project focusing on the ten BUCs defined in the deliverable D2.2 of the project. The methodology presented in this deliverable will be applied in D10.4, "Scalability and Replicability analysis of the EUniversal solutions".

Since the SRA can be done for different dimensions, the H2020 BRIDGE initiative developed some guidelines or methodology to support European projects to perform high-quality SRA studies, regardless of the particularities of each project, by providing common and consistent grounds [1]. For the SRA definition, these guidelines use the SGAM (Smart Grid Architecture Model) framework. The SGAM includes different interoperability layers to represent the different entities and their relationship in the context of smart grid domains and zones. The EUniversal SRA is organized around the functional layer and the business layer of the SGAM framework according to the project's Description of the Action (DoA) [2].

Concerning the functional layer, the dimensions addressed include the use case scalability and the use case replicability. For the business layer, the regulatory analysis and the stakeholder perspectives dimensions will be addressed. For each of these dimensions, a specific methodological approach is defined in this deliverable:

- For the functionality-oriented dimensions, a quantitative SRA is proposed. This is a technical approach based on simulation analysis of the BUCs defined in D2.2 under different scenarios. Simulation models will be used to quantify the Key Performance Indicators (KPIs) of the EUniversal BUCs from a functional perspective under different technical boundary conditions, such as network architecture or technical constraints. The choice of simulation models, KPIs, and key sensitivities will be explicitly defined for each BUCs in Chapter 3.

- For the business-oriented dimensions, a qualitative SRA is proposed. This is a non-technical approach focused on the boundary conditions related to regulatory issues, associated business models' constraints, and the perspectives of key stakeholders that can affect the potential for replication or upscaling of the BUCs.

Furthermore, given that the SRA scope and methodology must be tailored to the objectives of each BUC and that the project focuses on local flexibility markets, this report evaluates the EUniversal BUCs to identify which BUCs will be part of the quantitative or qualitative SRA. This evaluation is based primarily on the characteristics of the market design.

As mentioned before, the outputs of the EUniversal SRA will be presented in the deliverable D10.4, where the selected KPIs will be computed through simulations considering the scenarios and methodologies defined in this deliverable. These outputs will be further analyzed to draw conclusions on the SRA potential of each BUC. Likewise, the key lessons learnt concerning the qualitative SRA will be incorporated into the aforementioned deliverable. Furthermore, the results of EUniversal SRA will support the deliverable D10.5, “Roadmap – strategy for the further deployment of the EUniversal solutions”. The roadmap will identify a coherent set of key results and main project messages to be exploited.

1. Introduction

This chapter provides an overview of the scope and objectives of the deliverable. In addition, relevant definitions related to scalability and replicability analysis are discussed. Subsequently, the structure of the deliverable will be described.

1.1 Scope, objectives, and definitions

The EUniversal project, funded by the European Union, aims to develop a universal approach on the use of flexibility by Distribution System Operators (DSO) and their interaction with the new flexibility markets, enabled through the development of the concept of the Universal Market Enabling Interface (UMEI), which is a unique approach to foster interoperability across Europe. The UMEI represents an innovative, agnostic, adaptable, modular and evolutionary approach that will be the basis for the development of new innovative services, market solutions and, above all, implementing the real mechanisms for active customers' (e.g., consumer, prosumer, and energy communities) participation in the energy transition.

In order to fulfill this goal, the EUniversal project comprises three different demonstrators located in Germany, Poland, and Portugal, in which ten Business Use Cases (BUCs) will be tested on real distribution networks at different locations. The majority of these BUCs are focused on implementing local flexibility markets for the procurement of flexibility by DSO in the short-term and long-term timelines. In addition, they are concentrated on the delivery of congestion management or voltage control services through active and/or reactive power.

The results obtained from the demonstrators will provide helpful information on the impact of the BUC solutions. However, these results will be subject to the boundary conditions of each location, such as technical, regulatory, environmental, and social contexts. Therefore, it is necessary to perform a Scalability and Replicability Analysis (SRA) to understand the effects of implementing similar solutions under different technical boundary conditions (network characteristics and technical constraints) and non-technical boundary conditions (regulatory issues, associated business models' constraints, and the perspectives of key stakeholders), that may affect the outcomes expected from the EUniversal project.

The scalability part of the analysis aims to determine the ability of a process, system, or network to increase in size or range to meet a growth in demand correctly. Two types of scalability analysis can be carried out [3]:

- **Scalability in density:** It shows the effects of varying one or more controllable parameters over a given area. For example, the location and penetration level of a technology in the grid or the number of consumers.
- **Scalability in size:** It shows the effects of implementing the use case over a larger geographical area, where different types of networks might be present. For instance, the deployment of the functionality at a country-wide level.

On the other hand, the replicability part of the analysis aims to determine how the modification of the boundary conditions affects the conclusions extracted from the use case with the objective of applying it in other regions, whether intranational or international according to:

- **Intranational Replication:** A use case is replicated in different networks (of the same or different DSO) in the same country at a different time. Hence, common boundary conditions such as regulatory framework or grid planning criteria could be applied.
- **International Replication:** A use case is replicated in different networks of a DSO in another country at a different time, changing boundary conditions.

Furthermore, the boundary conditions directly affect the key performance indicators (KPIs) observed for each use case. Therefore, they have to be adequately characterized to evaluate their influence on the scalability and replicability potential of the different EUniversal BUCs [3].

In this context, Deliverable 10.2 aims to define the SRA methodology and scenarios for evaluating the scalability and replicability potential of the EUniversal BUCs. The SRA will be focused on the ten BUCs defined in the deliverable D2.2 of the project. This deliverable is related to task T10.3.

1.2 Structure of the document

The remainder of this deliverable is organized into four sections, as presented in Figure 1.1. First, chapter 2 describes the steps to perform the EUniversal SRA and identifies which BUCs will be part of the quantitative or qualitative SRA. Subsequently, chapters 3 and 4 describe the quantitative and qualitative SRA methodologies. Last, chapter 5 provides concluding remarks and relates this report to the future work within EUniversal.

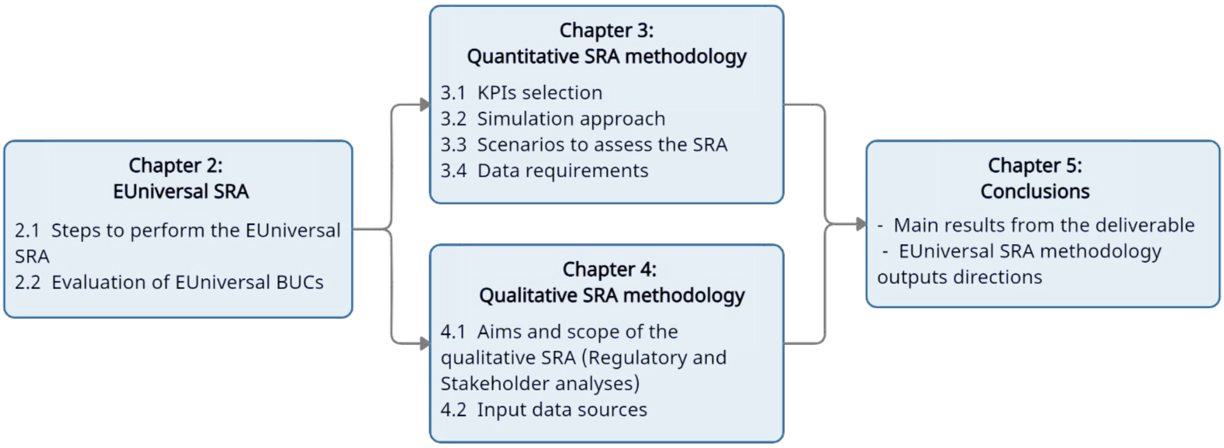

Figure 1.1: Structure of the deliverable

2. EUniversal SRA

The main purpose of this chapter is to define the SRA approach for the EUniversal project. Therefore, Subchapter 2.1 will describe the steps to perform the EUniversal SRA, where the main goal is to illustrate how the SRA scope and the SRA methodologies are defined. Furthermore, Subchapter 2.2 will identify which BUCs will be part of the quantitative or qualitative SRA.

2.1 Steps to perform the EUniversal SRA

Since the SRA analysis can be done for different dimensions, the H2020 BRIDGE initiative developed some guidelines or methodology to support projects when performing SRAs, regardless of the particularities of each project, by providing common and consistent grounds [1]. Recently, various European research projects have applied this methodology, such as Grid4EU [4], InteGRID [5], IElectrix [6], among others.

The methodology proposed by the BRIDGE initiative consists of five main steps, which will be described below along with how they will be implemented in the EUniversal context.

Step 1, Select Smart Grid Architecture Model layers: Figure 2.1 illustrates the SGAM (Smart Grid Architecture Model) framework, which is used as the backbone for the SRA definition. The SGAM includes different interoperability layers to represent the different entities and their relationship in the context of electrical domains and information management zones. The EUniversal SRA is organized around the business and the functional layers according to the project's Description of the Action (DoA) [2]. The functional layer is intended to represent functions and their interrelations concerning domains and zones. Functions are derived from the use case by extracting its functionality. The business layer represents the business view on the information exchange related to smart grids. This layer hosts the business processes, services, economic and regulatory constraints, and organizations linked to the use case [7].

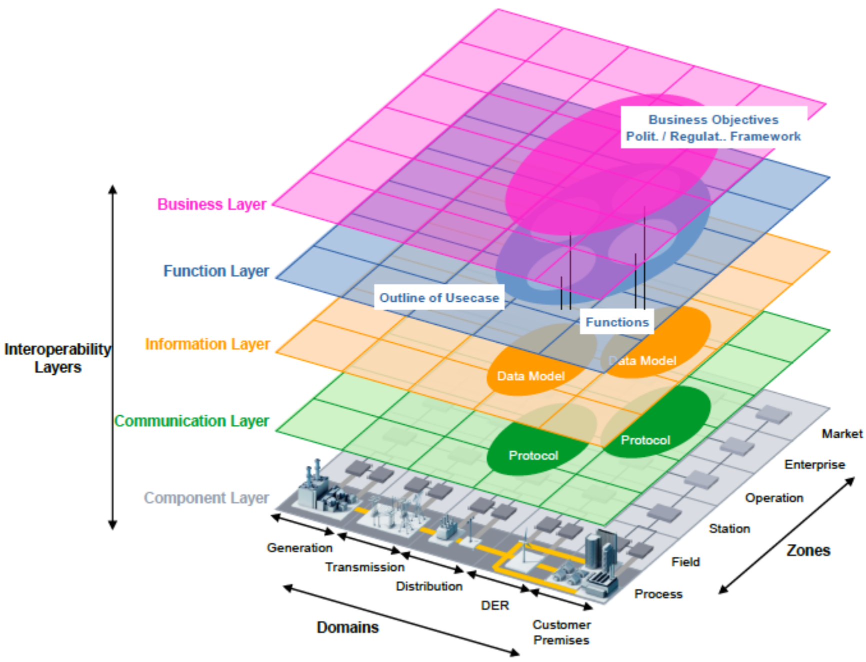

Figure 2.1 SGAM framework [1]

Step 2, Select SRA dimensions: Within each SGAM layer, the SRA dimensions that will be assessed need to be selected. On the one hand, the functional layer will analyze the use case scalability and use case replicability dimensions. On the other hand, the business layer will focus on the regulatory analysis and stakeholder perspective dimensions.

Step 3, Define the methodology for each SRA dimension: The third step requires defining a specific methodological approach for the previously selected dimensions. For the EUniversal project, the below methodologies are defined:

- For the functionality-oriented dimensions, a quantitative SRA methodology is proposed in Chapter 3. This is a technical approach based on simulation analysis of the BUCs defined in D2.2 [8] under different scenarios. Simulation models will be used to quantify the KPIs of the EUniversal BUCs from a functional perspective under different technical boundary conditions, such as network architecture or technical constraints. The choice of simulation models, KPIs, and key sensitivities will be explicitly defined to each BUCs in Chapter 3.

- For the business-oriented dimensions, a qualitative SRA methodology is proposed in Chapter 4. This is a non-technical approach focused on the boundary conditions related to regulatory issues, associated business models' constraints, and the perspectives of key stakeholders that can affect the potential for replication or upscaling of the BUCs. The information required to carry out this step will come from D1.1 [9], D5.1 [10], D10.1 [11], as well as the tasks, T5.4 and T10.2 of the EUniversal project.

Steps 4 and 5: Once the SRA methodology has been defined, Step 4 performs the SRA for each dimension selected, and Step 5 extracts conclusions and SRA rules. Details and outcomes of these steps will be available in the deliverable D10.4 of the EUniversal project. Adaptations may be needed during the execution of the study. Furthermore, the results of EUniversal SRA will support the roadmap in D10.5. The roadmap will identify a coherent set of key results and main project messages to be exploited.

In summary, the complete SRA scope within EUniversal will be characterized as shown in Table 2.1. Note that some other dimensions of the SGAM layers, despite falling outside the scope of SRA, will be addressed within EUniversal. For instance, the business models of the three EUniversal demos were analyzed in D10.1 [11].

Table 2.1: EUniversal SRA scope

SGAM Layer	EUniversal dimension	Type of SRA methodology
Function	Use case scalability	Quantitative
Function	Use case replicability	Quantitative
Business	Regulatory analysis	Qualitative
Business	Stakeholders perspectives	Qualitative

2.2 Evaluation of EUniversal BUCs

In EUniversal, as described in the deliverable D2.2 [8], there are three different demonstrators located in Germany (DE), Poland (PL), and Portugal (PT), for which a total of 10 BUCs have been identified as shown in Table 2.2 and Table 2.3. For instance, the German demo comprises 2 BUCs, namely DE-AP and DE-RP. The Polish demo includes four BUCs, PL-AP, PL-RP, PL-DR, and PL-FS. Similarly, the Portuguese demo considers four BUCs, PT1, PT2, PT3, and PT4.

Since the SRA scope and methodology must be tailored to the objectives of each BUC, this subchapter aims to evaluate the EUniversal BUCs to identify which BUCs will be part of the quantitative or qualitative SRA. This evaluation is mainly based on the market design characteristics in each BUC since the focus of the project is on local flexibility markets. An overview of the BUCs market designs can be found in Annex I of this deliverable. Furthermore, the prioritization (obligatory/mandatory, optional, and business need) of the BUCs indicated in D2.2 is another relevant aspect considered in this analysis. A detailed description of the EUniversal BUCs including their prioritization, can be found in Sections 5, 6, and 7 of the deliverable D2.2 [8].

From the market design, it is clear that the 10 BUCs are focused on the delivery of congestion management and/or voltage control services through active and/or reactive power. However, most of them address the procurement of flexibility by DSO in short-term markets, such as DE-AP, DE-RP, PL-AP, PL-RP, PT1, and PT2. Moreover, these 6 BUCs were identified as obligatory or mandatory by the demonstration partners. Therefore, due to the similar characteristics and goals of these BUCs, they will be considered in the Quantitative SRA, as shown in Table 2.2. They will also be analyzed from a qualitative perspective, together with the BUCs presented in Table 2.3.

Table 2.2 EUniversal BUCs to perform Quantitative and Qualitative SRA

<table>
<tr><th>Demo</th><th>BUC ID</th><th>BUC Name</th><th>Mechanism</th><th>Timeline</th><th>Service</th><th>Product</th></tr>
<tr><td rowspan="2">Germany</td><td>DE-AP</td><td>Congestion management & Voltage Control with market-based active power flexibility.</td><td rowspan="6">Local flexibility markets</td><td rowspan="4">Day-ahead, Intraday</td><td rowspan="4">Congestion management and Voltage control</td><td>AP</td></tr>
<tr><td>DE-RP</td><td>Congestion management & Voltage Control with market-based reactive power flexibility.</td><td>RP</td></tr>
<tr><td rowspan="2">Poland</td><td>PL-AP</td><td>Congestion management & Voltage Control with market-based active power flexibility.</td><td>AP</td></tr>
<tr><td>PL-RP</td><td>Congestion management & Voltage Control with market-based reactive power flexibility.</td><td>RP</td></tr>
<tr><td rowspan="2">Portugal</td><td>PT1</td><td>Congestion management in MV grids for the day-ahead market (or between 1 to 3 days in advance).</td><td rowspan="2">Day(s)-ahead</td><td>Congestion management</td><td>AP</td></tr>
<tr><td>PT2</td><td>Integrated Voltage Control in MV and LV grids for the day-ahead market (AP+RP).</td><td>Voltage control</td><td>AP/RP</td></tr>
</table>

Table 2.3 EUniversal BUCs to perform only Qualitative SRA

Demo	BUC ID	BUC Name	Mechanism	Timeline	Service	Product
Portugal	**PT3**	Contracting flexibility services for avoiding voltage and/or congestion issues during planned maintenance action in MV grids.	Local flexibility markets	Day(s)-ahead Weeks-ahead	Congestion management, Voltage control	AP/RP
	PT4	Voltage control and congestion management for medium and long-term grid planning through market mechanisms		Days-ahead Years-ahead	Predictive congestion management, Predictive voltage control	AP
Poland	**PL-DLR**	Congestion management using permissible line capacity based on Dynamic Line Rating (DLR) system.		Day-ahead	Congestion management	RES generation above connection agreement limit
	PL-FS	Voltage control with the use of flexstation solutions.	Bilateral contracts		Voltage control	Flexstation solutions

On the other hand, in the Polish demo, two BUCs will not test a typical local flexibility market. For example, PL-DLR focuses on a market with only one Flexibility Service Provider (FSP), and PL-FS considers the delivery of services through bilateral contracts. Moreover, these 2 BUCs were identified as optional BUCs in the EUniversal D2.2. In particular, PL-DR was identified as optional because the BUC may be deployed when the Dynamic Line Rating (DLR) system has already been utilized in the DSO IT environment. Furthermore, the Portuguese demo implements the procurement of flexibility in the long-term, contracting flexibility services during planned maintenance action in PT3, and implementing voltage control and congestion management solutions for medium and long-term grid planning in PT4. PT3 and PT4 were identified as optional business needs in D2.2. These 4 optional BUCs from the Polish and Portuguese demos will only be treated in the Qualitative SRA, as shown in Table 2.3.

Summarizing the evaluation presented in this subchapter, the EUniversal SRA will consider all BUCs defined in the project. The quantitative SRA will focus on six BUCs, DE-AP, DE-RP, PL-AP, PL-RP, PT1, and PT2. The qualitative SRA will examine the ten EUniversal BUCs. More details of the quantitative and qualitative SRA methodologies will be given in Chapters 3 and 4, respectively.

3. Quantitative SRA methodology and scenarios

The quantitative SRA aims to evaluate from the functional perspective the impact of scaling-up and replicating of the BUCs selected in Table 2.2 of Section 2.2. This evaluation is based on simulation of the implemented solutions on representative networks to compute a set of KPIs under different technical boundary conditions.

The proposed methodology for the quantitative SRA consists of the below stages that will be further described in the next sections of this chapter as follows:

i. Selection of relevant KPIs to quantify the impact of the BUCs
ii. Definition of the simulation approach
iii. Selection of the scenarios to assess the scalability and replicability
iv. Identification of data requirements to perform the SRA

3.1 Selection of relevant KPIs

Deliverable 6.2 [12] identified and defined three types of KPIs for EUniversal, namely Project KPIs, Demo common KPIs, and Demo specific KPIs. Among these indicators, a set of KPIs was selected for the quantitative SRA based on the information provided in the KPI definition templates of D6.2 and the following criteria:

- KPIs related to BUCs of Table 2.2 whose calculations allow quantitative evaluations and comparisons (therefore, KPIs of the BUCs selected for only Qualitative SRA were excluded).
- KPIs whose formulations are based on input data obtained from simulations.
- Project level KPIs that were assigned as part of the SRA according to D6.2.

Table 3.1 summarizes the selected KPIs, where their domains and link with the BUCs are detailed.

Table 3.1 EUniversal KPIs to consider for the quantitative SRA

KPI ID	KPI Name	KPI Domain	EUniversal BUCs					
			DE AP	DE RP	PL AP	PL RP	PT1	PT2
EU_KPI_1	Increased RES and DER hosting capacity	Technical	✓	✓	✓	✓	✓	✓
EU_KPI_2	Increase of energy storage solutions penetration		✓	✓	✓	✓	✓	✓
CM_KPI_4	Avoided Restrictions		✓	✓			✓	✓
DE_KPI_05*	Baseline accuracy		✓	✓				
DE_KPI_01	Cost of congestion management with flex market vs. curtailment	Economic	✓	✓				
PT_KPI_03	Avoided CO2 emissions from increased RES and DER hosting capacity	Environmental					✓	✓
PT_KPI_04*	Energy consumption	Social					✓	✓

* These KPIs are not expected to be quantified as a result of the simulation analyses. Instead, the impact of variations in these KPIs will be assessed by running sensitivities to the input parameters.

3.2 Simulation approach

As highlighted in Section 2.2, the six BUCs selected to perform the quantitative SRA in EUniversal are focused on implementing local flexibility markets for the procurement of flexibility by DSOs in the day-ahead or intraday timelines, to deliver congestion management and voltage control services through active and/or reactive power. Therefore, a starting point to define the SRA simulation approach is to analyze the local flexibility market's different phases and functions. According to EUniversal D5.1 [10], the implementation of a local flexibility market requires a series of functions divided into six main phases:

- Preparation, which is focused on the product definition and flexibility resources registration and prequalification.
- DSO needs identification, where the DSO defines its flexibility needs based on load and generation forecasting.
- Market operation, where the bids are collected, and the market-clearing process is performed.
- Monitoring and activation, in this phase, a grid monitoring is performed once the market is cleared, then the activation of selected FSPs has to be executed.
- Measurement and settlement, in this phase, the measurement and financial settlement have to be performed to compensate for the service delivered or penalize the lack of response.
- TSO (Transmission System Operator) and DSO coordination, where coordination between system operators may be required to coordinate flexibilities procurement and mitigate conflict situations depending on the service and the network considered.

From the description of these phases and functions, it is clear that the **DSO needs identification and market operation phases** could be modeled and tested through a simulation process to the KPIs' calculation. Therefore, the quantitative SRA simulation approach for EUniversal will focus on these two phases for the modelling and simulation of the BUCs, as illustrated in Figure 3.1. This figure summarizes the proposed approach where the BUCs will be simulated on the representative networks obtained, as will be described in Section 3.4. Their results will then quantify the KPIs for the different scenarios defined in Section 3.3 to analyze the scalability and replicability potential of the BUCs.

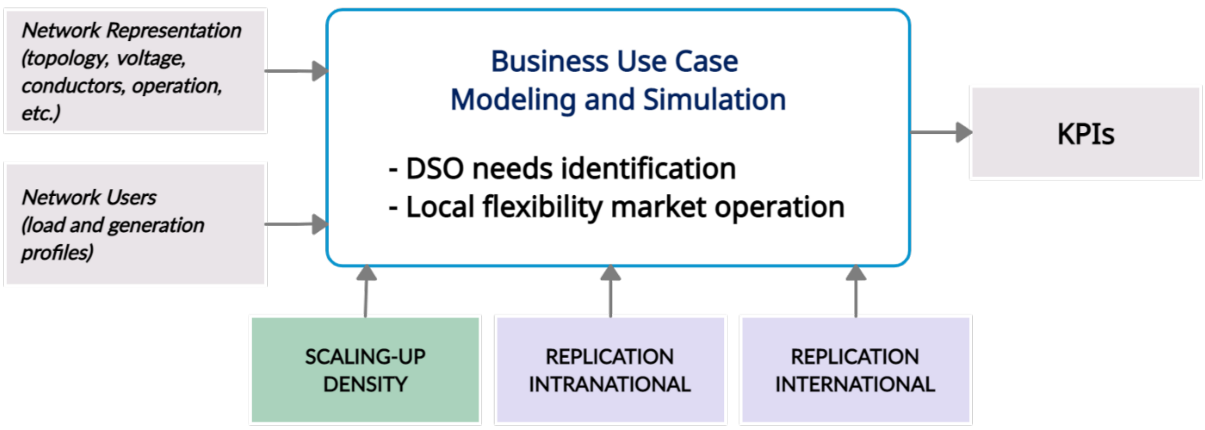

Figure 3.1 Simulation approach for EUniversal quantitative SRA

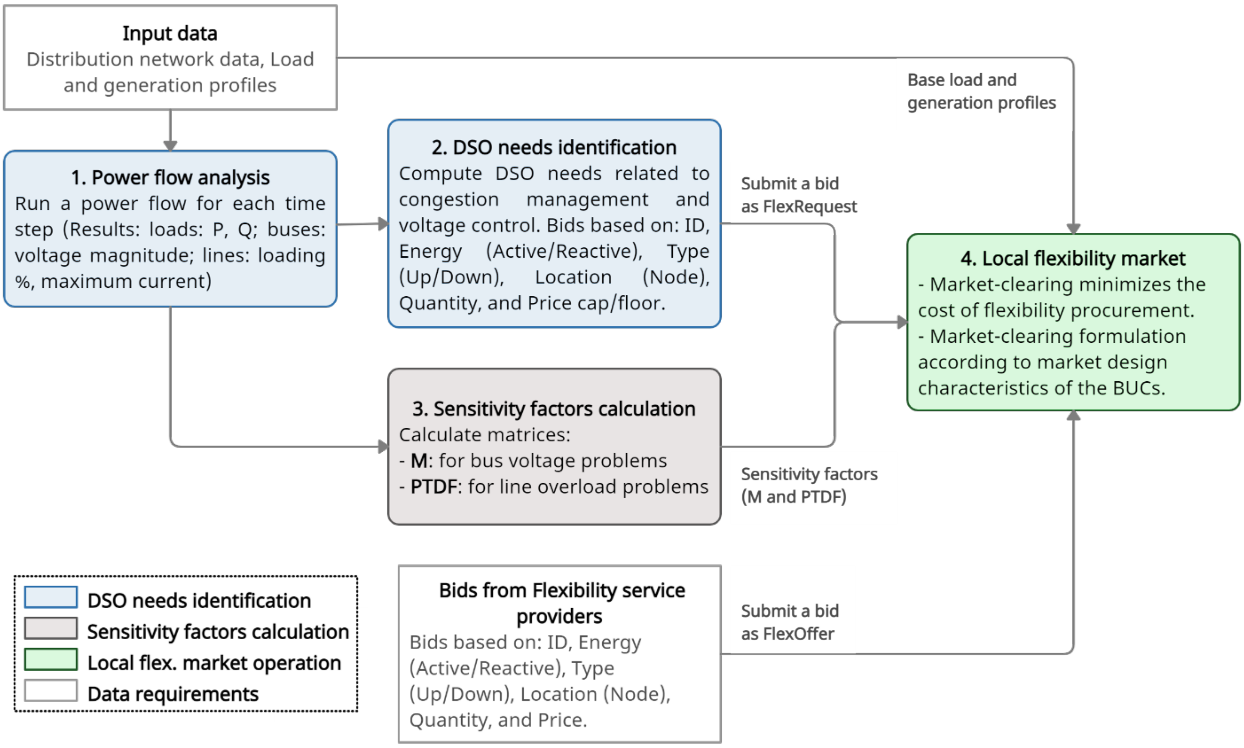

Figure 3.2 BUCs modeling and simulation process

Since the BUC modeling and simulation process is considered a key part of the simulation approach presented previously, Figure 3.2 shows further details of this process according to the below description.

– **DSO needs calculation (Steps 1 and 2):** In EUniversal, the BUCs are based on the assumption that grid congestions (overloading of lines or voltage violations) can be forecasted in terms of location and quantity. Therefore, the first step is to perform a power flow analysis for each time step to detect eventual constraints. To do this, the distribution network data and load and generation profiles described in Section 3.4 are utilized for this analysis. In the second step, the DSO calculates its flexibility needs related to congestion management and voltage control based on the power flow results. These DSO needs are inputs for the local flexibility market-clearing described in the next step, where DSOs submit a bid as *FlexRequest*s for active/reactive power in either upward or downward direction considering the bid location (network bus), quantity, and price cap/floor.

– **Sensitivity factors calculation (Step 3):** A local flexibility market-clearing could be solved with or without considering the network data. There are different solutions to incorporate network data and flow constraints in market models for distribution systems, such as second order cone programming (SOC) formulations [12], quadratically constrained programming [13], or linearization proposals of the power flow constraints [14]. However, these solutions can still pose challenges for implementation in practice, particularly with networks of thousands of nodes, as in the case of the EUniversal demonstrators. Therefore, the sensitivity factors could be a solution for linear market representations when considering grid information in the market-clearing.

  Within the EUniversal SRA approach, the DSO calculates the sensitivity factor for each FSP relative to the flexibility need, and they are computed depending on the locations of the FSP assets, their impact on solving grid constraints, and their potential bid limitations. To compute the sensitivity factors, the following procedures are considered for congestion management and voltage control:

- **Congestion management:** Congestions are generally caused by the limited power capacity of some branches. Therefore, it is necessary to analyze the sensitivity of the power flow of the critical branches to the FSPs power injections. This sensitivity is based on the power transfer distribution factor (PTDF) matrix, where the change in the flow of line ij associated with a power injection at node k and equivalent withdrawal at node m is:

$$\Delta P_{ij} = PTDF_{ij,km} \Delta P_{km}$$

  To calculate the total flow over a line, this is given by:

$$P_{ij} = \sum_{m} PTDF_{ij,km} P_m$$

  Where node k is the slack bus and all the PTDFs are calculated with respect to this node. Further details of the PTDF derivation can be found in [13].

- **Voltage Control:** Similar to the concept of PTDF, a matrix M can be derived whose elements represent the sensitivity between the nodal voltage magnitude changes and the nodal active/reactive power injections. Therefore, we can derive the sensitivity factors as follow:

  - Using matrix notation, the power flow equations can be expressed as [14]:

$$\begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} = \begin{bmatrix} \frac{\partial\theta}{\partial P} & \frac{\partial\theta}{\partial Q} \\ \frac{\partial V}{\partial P} & \frac{\partial V}{\partial Q} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

  - Where ΔP and ΔQ represent the nodal active and reactive power injection vectors, respectively, furthermore, $\Delta\theta$ represents the vector formed by the variation of node phases, ΔV represents the vector formed by the variation rate of node voltage magnitudes, and J is the Jacobian matrix. Since our focus is the bottom part of the matrix J^{-1}, the M matrix can be computed as:

$$\Delta \mathrm{V} = \begin{bmatrix} \frac{\partial V}{\partial P} & \frac{\partial V}{\partial Q} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = M \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

$$M = \begin{bmatrix} \frac{\partial V}{\partial P} & \frac{\partial V}{\partial Q} \end{bmatrix}$$

– **Local flexibility market-clearing (Step 4):** In the local flexibility market-clearing, the most efficient flexibility bids from FSPs are selected to mitigate the identified DSO needs at minimum cost. As highlighted in Figure 3.2, the possible inputs of the market-clearing are:

  - Base load and generation profiles.
  - DSO needs for congestion management/voltage control calculated according to steps 1 and 2 (*FlexRequest*).
  - Flexibility bids from FSPs (*FlexOffer*): These bids are composed of their quantity, location, price, and direction. Here, the direction indicates: i) Volumes of increase and reduction of generation (upward and downward flexibility, respectively) connected at a distribution node, and ii) Volumes of reduction and increase of demand (i.e., upward and downward

flexibility) at a distribution node. The cost for the flexibility activation is also included in the bid because the FSPs are considered as active traders deciding on their flexibility price.

- Sensitivity factors: The sensitivity factors calculated in Step 3 will affect merit order on the market since the combination of the bid price, quantity, and location in the form of sensitivity factor together will decide which order bids will be cleared.
- Another critical aspect when implementing the market is its characterization, i.e., services and products definition, auction type, timeline, buyers, sellers, remuneration scheme, etc. This information will be included according to Table 0.2 (Annex I), which summarizes the market design characteristics of the BUCs defined in D2.2 of EUniversal.

In addition to previous steps, the EUniversal SRA simulation approach could include an ex-post validation process to ensure that the clearing solution does not violate the limits exposed by the DSO. Therefore, a discussion of how to achieve feasible solutions at both the market-clearing stage and real-time is needed to ensure that the flexibility can be activated without causing any congestion.

On the other hand, DSOs can currently own and operate, under certain conditions, specific technologies such as distribution network reconfiguration (DNR), on load-tap changers (OLTC), power electronic devices, etc. Therefore, DSOs can choose between using their own flexible resources or procuring flexibility from third parties, or a combination of them to solve potential operational and planning problems related to congestion management or voltage control and deal with the uncertain and variable power production in the distribution system. In this regard, it could be beneficial to propose a framework for analyzing the interaction between flexibilities from DSO and local flexibility markets to determine which solutions are the most attractive from the point of view of economic efficiency, voltage level, network topology, and other criteria to be explored within the EUniversal SRA scope.

3.3 Scenarios to assess scalability and replicability

To perform the required SRA, the BUCs will be evaluated through the simulation approach and KPIs defined earlier. In addition, several scenarios need to be developed to assess the effect of the parameters that comprise the technical boundary conditions (network characteristics and technical constraints). Some parameters are focused on the scalability of the BUC, while others are related to its replicability.

Therefore, this section presents a preliminary identification of required scenarios and sensitivities for the quantitative SRA. In order to define these scenarios, the following guiding questions have been identified as relevant to be addressed by the quantitative SRA:

- Are there trade-offs between active and reactive power activation to solve network constraints?
- How do the differences between MV and LV grids in terms of grid parameters or FSP characteristics affect the scalability and replicability analysis?
- Is it better to procure small amounts of flexibility from several FSPs or bigger amounts of flexibility from a few FSPs?
- Could the same flexibility be used to solve grid congestions in LV, MV, and HV networks, and what are the FSP categories most suited to solve these congestions?
- How does the market-clearing objective function impact the selected flexibility bids and KPI values?
- What are the implications of considering or not the network information and its associated constraints within the market-clearing?

Subsequently, the selected BUCs to perform the quantitative SRA were divided into two groups for the scenarios' evaluation. Group 1 considers the BUCs of the German and Polish demonstrators because their BUCs will be implemented based on the NODES market platform, which means that their services, timeline, trading type are similar. Also, the KPIs related to these BUCs are equivalent. On the other hand, Group 2 considers the BUCs of the Portuguese demo where two market platforms will be tested, NODES and N-SIDE. Therefore, the SRA may simulate the performance of the flexibility market under continuous and closed-gate auctions and additional KPIs. Further details are provided below. Additionally, it is important to highlight that the final number of scenarios analyzed will be subject to data availability, resources, and the preliminary results obtained, which may render some sensitivities useless or require sensitivities to new parameters not foreseen in this report.

- **Group 1: Preliminary identification of required scenarios and sensitivities for BUCs DE-AP, DE-RP, PL-AP, and PL-RP**

The approach to performing the quantitative SRA for these BUCs is depicted in Figure 3.3. and based on the simulation framework and BUC model of Section 3.2. Accordingly, the functionalities regarding the DSO needs identification and market operation phases are illustrated in the figure.

The parameters related to load profiles, distributed generators (DGs) and storage sizes and penetration may affect the scalability of the BUC. In addition, the parameters associated with FSPs, such as their number, location, capability, and cost may be related to both scaling-up and replication. Concerning replicability, it will be interesting to assess how the active and reactive power control from available FSPs impact the market performance. Likewise, replicability will also be strongly affected by the technical characteristics of the LV and MV distribution networks, including their initial stress conditions and the technical constraints set by the DSO, such as admissible voltage range and overloading limitations, etc.

Furthermore, the expected simulation results to calculate the KPIs defined in Table 3.1. are also listed. In particular, the BUCs of the German demonstrator will be assessed based on the results of network and storage capacity, the number of avoided restrictions, and the relation of the cost of traded flexibility on the market with the cost of energy curtailment. Similarly, the Polish demo will consider the listed KPIs except for the indicator that expresses the relation of flexibility and curtailment.

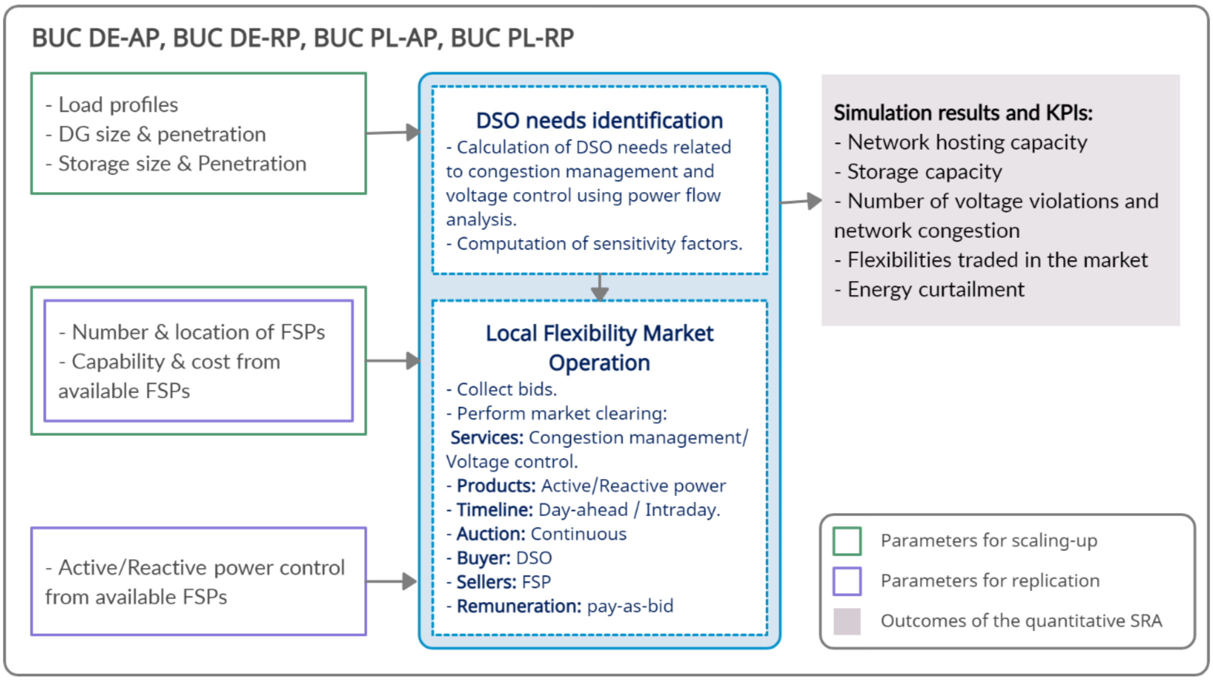

Figure 3.3: Quantitative SRA for BUCs DE-AP, DE-RP, PL-AP, and PL-RP

- **Group 2: Preliminary identification of required scenarios and sensitivities for BUCs PT1 and PT2**

To perform the quantitative SRA for the BUCs PT1 and PT2, an approach similar to the previous one is proposed, see Figure 3.4. In this case, the market design includes additional options since the Portuguese demo will test two market platforms, NODES and N-SIDE. Therefore, the SRA may simulate the performance of the flexibility market under continuous and closed-gate auctions and pay-as-bid or pay-as-cleared remuneration schemes.

To measure the scalability and replicability of the BUCs PT1 and PT2, the same parameters identified for the German and Polish demonstrators will be considered in the sensitivity analysis. However, the expected simulation results are related to the following KPIs: network and storage capacity, number of avoided restrictions, avoided CO_2 emissions, and energy consumption.

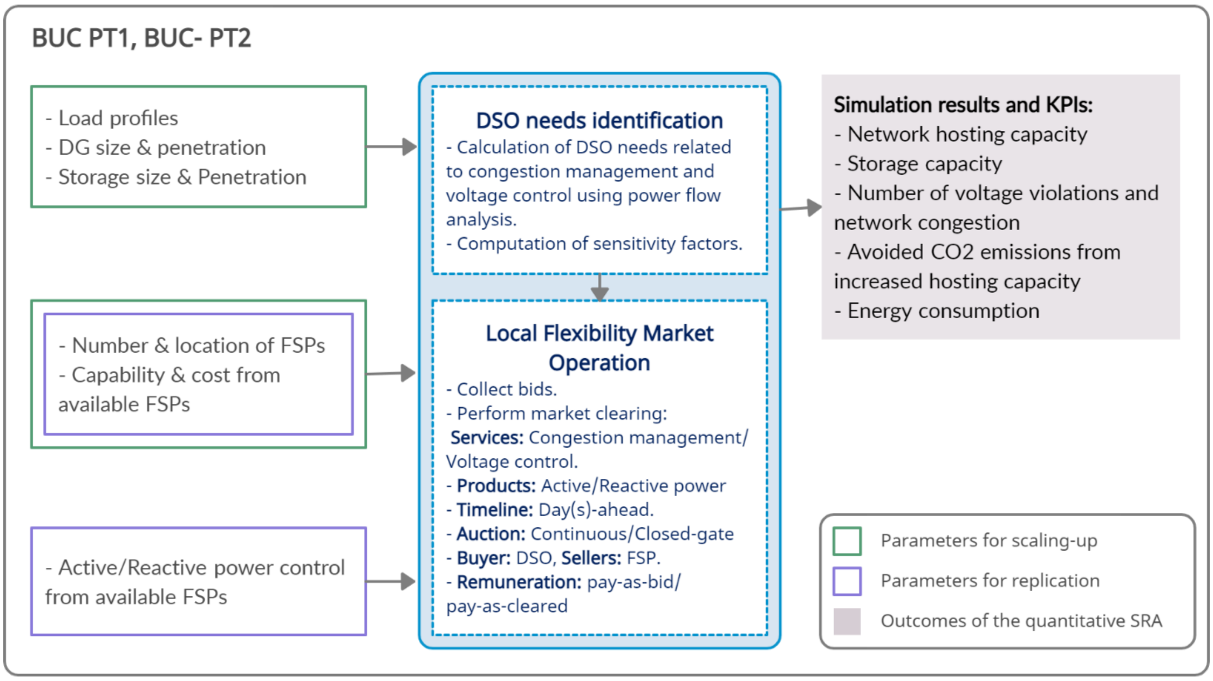

Figure 3.4: Quantitative SRA for BUCs PT1 and PT2

3.4 Data requirements and sources

As stated in previous subsections, the quantitative SRA requires running extensive simulations using power flow studies and optimization problems. Different input data must be gathered for each demonstration location to perform these simulations. Since this data is mainly composed of network models and load and generation profiles, the data collection process needs to start early in order to assess data availability and define priorities in the studies for the three demo countries. Therefore, this section presents a tentative list of the different types of input data to implement the quantitative SRA. These data will be confirmed in the D10.4.

- **Distribution network modelling**

It is necessary to build a set of representative MV and LV grids to characterize the distribution systems for the three demo countries of EUniversal. The representative grids will be formed using the input data received from DSOs in an interactive process, consulting the DSOs to check the validity of assumptions made and the accuracy of the proposed networks representations. To develop these network representations, two approaches could be considered: either to base it on actual anonymized grids provided by the DSOs or to the synthetic grids that present similar characteristics to the real ones.

Consequently, the first step of this process would be to clarify what would the preferred or feasible approach for each country, and the next step is to identify how many types of representative networks should be considered for each country. For example, according to the load size or dispersion, the MV and LV networks could correspond to urban, sub-urban, rural, industrial, or any other subdivision.

Concerning the implementation of the synthetic grids, the Reference Network Model (RNM) would be used. The RNM is a large-scale planning tool that plans the electrical distribution network using GPS coordinates and power of every customer and distributed energy resource (DER) [15]. This tool has been used for different applications and research studies, such as DiNeMo [16], which is an online platform that allows the development of distribution network models based on RNM.

The RNM models the high, medium, and low voltage networks, planning both substations and feeders. There are two versions of RNM, greenfield and brownfield. Figure 3.5 summarizes the approach of the greenfield version, which builds the network from scratch using a street map image as input to the model. After that, the RNM automatically selects the consumers' location and builds the synthetic network using general statistical information from consumers and a standard library of network components. Once the synthetic network has been obtained, structural network indicators are calculated and compared with the indicators of the actual network provided by DSOs. The iterative process of Figure 3.6 is used to compare these indicators until the synthetic grid resembles the actual network. A detailed representation of the main DSO indicators is provided in [17].

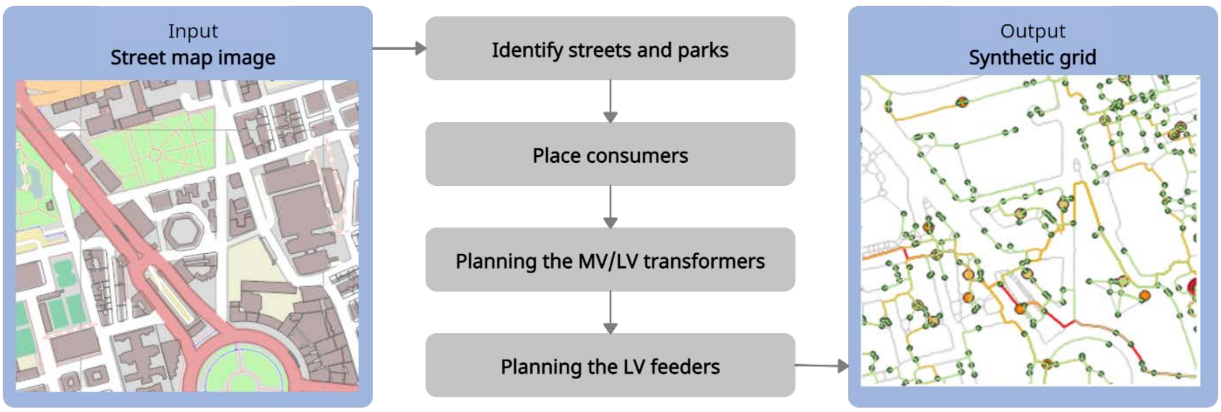

Figure 3.5: RNM approach for the distribution grid modelling (greenfield version)

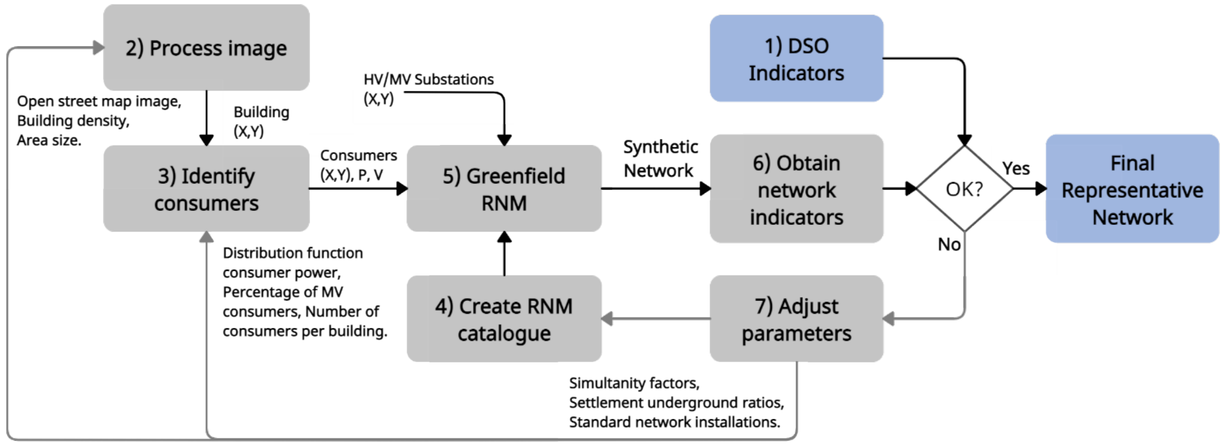

Figure 3.6: Iterative process to ensure the synthetic grid resembles the actual network

- **Load and generation profiles**

It is necessary to characterize the different network users, particularly consumers and DGs, which need to be considered in each case. For instance, different end-consumer categories may be regarded (residential, commercial, industrial), and the following information will have to be collected:

- Load profiles may correspond to standard load profiles, real individual profiles (duly anonymized), or averaged across a high number of consumers within a given category.
- Range of sizes of each consumer in terms of contracted power or peak demand.
- Simultaneity factors to transform individual load profiles into aggregate load profiles in a realistic manner.
- Estimated degree of flexibility from the different consumers.

Regarding the DGs characterization, the following information would be needed per voltage level and type of area:

- Generation profiles, either real examples or averaged.
- DG technologies penetration.
- Typical or common unit sizes.
- Estimated degree of flexibility from DGs.

- **Other data**

Furthermore, the calculation of some KPIs may require some additional data input beyond the indicated before. For instance, for the calculation of the PT_KPI_03, the following input data is needed; the average number of electricity generation hours of DERs, the reference number for electricity generation hours of DER in Portugal, annual emission factor from the Portuguese thermal power plants, and the annual emission factor from the Portuguese energy mix. As part of the services provision by FSPs, possible inputs are the flexibility resources characteristics, services and products definitions, bids information, and estimated degree and cost of flexibility.

4. Qualitative SRA methodology

In addition to the technical characteristics of the specific distribution network and the FSPs, scalability and replicability can be heavily influenced by non-technical boundary conditions related to regulation, economic, or stakeholder-related factors. Therefore, the technical analyses will be complemented with a qualitative assessment of these non-technical boundary conditions.

The qualitative SRA will be discussed in two parts. First, the aims and scope of the SRA will be discussed. Second, the input data sources will be described. The methodology of the qualitative SRA will heavily rely on other tasks of the project that analyze related aspects, namely tasks T1.1 ("Analysis of current EU and national policies"), T5.1 ("Identification of relevant market mechanisms"), T5.4 ("Evaluation of market mechanisms"), T10.1 ("Business models and cost benefit analysis methodologies") and T10.2 ("Regulatory recommendations").

4.1 Aims and scope of the qualitative SRA

The qualitative SRA aims to identify potential non-technical barriers and/or drivers for the replication and upscaling of the relevant EUniversal solutions/BUCs. As mentioned in section 2.2, the qualitative SRA will analyze all 10 BUCs presented in D2.2, i.e., including not only those relying on local flexibility markets for voltage and congestion management to support grid operation, but also those which rely on flexibility to support grid maintenance or long-term planning (Portuguese demo), or aim to exploit the internal flexibility of the DSO through DLR or flexible transformer stations (Polish demo).

In terms of geographical scope, the focus will be on the three EUniversal demo countries, i.e., Portugal, Germany, and Poland. Nonetheless, in order to broaden the coverage and enable some generalization of the conclusions drawn, additional countries from some EUniversal participants, such as Belgium, Norway, Spain, and the UK, will be taken into consideration. Lastly, other relevant countries analyzed in previous project deliverables (e.g., France, Italy, or the Netherlands) can be incorporated as well, mostly due to best practices identified in some specific topics.

The ensuing subsections describe the scope of the qualitative analyses related to regulation and stakeholders' perspectives, respectively.

4.1.1 Regulatory analysis: aims and scope

The regulatory SRA aims to identify barriers and drivers for replication or upscaling of the BUCs posed by power system regulation. This includes all the rules determining whether and how grid users may provide flexibility services, the role of the different agents involved, the remuneration of certain services or activities, tariffs, metering deployment, data management, etc. More specifically, the emphasis will be placed on the implications of the regulation for the business models of DSOs, FSPs and flexibility market operators (MOs).

Figure 4.1 illustrates the methodology and scope followed for the qualitative regulatory analysis. The inputs and the methodology steps are highlighted in the figure, and each step is further detailed below.

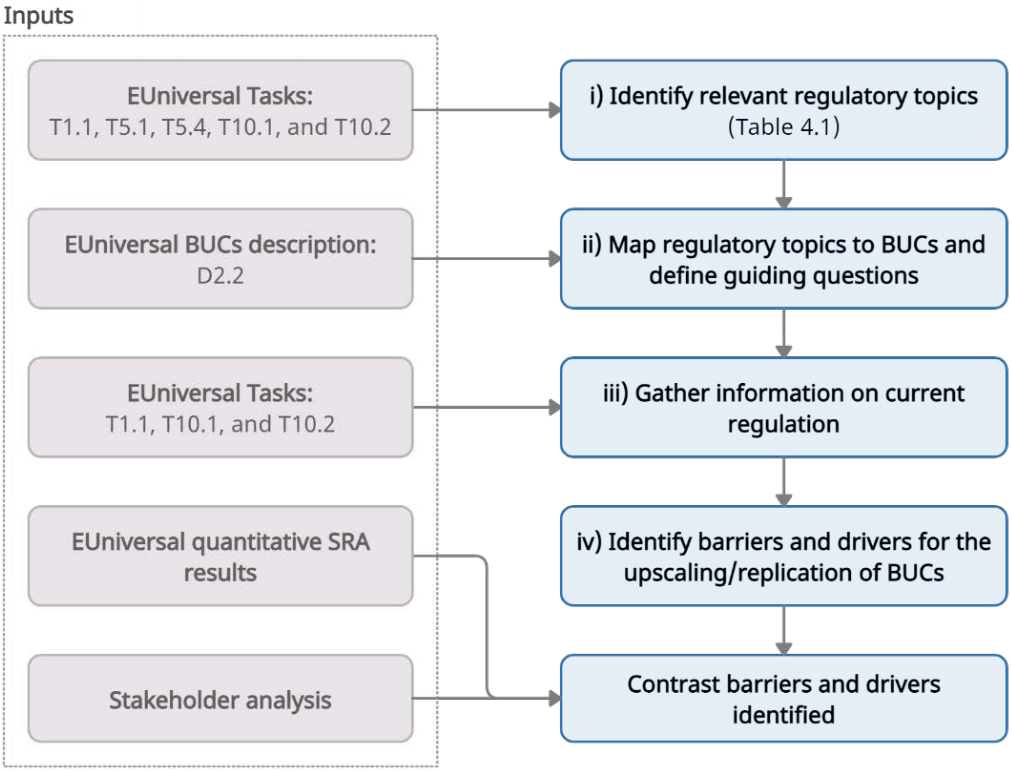

Figure 4.1: Regulatory analysis methodology and scope

i. Identify relevant regulatory topics

Power system regulation covers many different aspects. However, not all of these are relevant for the BUCs of the project. Therefore, the first step consists in identifying those regulatory issues that are most relevant to EUniversal. This selection builds further on previous project tasks. Table 4.1 presents a preliminary identification of the main regulatory topics that will be addressed in the qualitative SRA, as well as the main stakeholders affected by each of these topics, i.e., DSOs, FSPs, or MOs. It can be seen that most topics are transversal and relevant to all stakeholders, whereas some topics specifically affect one of these groups.

There are some additional regulatory topics that could be somehow related to the EUniversal use cases. Some examples of these peripherical topics include TSO-DSO coordination, appropriate forecasting by DSOs, storage ownership by DSOs, DSO unbundling, and incentives for DSOs to improve quality of supply or energy losses. However, they will not be addressed in detail since they are not at the core of this project.

Table 4.1 Preliminary identification of relevant regulatory topics

Topic	Main Stakeholder		
	DSO	FSP	MO
Distribution network tariffs	X	X	X
Connection agreements	X	X	X
Flexibility services and markets	X	X	X
Balancing market design	X	X	X
Redispatch market design	X	X	X
Regulatory sandboxes	X	X	X
DSO incentives for innovation	X		
DSO remuneration	X		
Grid investment plans	X		
Smart meter infrastructure	X		
Grid data sharing	X	X	X
Customer data sharing and GDPR	X	X	X
Aggregation		X	
Energy communities		X	
Responsibilities for market operators			X

ii. Map regulatory topics to BUCs and define guiding questions

Next, the identified regulatory topics will be mapped against the BUCs of the EUniversal demos. This mapping will highlight what topics are relevant to what BUCs or, in other words, what are the relevant topics to consider for each BUC. Moreover, a set of guiding questions will be developed. The purpose of these guiding questions is to facilitate drawing understandable conclusions. The following are examples of potential guiding questions for this regulatory SRA:

- Could distribution tariffs be used together with local flexibility markets or should they serve different goals (cost-recovery vs. efficient grid utilization)?
- Are flexibility market rules technology-neutral in practice?
- Is there a level-playing field for aggregators and energy communities?
- Where do flexibility markets fit in the current sequence of electricity markets?
- What is the best way to incentivize DSOs to use flexibility?
- Is flexibility adequately integrated into DSO economic/financial plans?
- Do smart meter infrastructure and data sharing foster the development of flexibility markets?

iii. **Gather information on current regulation**

The next step is to collect information on existing national regulation to enable cross comparisons and best practice identification. This step has already partly been performed in other project tasks mentioned above. Nonetheless, additional efforts may be necessary within task 10.3 in case of recent changes in the regulation of some countries or in order to assess some best practices from additional countries not identified in previous tasks.

iv. **Identify barriers and drivers for the upscaling/replication of the BUCs**

Lastly, based on current regulation, barriers and drivers for upscaling and replication will be identified. The results of this step will be compared and combined with those of the quantitative SRA, as well as the inputs received from the different stakeholder consultation activities described in the next subsection.

4.1.2 Stakeholder analysis: aims and scope

In addition to assessing the current regulatory conditions, the qualitative SRA will be complemented with the inputs gathered from the different stakeholder interactions taking place within the project. This aims to capture potential barriers or drivers that are not directly observable by the analyses previously described due to their being related to business strategies, stakeholder preferences, etc. More specifically, the SRA will try to collect the view of relevant stakeholder groups on the EUniversal solutions including the UMEI, the different BUCs, flexibility market design, etc.

The main stakeholder categories targeted in the previous section comprise FSPs, DSOs, and MOs; all of which are represented by project partners. Moreover, other interesting stakeholder categories such as regulators and TSOs will be addressed too. This will be achieved by conducting targeted interviews and integrating the topics in existing workshops organized in the context of the EUniversal project (e.g., International Advisory Board (IAB) meetings, deliverable D5.4 workshops). Some additional stakeholder groups will not be specifically targeted by the qualitative SRA since they are not covered in the stakeholder consultation activities performed within the aforementioned project tasks. These groups comprise the following: end-consumers, equipment manufacturers, and retailers.

4.2 Input data sources

The inputs that will be used to perform the qualitative SRA will mostly come from other project tasks, which are detailed later in this section. Note that when the corresponding final deliverable is not publicly available yet, internal draft versions will be used as the basis for the SRA.

The main tasks and deliverables that will be used as inputs, as well as the main information coming out of each of them, are the following:

- **Regulation:**
  - D1.1 will provide input on national regulation on network tariffs, connection agreements, and flexibility market. Also, this deliverable analyzed the European regulation on aggregators and energy communities which can serve as an input.
  - D5.1 provides additional information on the current practices and compatibility of distribution network tariffs, access and connection agreements, and local flexibility markets.
  - D5.4 serves as an input for specific aspects of flexibility procurement such as data sharing, responsibilities for market operators, balancing market and redispatch market design.

- D10.1 provides an analysis of the business models of the EUniversal demos and current practices on distribution network planning.
- D10.3 serves as an input on the current practices of regulatory sandboxes and DSO incentives for innovation.

- **Stakeholders:**

The multistakeholder perspective of the findings of Deliverable 5.4 will be included using the EUniversal workshops towards the IAB and targeted interviews. These approaches can also be used to achieve the perspective of TSOs and regulators on the other identified regulatory topics.

5. Conclusions

The SRA scope and methodology to be applied in the EUniversal project have been established in this deliverable. The EUniversal SRA scope is characterized by the functional and the business layers of the SGAM framework. Concerning the functional layer, the dimensions addressed include the use case scalability and the use case replicability. For the business layer, the regulatory analysis and the stakeholder perspectives dimensions are considered. This deliverable defined a specific methodological approach for each of these dimensions.

On the one hand, a quantitative SRA methodology was selected for the functional-oriented dimensions. This methodology is based on a simulation analysis of the BUCs under different scenarios to assess the effect of the parameters that comprise the technical boundary conditions. The choice of simulation approach, selection of relevant KPIs, identification of required scenarios and sensitivities, and data requirements were defined in this deliverable.

The simulation approach for the quantitative SRA is divided into two stages. In the first stage, the BUC is modeled considering the DSO needs identification and market operation phases. In the second stage, the BUC is simulated on the representative networks. Then the values of the KPIs are computed for the defined scenarios to analyze the BUC's scalability and replicability potential.

Furthermore, this deliverable highlighted a tentative list of the different types of input data required to implement the quantitative SRA. Two approaches will be considered to build a set of representative grids to characterize the distribution systems for the three demo countries of EUniversal. They may correspond to actual anonymized grids provided by DSOs or to the synthetic grids that present similar characteristics to the real ones. Also, it is necessary to characterize the different network users, particularly consumers and DGs. As part of the services provision by FSPs, possible inputs are the flexibility resources characteristics, services and products definitions, bids information, estimated degree and cost of flexibility.

On the other hand, a qualitative SRA methodology was selected for the business-oriented dimensions. This methodology focuses on analyzing the non-technical boundary conditions that can affect the potential for replication and upscaling of the BUCs. The methodologies for the regulatory and stakeholders' perspectives analyses were provided in this deliverable. Also, the most relevant data sources for the qualitative SRA were highlighted.

Furthermore, since the SRA scope and methodologies must be tailored to the objectives of each BUC, this deliverable evaluated the EUniversal BUCs to identify which BUCs will be part of the quantitative or qualitative SRA. This evaluation was mainly based on the market design characteristics in each BUC since the focus of the project is on local flexibility markets.

The outputs of the EUniversal SRA will be covered in D10.4, where the selected KPIs will be computed through simulations considering the scenarios and methodologies defined in this deliverable. These outputs will be further analyzed to draw conclusions on the potential of each BUC for scaling-up and replication. Moreover, the results of EUniversal SRA will support the roadmap in D10.5. The roadmap will identify a coherent set of key results and main project messages to be exploited.

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Annex I – Overview of EUniversal BUCs

Table 0.1: EUniversal BUCs general information

Demo	BUC ID	BUC Name	Demo Locations	Grid Level	Prioritization from D2.2
Germany	DE-AP	Congestion management & Voltage Control with market-based active power flexibility	**East of Germany:** South Brandenburg, South Saxony-Anhalt, and West and South Saxony Region.	**Focused on LV grid.** However, the transition from LV to MV (provision of aggregated LV flexibility for the MV level) is being examined.	**Obligatory**
	DE-RP	Congestion management & Voltage Control with market-based reactive power flexibility			**Mandatory**
Poland	PL-AP	Congestion management & Voltage Control with market-based active power flexibility	**Different locations (north and central parts of Poland):** HV grid (ENERGA-OPERATOR's HV network – **DLR functionality**), MV grid (North near the city of Wladyslawowo), LV grid (region of Plock, Kalisz, Gdansk).	HV, MV, and LV grids	**Mandatory**
	PL-RP	Congestion management & Voltage Control with market-based reactive power flexibility		HV, MV, and LV grids	**Mandatory**
	PL-DLR	Congestion management using permissible line capacity based on Dynamic Line Rating (DLR) system		HV, MV, and LV grids	**Optional, Nice to have**
	PL-FS	Voltage control with the use of flexstation solutions		HV, MV, and LV grids	**Optional**
Portugal	PT1	Congestion management in MV grids for the day-ahead market (or between 1 to 3 days in advance)	**Different locations:** Valverde, West zone of Portugal, Alcochote, E-REDES EV charging infrastructures in urban areas.	LV and MV grids	**Obligatory**
	PT2	Integrated Voltage Control in MV and LV grids for the day-ahead market (AP+RP)		LV and MV grids	**Obligatory**
	PT3	Contracting flexibility services for avoiding voltage and/or congestion issues during planned maintenance action in MV grids		LV and MV grids	**Business need**
	PT4	Voltage control and congestion management for medium and long-term grid planning through market mechanisms		LV and MV grids	**Business need**

Table 0.2: EUniversal BUCs market design characteristics

BUC MARKET DESIGN													
Demo	**BUC ID**	**Mechanism**	**Service**	**Product**	**Market Platform**	**Timeline**	**Market opening**	**Market closing**	**Auction type**	**Buyer**	**Pricing**	**Netw. info**	**Loc. info**
Germany	DE-AP	Local flexibility market	Congestion management, Voltage control	AP	NODES	Day-ahead Intraday	Day-ahead	Several hours before real-time (TBD)	Continuous market	DSO: MITNETZ	Pay-as-bid	No	Yes (grid node)
	DE-RP			RP									
Poland	PL-AP	Local flexibility market	Congestion management, Voltage control	AP	NODES	Day-ahead Intraday	Day-ahead	1h before delivery (to be verified during field tests)	Continuous market	DSO: ENERGA-OPERATOR	Pay-as-bid	No	Yes (grid node)
	PL-RP			RP									
	PL-DLR		Congestion management	RES generation above connection agreement limit		Day-ahead		1h ahead		Producers			
	PL-FS	Bilateral contracts	Voltage control	No market platform is required									
Portugal	PT1	Local flexibility market	Congestion management	AP	NODES / N-SIDE	Day(s)-ahead	72h before activation	24h before activation	NODES: Continuous market, N-SIDE: Call market (closed-gate auction)	DSO: E-REDES	NODES: Pay-as-bid, N-SIDE: Pay-as-bid or pay-as-cleared	NODES: No, N-SIDE: partially shared by DSO.	Yes (grid node)
	PT2		Voltage control	AP and/or RP									
	PT3		Congestion management, Voltage control	AP and/or RP		Day(s)-ahead Weeks-ahead	Short term: 72h before activation, Long term: 3 weeks before activation	Short term: 24h before activation, Long term: 2 weeks before activation					
	PT4		Predictive congestion management, Predictive voltage control	AP		Days-ahead Years-ahead	Short term: D-3 before activation, Long term: Y-3 before activation	Short term: D-1 before activation, Long term: Y-2 before activation					