PLATFORM FOR OPERATION OF DISTRIBUTION NETWORKS

Platone

PLATform for Operation of distribution NEtworks

D7.6

Main findings and recommendations

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Abstract

The objective of this report is to provide a comprehensive summary of main contributions and outcomes obtained from the activities of Scalability and Replicability Analysis as well as Multi-Criteria Cost Benefit Analysis performed within the Platone project to ensure the successful rollout of the innovative solutions tested in the demos and evaluate their cost-effectiveness.

In particular, the software architecture specifically elaborated to conduct the Scalability and Replicability Analysis simulations is described, the Scalability and Replicability Analysis application to the classes of Use Cases representing the Platone demo use cases is detailed, and main findings are extracted for each of the three demos. Moreover, non-technical boundary conditions such as regulatory and stakeholder-related concerns which may affect the replication and upscaling of the Platone use cases is presented. In addition, the developed methodology for Multi-Criteria Cost Benefit Analysis is described and applied to all the solutions investigated within the Platone demos, by accounting for Key Performance Indicators pertaining different viewpoints (such as economic, societal, environmental, etc.).

Overall, the obtained outcomes demonstrated the significance of performing proper Scalability and Replicability Analysis as well as Cost Benefit Analysis.

Keyword list

Scalability and Replicability Analysis, Multi-Criteria Cost Benefit Analysis

Executive Summary

Innovation for the customers, innovation for the grid" is the vision of project Platone - Platform for Operation of distribution Networks. Within the H2020 programme "A single, smart European electricity grid", Platone addresses the topic "Flexibility and retail market options for the distribution grid". Modern power grids are moving away from centralised, infrastructure-heavy transmission system operators (TSOs) towards distribution system operators (DSOs) that are flexible and more capable of managing diverse renewable energy sources. DSOs require new ways of managing the increased number of producers, end users and more volatile power distribution systems of the future.

Platone is using blockchain technology to build the Platone Open Framework to meet the needs of modern DSO power systems, including data management. The Platone Open Framework aims to create an open, flexible and secure system that enables distribution grid flexibility/congestion management mechanisms, through innovative energy market models involving all the possible actors at many levels (DSOs, TSOs, customers, aggregators). It is an open source framework based on blockchain technology that enables a secure and shared data management system, allows standard and flexible integration of external solutions (e.g. legacy solutions), and is open to integration of external services through standardized open application program interfaces (APIs). It is built with existing regulations in mind and will allow small power producers to be easily certified so that they can sell excess energy back to the grid. The Platone Open Framework will also incorporate an open-market system to link with traditional TSOs. The Platone Open Framework is tested in three European demos, namely Italy, Greece and Germany.

To ensure the successful rollout of the innovative solutions tested in the demos of the Platone project, methodologies for Scalability and Replicability Analysis (SRA) as well as Cost Benefit Analysis (CBA) are developed as part of WP7, with the objective of identifying technical, economic and regulatory barriers for their large-scale deployment. In this context, the present report provides a comprehensive summary of the main contributions and outcomes stemming from the SRA and CBA activities.

The scope of SRA is to estimate how the KPIs calculated in the demos might change when boundary conditions will change (replicability analysis) or when the project will be deployed at a larger scale (scalability analysis). To this aim, two SRA Use Cases (UCs) have been identified, namely the "zero power exchange" as well as the "desired power exchange" and mapped to the specific UCs implemented in the Platone project demos (in Italy, Greece and Germany). In particular, these two SRA UCs have been adopted for performing analyses of: (i) scalability in density, to study the effect of increased penetration of a given solution within the same demo area; replicability intra-national, to study the effect of replicating the same solution in the same country hosting the demo but in situations in which technical boundary conditions may differ, still with the same economic and regulatory boundary conditions; and (iii) inter-national, to study the effect of replicating the same solution when all types of boundary conditions may differ (e.g., due to different regulation schemes, types of networks, social concerns etc).

To perform these analyses, a software architecture has been put in place: starting from information about network topology as well as current and expected/target profiles of load and generation, a set of random scenarios has been produced to account for geographical and parametric variability of the power profiles. Out of these, the congested scenarios have been identified via load flow analysis, and sent to an ad-hoc modified Optimal Power Flow algorithm to obtain the set points of the loads and generators which can allow the system to solve the identified congestions by utilizing local flexibility installed in the grid for each of the investigated SRA scenario.

Following this workflow, the main findings of the SRA activities can be summarized as follows:

- Both the "desired power exchange" and "zero power exchange" SRA UCs can be successfully implemented in most of the considered scenarios for scalability in density and replicability intra- and inter-national; when urban networks are considered, the amount of local flexibility sources envisaged by the latter are sufficient to compensate most of the congestions caused by the application of both SRA UCs.
- In the case the SRA UCs are applied to rural networks, the significant growth of DG and flexible loads lead to higher over-voltages and consequently leads to important congestions. This is due to the fact that rural grids have longer lines, lower degree of undergrounding, and a more radial structure with ramifications. To mitigate such contingencies, the usage of local sources of

flexibility might be complemented with the installation of special devices that can compensate the local lack of reactive power.

- In the case the SRA UCs are applied to situations where it is observed power export to the main grid in some hours of the day and power import in others, both the "negative" and "positive" flexibility of the installed distributed generators is activated, especially in urban networks. This outcome suggests the need to invest in solutions that can offer both types of flexibility services.

Finally, barriers that might hinder the large-scale deployment of the two SRA UCs related to regulatory aspects as well as customer participation have been identified and can be summarized as follows:

- Regulatory barriers significantly vary among the three countries hosting the Platone demos.
  In Italy, one of the main regulatory gaps is the lack of a final definition of the roles and responsibilities of DSOs, aggregators, and other market players: although the National Regulatory Agency has published several resolutions to enable the new two roles of the DSO in the flexibility market (market enabler and flexibility buyer), the process of a full framework definition is still ongoing. In Greece, the main obstacle is the lack of regulation in terms of Blockchain technology in the energy sector; additionally, in the Greek legislation, the role of the aggregator is not clearly stated. Finally, although the regulatory landscape of the German energy sector has undergone significant expansion, the implementation and functioning of the German demo have revealed challenges and deficiencies, e.g., the need of a more defined regulatory structure concerning flexibility mechanisms (especially in cases involving devices like remote controllers for control mechanisms), the need of enhancing the regulatory framework governing use of batteries by the DSO.
- Regarding customer engagement, several barriers were identified and discussed for each stakeholder type (e.g., DSO, TSO, aggregators, and customers) individually focusing on harnessing the local flexibilities to alleviate grid congestions, and the solutions identified during the course of the Platone project have been described.

The scope of CBA is to assess the cost-effectiveness of the innovative solutions implemented in the project demos in a given time horizon after the end of the project. In particular, a hybrid approach has been developed, which merges the CBA developed by the European Commission Joint Research Centre (to identify and monetise benefits and costs related to Smart Grid projects) with the Multi-Criteria (MC) Analysis proposed by the International Smart Grid Action Network (ISGAN), so that different types of impacts (economic and non-economic) can be effectively considered and assessed under a common framework. For each demo, the developed MC-CBA methodology applied to all the alternative solutions investigated has allowed to elaborate a decision-making problem composed of a set of demo- or project-specific Key Performance Indicators (KPIs) pertaining different dimensions (e.g., monetary, societal, environmental, etc.). Each KPI has been quantified for each alternative solution, weights have been considered for each of the considered dimensions, and the Analytical Hierarchy Process has been used to produce performance scores for each solution, leading to a MC-CBA ranking of the considered solutions.

Following this workflow, the main findings of the MC-CBA activities can be summarized as follows:

- For the Italian demo, the scenarios based on utilizing local flexibility sources for facing the demand increase has been revealed to be more cost-effective, for few hours per year, when compared to scenarios based on full grid reinforcement. Overall, the Italian demo underscored the importance of a common DSO-TSO market for ancillary services, facilitated by liquid markets with high participation of distributed resources. Moreover, the dynamism of distribution networks favoured granularity per Point of Delivery (PoD) and emphasized the need for data sharing and centralization for successful flexibility processes.
- For the Greek demo, the scenarios based on hourly network tariffs proved to be more cost-effective than the flat network tariff scenario. Overall, the Greek demo demonstrated substantial benefits through advanced tools like State Estimation and optimized DER control, highlighting their potential in diverse network settings.
- For the German demo, the scenario based on solving grid congestion problems via flexibility utilization (with battery control) have shown to be more cost-effective than the scenario considering conventional grid reinforcement as the only solution. Overall, the German demo showcased the positive impact of the energy management system in reducing power peaks and energy exchange.

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1 Introduction

The project "PLATform for Operation of distribution Networks – Platone" aims to develop an architecture for testing and implementing a data acquisition system based on a two-layer Blockchain approach: an "Access Layer" to connect customers to the Distribution System Operator (DSO) and a "Service Layer" to link customers and DSO to the Flexibility Market environment (Market Place, Aggregators, …). The two layers are linked by a Shared Customer Database, containing all the data certified by Blockchain and made available to all the relevant stakeholders of the two layers. This Platone Open Framework architecture allows a greater stakeholder involvement and enables an efficient and smart network management. The tools used for this purpose are based on platforms able to receive data from different sources, such as weather forecasting systems or distributed smart devices spread all over the urban area. These platforms, by talking to each other and exchanging data, allow collecting and elaborating information useful for DSOs, transmission system operators (TSOs), Market, customers and aggregators. In particular, the DSOs will invest in a standard, open, non-discriminatory, blockchain-based, economic dispute settlement infrastructure, to give to both the customers and to the aggregator the possibility to become flexibility market players. This solution allows the DSO to acquire a new role as a market enabler for end users and a smarter observer of the distribution network. By defining this innovative two-layer architecture, Platone strongly contributes to aims to removing technical and economic barriers to the achievement of a carbon-free society by 2050 [1] creating the ecosystem for new market mechanisms for a rapid roll out among DSOs and for a large involvement of customers in the active management of grids and in the flexibility markets. The Platone platform is tested in three European demos (Greece, Germany and Italy). The Platone consortium aims to go for a commercial exploitation of the results after the project is finished. Within the H2020 programme "A single, smart European electricity grid" Platone addresses the topic "Flexibility and retail market options for the distribution grid".

For the successful rollout of the innovative solutions tested in the Platone demos, methodologies for Scalability and Replicability Analysis (SRA) as well as Cost Benefit Analysis (CBA) are developed as part of Work Package 7, with the scope to identify technical, economic and regulatory barriers that might pose a limit to their large-scale deployment.

1.1 Task 7.3 - Performing SRA and CBA analysis

Task 7.3 builds on the methodologies for SRA and CBA and respective data collected in Task 7.1 and Task 7.2. The aim of this task is to perform simulation-based technical analyses, whose outcomes will be complemented with extensive discussions regarding how non-technical boundary conditions (such as regulation and stakeholders' perspectives) may impact the replication and upscaling of the Platone use cases.

In particular, Task 7.3.1 focuses on performing quantitative simulations for SRA based on the methodology developed in D7.2 [2], whereas Task 7.3.2 aims at applying the CBA methodology developed in D7.3 [3] for each of the three smart grid demos of the Platone project.

1.2 Task 7.4 - Elaboration of final messages

The results achieved in Task 7.3 are employed to elaborate recommendations for the support of the large scale deployment of the innovative solutions tested in the demos. In particular, barriers are identified which pertain to the technical aspects (e.g., standardization needs, grid characteristics), economic aspects (e.g., improvement in market designs, research needs to improve the adopted CBA methodology), regulatory aspects (e.g., identification of the optimal regulatory schemes to better support the deployment of the tested solutions), and the customers engagement (e.g., suggestions to enhance customer participation in the management of the tested solutions). The identified barriers are accompanied by a set of possible recommendations in collaboration with the demo leaders.

1.3 Objectives of this Deliverable

The objective of this deliverable is to provide a comprehensive summary of the main contributions and final results stemming from Task 7.3 and 7.4 obtained within the Platone CBA and SRA, with focus on the work developed within the fourth and final year of the project.

First, the software specifically developed for performing the SRA simulations is described in a step-wise manner, the application of the SRA methodology [2] to the Platone demo UCs is detailed and results and main findings are elaborated for each of the three demos. Then, the CBA combined with the Multi-Criteria Analysis (MCA) developed in D7.3 is applied to evaluate the cost-effectiveness of the innovative solutions tested in the three demos. Discussion on the non-technical boundary conditions (e.g., regulation and stakeholders' perspectives) which may affect the replication and upscaling of the Platone use cases is presented. Finally, concluding remarks are reported to highlight future work directions as well as main barriers encountered during the development of the work.

1.4 Outline of the Deliverable

This deliverable is organized as follows:

- Chapter 2 describes the steps that were followed to apply the Scalability and Replicability methodology described in D7.2 [2] to the analysis of the different demo use cases that have been selected for the SRA, as well as the tools and algorithms developed for this purpose.
- Chapter 3 reports the results of the SRA, summarizes the main conclusions that have been obtained from the elaboration of the results, and elaborate recommendations for supporting the large-scale deployment of the solutions tested in the demos, by identifying barriers related to the regulatory as well as customer engagement aspects.
- Chapter 4 provides a description of the Smart Grid Evaluation toolkit adopted to perform the MCA-CBA of the innovative solutions of the Platone demo use cases;
- Chapter 5 applies the MCA-CBA to the Platone demo use cases and reports the per-demo results and main findings;
- Chapter 6 provides a brief discussion on the innovative business models that have been identified to support the utilities in their smart solutions development at a broader scale;
- Chapter 7 concludes the report.

1.5 How to Read this Document

As this document is part of the WP7 of Platone project, its general goals and innovations are briefly summarized in the first paragraph of Chapter 1. General overview of the three demos of the Platone project is beneficial, in which regard a detailed description can be obtained from D3.6 [4] (Italian demo), D4.1 [5] (Greek demo) and D5.2 [6] (German demo).

As this deliverable reports the main findings and recommendations for the SRA and MCA-CBA methodologies developed in the Platone project WP7, basic knowledge of them is desirable. More details of the two methodologies can be found in D7.2 [2] and D7.3 [3], respectively. The confidential results and sensitive data relative to the content presented in this deliverable are reported in the confidential deliverable D7.4 [7].

2 Scalability and Replicability Analysis: methodology and software architecture

2.1 Overview of the SRA methodology

The SRA goal is to evaluate the large-scale potentials of deployment of the most innovative solutions tested in the demo at EU level. The scope of this activity is to estimate how the KPIs calculated in the demos might change when boundary conditions will change (replicability analysis) or when the project will be deployed at a larger scale (scalability analysis). Section 2.1 describes the characteristics of the use cases implemented in the SRA (SRA-UCs) and their relations with the demo UCs. Section 2.2 describes the software tools developed to perform the SRA simulations.

It is noteworthy that the analysis presented hereafter is complemented by the technological scalability assessment performed in WP2, that aims at evaluating the performance of the Platone platform and Platone Open Framework when the number of customers served by the Platone architecture increases. In particular, two main aspects are addressed in D2.16 [8], namely platform scalability (in terms of computational load when the number of users increases) and system scalability (in terms of various performance metrics related to execution and communication time), and the Italian demo use case UC-IT-1 has been chosen for these tests.

The platform scalability performed in WP2 is focused on two UCs implemented in the Italian demo (congestion management and voltage control) and it foresees an extension of the two Italian use-cases in terms of number of DER involved in the execution of the workflow (approximately the 30% of DER expected in the Italian demonstrator geographical area in the present grid conditions). The complete process has been simulated, and no real users have been involved in the simulation. The Platform scalability demonstrated the possibility to extend the Platone Open Framework up to a target value in the current demo geographical area.

The System scalability performed in WP7 assesses the amount of flexibility that shall be provided by flexible resources (loads and generators) in order to solve congestion issues and voltage violations without further reinforcing the grid in a future year (2030) or under different boundary conditions (e.g. rural network). Moreover, the SRA performed in WP7 simulated two different UCs: a “desired power exchange” between MV and LV and the “zero power exchange” operation.

As stated in D7.2 [2] the most important definitions and the main outlines of the methodologies for SRA are:

<u>Definitions</u>

- *Scenario:* a specific combination of load and generation values at a specific time t for the set of N_{nodes} (total number of grid nodes).
- *Profile:* a set of load/generation values over a specific time interval $\{0,1,\ldots,T\}$ (e.g., one day). At each time we consider the power value of a given profile as the sum of the power values of the corresponding load/generation scenario.
- *Load Flow (LF):* a numerical analysis of the flow of electric power in an interconnected system. A power-flow study usually uses simplified notations such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, real power and reactive power. It analyzes the power systems in normal steady-state operation.
- *Optimal Power Flow (OPF):* an optimization problem that dispatches the total demand to the power generation units of the system according to their cost factors, subject to constraints of power balance, power injections and power flows in the system, as well as operational and capacity limits of voltage and power variables.
- *Scalability analysis:* aims at answering the question “what to expect if the use case were to be implemented at a larger scale under the same boundary conditions?” The implementation of a use case at a larger scale could mean the implementation of a higher degree of smartness, a larger area of action, the engagement of a larger number of consumers, the penetration of higher volumes of distributed resources, etc. In this regard, scaling-up may be classified according to the two main dimensions.
- *Scalability in density*: analysis that includes the evaluation of the effects of the increased penetration of a given solution within the same area that hosts the demo: e.g.: higher penetration

degree of distributed generation in the network, higher degree of flexibility of consumers, higher degree of network automation, etc.

- *Scalability in size*: analysis that includes the evaluation of the effects of the deployment of a given solution at a larger scale involving different types of areas within a region or country.
- *Replicability analysis:* analysis that aims at answering the question "what to expect if the use case were to be implemented at a different location, where different boundary conditions can be found?" To analyze replicability, different scenarios must be considered and sensitivity to the main parameters that constitute the boundary conditions of the demonstrator has to be assessed. Replicability analysis has two main dimensions:
    - *Intra-national replication*: it addresses the analysis of the replication of the same solution in the same country that hosts the demo but in situations in which technical boundary conditions may differ, but the same economic and regulatory boundary conditions prevail and the different stakeholders have similar points of view. Variations in the penetration degree of distributed resources, degree of automation in the network, impact of demand side management, etc. will be also studied, to account for the effect of changes in the regulatory and stakeholder related boundary conditions.
    - *International replication*: it addresses the analysis of the replication of the same solution when all types of boundary conditions may differ from those in the demo site due to different regulation schemes and incentives, different economic situations, different strategies from policy makers and distribution companies, different types of networks, different social concerns, etc.

To simulate the selected demo UCs in the SRA, ad hoc tools and algorithms have been developed by WP7 partners to simulate advanced strategies for the operation of distribution grids that allow the DSOs to exploit flexibility services provided by distributed resources to solve local congestions.

These innovative sets of algorithms and tools have been used to replicate the control strategies implemented in the project demos. In the context of SRA, two control strategies have been simulated:

- Desired power exchange
- Zero power exchange

These are referred to as "SRA-UCs" for the rest of the document.

2.1.1 "Desired power exchange" SRA-UC

The "desired power exchange" SRA-UC aims at simulating a control strategy that enables the DSOs to curtail a selected amount of energy imported (or exported) from (to) the main grid. The curtailment of imported power is compensated by the provision of flexibility services provided by local sources of flexibilities. This SRA-UC could also simulate a situation in which the DSO, in order to prevent potential congestions that can occur during peak days, asks the managers of the distributed sources of flexibility to modify their production and consumption curves.To model the demos use cases and KPIs, an ad hoc modification was implemented in the OPF algorithm of the software architecture illustrated in Figure 1. In the network model used in these studies, the power exchange between the observed grid and the external grid is simulated by a generator unit that is placed at the connection between the external grid and the observed grid. In the OPF algorithm modified to simulate the "desired power exchange" SRA UC, the production of this generation is set to a value equal to the desired amount of power injection from the external grid while the corresponding cost factor in the objective function is set to a large value in comparison to the costs associated to the other generators connected to the grid. This formulation aims at simulating a contingency in which the DSO is forced to curtail the power imported by the main grid by a predefined percentage (in the simulations such a percentage constitutes an input of the problem). This OPF formulation could also simulate a situation in which the DSO, to prevent potential congestions that can occur during peak days, asks the managers of the distributed sources of flexibility to modify their production and consumption curves.

2.1.2 "Zero power exchange" SRA-UC

The zero-power exchange SRA-UC aims at simulating a control strategy that enables the DSO to set the value of power exchange between the LV and MV grids or MV and HV grids equal to zero in the observed time slices. To model this use case, an ad hoc modification was implemented in the OPF algorithm of the software architecture illustrated in Figure 1. In the network model used in these studies, the power exchange between the observed grid and the external grid is simulated by a generator unit that is placed at the connection between the external grid and the observed grid. The parameters that represent this generator are set in such a way to force the power exchange at the connection point equal to zero in each observed timeslice. Specifically, the lower limit of this power generation allowed in this generator is set to zero and the corresponding cost factor in the objective function is set to a large value in comparison to the costs associated to the other generators connected to the grid. In this way, this power generation unit is considered as “expensive” in the OPF problem, and the algorithm assigns to this power variable its lowest possible value, which is zero. Thus, the observed network is not allowed to import or export power from the external grid. Thus, to satisfy the energy demand that would have been supplied by the energy imported from the main grid during the normal operation, the network can rely only on local sources of flexibility, i.e., it can only consume the power stored in the local batteries and can only rely on the curtailment of flexible loads.

2.1.3 Links between the SRA-UCs and the demo UCs

As stated in D7.2 [2], the scalability and replicability analysis performed in WP7 is limited to a selected list of demo use cases that have been agreed with the demo leaders. The lists of demo use cases and KPIs included in the SRA are summarized in Table 1.

Table 1: Recap of demo UCs analysed in the SRA (source: [2])

Demo Use case/ KPI	Country	Description
UC – DE - 1 – Virtual islanding	DE	The UC “virtual Islanding” of an energy community aims at balancing generation and demand of a local energy community in such a way that the load flow across the connecting MV/LV transformer is reduced to a minimum.
UC – DE- 2 - Flexibility Provision	DE	It demonstrates the practical feasibility of an innovative approach to operate the local distribution grid. In this approach the DSOs aims at maintaining a predefined value of power exchange between the community grid and the main grid for a defined duration
UC–IT–2: Congestion Management	IT	Its goal is to demonstrate the practical feasibility to unlock local flexibility sources to address local congestion and voltage stability
KPI_GR_07 Generation curtailment	GR	To achieve better operating conditions of the distribution network in the case of a frequency restoration reserve activation request by the TSO.
KPI_GR_08 Demand curtailment	GR	
UC-GR-4 - Distribution Network limit violation mitigation	GR	

The SRA analysis simulates the implementation of the above-mentioned demo UCs in different conditions that represent the different steps of the SRA analysis:

- scalability in density that aims at simulating the implementation of the demo UC when implemented in the same network with an increased penetration of the resources involved in the demo,
- replicability intra – national that aims at simulating the implementation of the demo UC when implemented in different types of networks with similar regulatory conditions;

- replicability international aims at simulating the implementation of the demo UC when implemented in different boundary conditions.

The **desired power exchange SRA – UC** is used to perform the following steps of the SRA analysis:

- Italian demo: scalability in density; replicability intra national;
- Greek demo: scalability in density; replicability intra national;
- German demo: scalability in density; replicability intra national (UC 2)

The demo UC – IT -2 [9] proved that simulated congestions could be resolved with the contribution of local flexibility sources. To model this use case in the SRA, the desired curtailment SRA-UC is used. In these simulations the load and generation curves that describe the 2018 Summer and Winter peak days are increased to simulate the expect Summer and Winter peak in 2030. In the simulations it has been assumed that the grid topology will not change with respect to the current situation. Moreover, to simulate congestions in the future grid scenarios, it is assumed that the import from the MV grid is curtailed by 10% with respect to the baseline import from the MV grid. The replicability intra national analysis implements the same SRA – UC in a different network topology, while maintaining the same load and generation curves used for the scalability in density SRA.

Similarly, the desired power exchange SRA – UC is used to perform the scalability in density and replicability intra national analysis of the Greek demo. In fact, based on D4.1 [5], the goal of UC-GR -4 is to achieve better operating conditions of the distribution network in the case of a frequency restoration reserve activation request by the TSO. In fact, in the tests performed in the Greek demo, in case the TSO needs a frequency support from the MV grid, a request is sent to both the Aggregator and the DSO to curtail the local request of power to resolve the local problem. The DSO calculates and communicates to the Aggregator the appropriate network tariffs that reflect the situation of the network. The flexible loads react to these tariffs and respond to the flexibility support request appropriately. To replicate this demo UC in the SRA software architecture, the desired curtailment is used: the flexibility request issued by the TSO is simulated in the model by requesting to curtail the injection from the HV grid by a fixed percentage with respect to the baseline scenario. In the “scalability in density” simulations, load and generation curves projected to year 2030 are used and the local flexibility sources are used to resolve the expected congestions generated by the TSO request to curtail part of the injection. The replicability intra national analysis is performed implementing the same SRA – UC in a different MV network topology with the same load and generation curves.

Finally, the desired power exchange SRA-UC is also implemented to simulate the UC2–DE Flexibility Provision use case that demonstrates the practical feasibility of an innovative approach to operate the local distribution grid (that represents a rural distribution model). In this approach the DSOs aims at maintaining a predefined value of power exchange between the community grid and the main grid for a defined duration. In the SRA simulations, the predefined value that shall be maintained s calculated as a fixed percentage of curtailment of the power exchange profile between the community and the main grid foreseen for the Summer peak 2030, while the intra national simulations are performed applying the same SRA-UC and profile to the urban LV network model.

The **zero power exchange SRA – UC** is used to perform the following steps of the SRA analysis:

- German demo: scalability in density, replicability intra national (UC1)
- Italian demo: replicability international;
- Greek demo: replicability international;

As stated in D5.2 [10] the scope of the German UC1 (Virtual Islanding) is the implementation of the “virtual Islanding” of an energy community. This demo UC aims at balancing generation and demand of a local energy community in such a way that the load flow across the connecting MV/LV transformer is reduced to a minimum, leveraging on the flexibility services that could be provided by local storage units and other local sources of flexibility services. To simulate this demo UC in the SRA software architecture, the Zero power exchange SRA UC is implemented with the modality described in Section 2.1.2.

The replicability analysis of the Greek and Italian demo is performed by applying the “zero power exchange” SRA- UCs to the same network models and load and generation curves that describe the expected evolution of local demos in 2030 (and have been used in the “scalability in density” simulations)

In fact, the goal of this analysis is to simulate the behavior of the solutions tested in the demos when applied to different boundary conditions. The Italian and the Greek demo did not include in their field tests the "virtual island" use case. Moreover, the current regulatory scheme prevents the implementation of this operating scheme in the real networks. Therefore, the application of the "zero power exchange" SRA-UC represents an application of the demo UCs under different boundary conditions. The scope of this analysis is to provide an estimation of the amount of flexibility that shall be procured by local source of flexibility to enable the implementation of this use case and to test the capability of the distribution grids to provide an amount of flexibility services adequate to resolve severe congestions.

2.2 Software architecture description

Figure 1 illustrates the software architecture that was developed by RSE and RWTH to perform the SRA. The input needed to run the model are the following:

1) Load and generation profiles (combinations of generation and load profiles) (steps 5 and 6)
2) Network topology files: CIM network models and JRC representative network models [11]
3) Limits for lines capabilities, voltage deviations; transformer limits (technical parameters fixed by national regulations, as reported in the 6th CEER benchmarking report on the quality of electricity and gas supply [12])

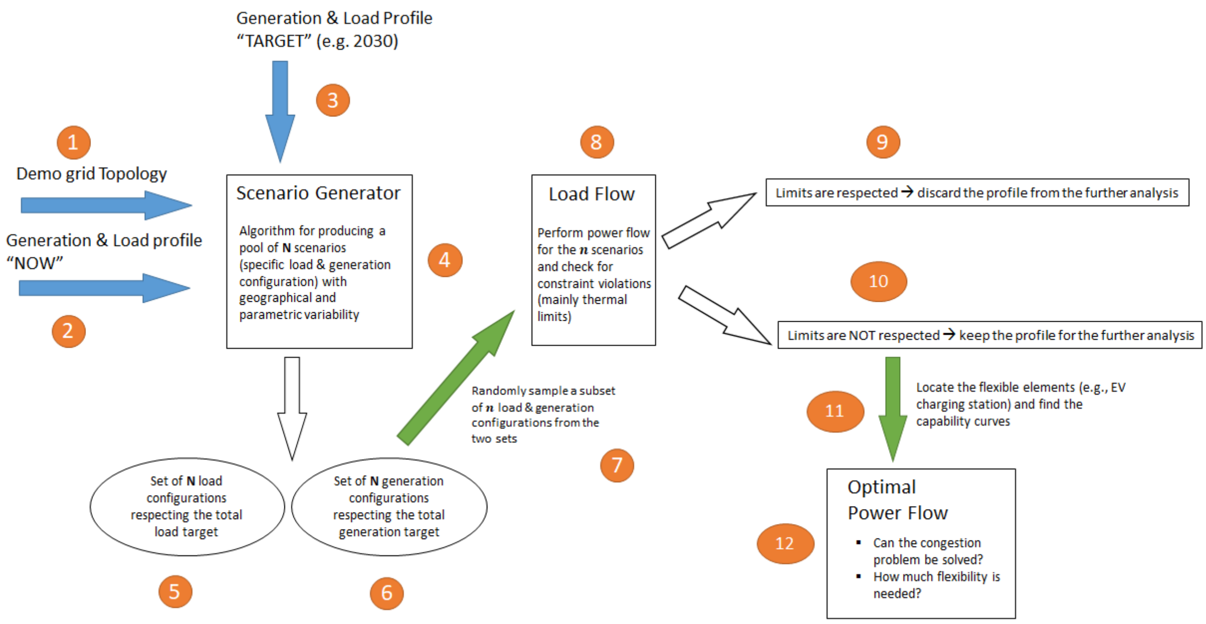


Figure 1: Schematic depiction of the SRA software architecture

2.2.1 Input data (step 1, 2 and 3)

The input data requested to perform the simulations are the following:

- Network topology (e.g., demo grid topology) (step1)
  - CIM network models representing demo areas
  - JRC network models for scaled up/ replicated networks
- Generation and load profile "as is" (e.g., 2018) as seen from the connection points between the demo grid area and the external grids (e.g.: primary or secondary substations) during a specific day (e.g., winter and summer peak days) (step 2). An example of data requested in this step is illustrated Table 2
- Generation and load "target" profile (i.e., evolution of the future profiles as defined by national development plans, e.g. for 2030), e.g. expected growth of loads, generations, expected penetration of EV, storage units, controllable loads etc. as illustrated in Table 7, Table 8, Table 9, Table 10 and Table 12 (step 3)

Table 2: Example of input data for loads

Time slice	Load 2018 [kVA]
0	1285.58
1	1179.05
2	1113.94
3	1072.27
4	1051.42
[…]	[…]
23	1454.86

2.2.2 Scenario generator (step 4)

The objective of the scenario generator is producing a family of N random scenarios (with the possibility to loop over time to create random profiles). The randomness is intended to be both geographical (e.g., different power values at different nodes) and parametric (different power values at a specific node). In Chapter 2.2.2.1, the overview is given in a general manner, while in Chapter 2.2.2.2 more details are given. The algorithm described in this chapter was implemented in a python code reported in Annex B.

2.2.2.1 General overview

Imagine that, for a 3-node grid, two daily profiles are given:

- "as is" profile in 2018 (e.g., blue curve in Figure 2)
- "target" profile in 2030, which is uncertain between a lower ($targetMIN$) and upper ($targetMAX$) limit (e.g., orange and grey curve in Figure 2).

In other words, the "as is" daily profile is assumed to be known without uncertainty, whereas the "target" profile is defined with a given uncertainty.

Figure 2: Profiles created in the algorithm

Assume that, at a given time t, the total load values of the "as is" and "target" profiles are as defined in Table 3.

Table 3: total load values of the "as is" and "target"

	As Is	$Target_{MIN}$	$Target_{MAX}$
$PLtot(t)$ [MW] at given time t	200	500	600

Figure 3 illustrates an example of the algorithm that was developed to calculate the load an generation curves in the target scenarios.

In particular,

- the "as is" total load $PLtot$ is given by the sum of the 3 loads in Figure 3

$$P_{Ltot}(t)=P_{LA}+P_{LB}+P_{LC}=50MW+110MW+40MW$$

In particular,

- the "as is" total load P_{Ltot} is given by the sum of the 3 loads in Figure 3:

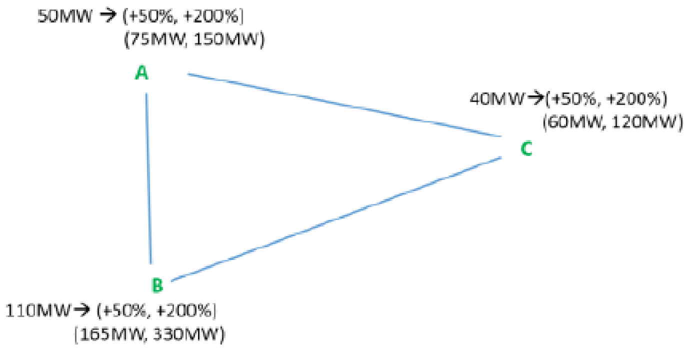


Figure 3: Example of 3-node grid with loads

In the example illustrated in Figure 3 the percentage of the increase of $PLtot$ from the "as is" to the "target" profiles is included between 150% ($200MW \rightarrow 500MW$) and 200% ($200MW \rightarrow 600MW$). Accordingly, the variability of each nodal load is included in the following values. It was assumed that the variability of these parameters is described by a uniform probability distribution (PDF):

- PLA=[75,150] MW
- PLB=[165,330] MW
- PLC=[60,120] MW

The three PDFs associated to each load value are used to run a Monte Carlo simulation aimed at collecting the correspondent Monte Carlo values of $PLtot$, as in Figure 4.

	P_L^A	P_L^B	P_L^C		$P_{L_{tot}}$
1	145.3634	220.8928	100.4420	1	466.6983
2	75.5968	253.4841	105.4548	2	434.5357
3	81.1613	206.0780	96.9483	3	384.1876
4	129.7379	245.4418	79.1338	4	454.3135
5	113.8326	288.3107	108.9068	5	511.0501
6	85.5956	212.1338	87.4511	6	385.1805
7	84.1655	218.8771	91.8977	7	394.9402
8	122.8320	260.6600	70.4207	8	453.9127
9	100.2135	239.1611	89.5491	9	428.9238
10	78.5503	309.9603	115.9471	10	504.4577
11	132.0064	226.7369	62.7801	11	421.5235
12	79.8207	228.0481	116.1845	12	424.0532
13	79.4794	273.8412	107.3646	13	460.6851
14	87.2233	234.2408	103.6155	14	425.0796
15	79.0018	247.8604	68.0813	15	394.9434
16	102.3170	317.7481	67.0103	16	487.0754
17	81.6019	311.3529	93.6508	17	486.6057
18	137.4236	223.6857	118.1698	18	479.2791
19	139.8409	271.6768	95.2255	19	506.7432
20	124.2397	276.9576	94.0511	20	495.2484
21	124.0177	260.1801	66.1808	21	450.3786

Figure 4: Application of the approach to select PLtot values

Each set of nodal load value combination is a load scenario. The set of all load scenarios respecting this constraint represent the family of load scenarios from which a set of N random load scenarios can be sampled by the user.

Figure 5 illustrates the target profiles created by the scenario generator algorithm.

Figure 5: Profiles created in the algorithm

A similar approach is used to calculate the generation profiles.

After creating the user-defined families of load and generation scenarios (each of them respecting the correspondent constraints), a random sampling within these two scenario sets can be performed. An example of one sample of load and generation scenario is reported in Figure 4. As many as N load and generation scenarios can be produced, with N selected by the user. To create a profile (i.e., set of scenarios at each time), the process so far described is repeated for all the time steps (e.g., 24 times for a daily profile), by considering the "as is" and "target" profiles.

2.2.2.2 Detailed explanation of the algorithm

The "scenario generator" program reported in Annex B is an open-source Python program developed in the framework of the Platone project. It creates automatically different scenarios that describe the expected evolution of the electricity grids taking as input the current profiles measured at the secondary or primary substation and a set of information describing global evolution of grids. This information is obtained by looking at the DSOs grid development plans and with interviews with the demos. The input data are summarized in Table 4.

Table 4: Input data requested by the model

Variable	Unit	Description
n_nodes	Number	Number of nodes below the substation
Cosφ		Power factor
perc_increase_load	[%]	Expected increase of load with respect to baseline scenario
uncertain_load	[%]	Error associated to the expected increase of load forecast
perc_increase_gen	[%]	Expected increase of generation with respect to baseline scenario
uncertain_gen	[%]	Error associated to the expected increase of gen. forecast
perc_nodes_gen	[%]	% of nodes equipped with generator in the target scenario
gen_types	labels	Types of generators connected to the grid in target scenario [default: PV; PV and storage]
gen_percs	[%]	Percentage of each type of generator (sum must be equal to 100%]
load_types	labels	Types of loads connected to the grid in target scenario [default: residential; EV; fixed; storage]
load_percs	[%]	Percentage of each type of load (sum must be equal to 100%]
min_contracted_power	[kW]	Minimum contracted power in the considered network in target scenario
med_contracted_power	[kW]	Medium contracted power in the considered network in target scenario
max_contracted_power	[kW]	Max contracted power in the considered network in target scenario
perc_min	[%]	% of loads equipped with meters that had the minimum contracted power in target scenario
perc_med	[%]	% of loads equipped with meters that had the medium contracted power in target scenario
perc_max	[%]	% of loads equipped with meters that had the max contracted power in target scenario

The python code developed for this purpose includes the following steps:

1) the program assigns to each node a specific IDs
2) Based on input parameters, a subset of the nodes IDs are selected using a random sampling. These nodes will host generation in the specific scenario
3) The program creates a profile for the active loads simulated in the specific scenario:
    a. Generate as is nodes profile from Load Aggregate Profile
    b. Generate node profile:
        i. for each time slice, the algorithm selects a random number included between max and min Target Load Aggregate Profile
4) Compute reactive power for load scenario.
5) Create active power generation Scenario.
6) Generate as is nodes profile from Generation Aggregate Profile
7) Generate max and min Target Generation Aggregate Profile
8) Generate node profile:

   a. for each time slice a random number is generated between max and min Target Generation Aggregate Profile at the time slice
9) Compute reactive power for generation scenario
10) For each load node generate random the type of node (selecting randomly from an assigned list of load categories)
11) Generate weighted load profiles based on the installed capacity:
   a. For each load node generate random the contracted power (selecting randomly from an assigned list of load categories)
   b. For each time slice, calculate the total energy consumed at target scenario (sum of each load profile)
   c. For each node, calculate load weight as ratio between the contracted power of each node and the total energy consumed (calculated in step b.)
   d. For each time slice, calculate the weighted load profile by multiplying, for each time slice, the relevant load weight by the total energy consumed in each time slice
12) For each generation node it assigns randomly the type of generator (selecting randomly from an assigned list of generator categories)
13) Generate different scenarios through a permutation of the nodes order

Steps 3) consists of a routine that takes as input the daily profiles as seen in the substation that connects the analyzed grid with the main grid (MV or LV). The algorithm then creates the daily profile (for both generation or load curves). The algorithm then computes the maximum and minimum load and generation profiles by multiplying the values calculated in each time slice for the expected increase of generation and loads and the related uncertainties:

$$Min\_Increase\_Target = 1 + (1 - uncertainty_{Load,\ Generation})$$

$$Max\_Increase\_Target = 1 + (1 + uncertainty_{Load,\ Generation})$$

Steps 3) and 7) consist in the creation of the maximum and minimum profile target (for load and generators respectively), as illustrated in Figure 2.
For each time slice included in the observation period, the program selects a random value included between the minimum and maximum limits. This value is selected with a random function that samples a random value by extracting it from a uniform distribution.

To get a more realistic characterization of the load profiles, the algorithm includes the following steps:

- 11)a: in the input file the DSO shall indicate the 3 most frequent values of contracted power that are offered to the final customers and the relevant percentages of customers that have chosen these options. The algorithm then assigns to each load a random value of the contracted power (selecting randomly from an assigned list of load categories)
- 11)b for each time slice, the algorithm calculates the total energy consumed at target scenario (sum of each load profile)
- 11)c for each node, the algorithm calculates the “load weight” as ratio between the contracted power of each node and the total energy consumed (calculated in step B)
- 11)d For each time slice the algorithm, calculates the weighted load profile by multiplying, for each time slice, the relevant load weight by the total energy consumed in each time slice.

In step 12) the algorithm sort randomly the ID nodes that will be equipped with a generator. The number of distributed generators in the network is calculated by multiplying the number of nodes by the percentage of nodes that will be equipped with generators. The algorithm can also assign a typology of the generator choosing from 2 alternatives: PV plants and PV plants equipped with storage units (PVs). In particular,
- PV plants can offer a flexibility profile that ranges from 1.0% to 0.1% of their baseline production
- PVs plants can offer a flexibility profile that ranges from 1.25% to 0.1% of their baseline production (they are allowed to inject more power with respect to the baseline production by leveraging on the power provided by the storage unit.

The algorithm assigns randomly the typology of each load connected to the grid by selecting randomly the category among the following list: (EV, Fixed, Residential, Storage). The number of load nodes associated to each category is calculated by multiplying the number of nodes in the network by the relevant percentage (this data is provided by the DSO). This option was not used in the simulations that had been performed to limit the computational time needed to run the simulations, however in future development of the software architecture, this option can be used to assign a different flexibility profile according to the load category. In the simulations that have been performed, it is assumed that each load will provide an amount of flexibility that is calculated as a fixed percentage of this baseline scenario. The percentages adopted in each scenario have been discussed with the demos.
To create a set of N random scenarios, in step 13) the Python *shuffling function* is finally called by the algorithm. This function changes the position of generators and loads in the selected network thus creating multiple scenarios starting from a single random sampling.

An example of the outcomes of the algorithm are illustrated Table 5 (generation profiles) and Table 6 (load profiles).

The "scenario generator" algorithm was implemented in a dedicated python script that is reported in Annex B.

Table 5: Example of generation scenarios calculated for a target year (4 scenarios)

time_slice 0	time_slice 1	time_slice 2	[..]	time_slice 23	node_type	node_id	scenario_id
387147	775117	1177351		120482	pvs	0	0
404911	819064	1223516		121187	pv	4	0
410159	787794	1162172		120774	pvs	1	0
387147	775117	1177351		120482	pvs	0	1
404911	819064	1223516		121187	pv	1	1
410159	787794	1162172		120774	pvs	4	1
387147	775117	1177351		120482	pvs	4	2
404911	819064	1223516		121187	pv	0	2
410159	787794	1162172		120774	pvs	1	2
387147	775117	1177351		120482	pvs	4	3
404911	819064	1223516		121187	pv	1	3
410159	787794	1162172		120774	pvs	0	3

Table 6: Example of load scenarios calculated for a target year (4 scenarios)

time_slice 0	time_slice 1	time_slice 2	[….]	time_slice 23	Node type	contracted power	Node id	Scenario id
265161	507511	481131		505494	Fix	6	0	0
266094	508135	482756		506838	Home	3	1	0
264961	502218	483875		501766	Home	9	2	0
266033	502441	482620		501764	Fix	6	3	0
265140	504084	480125		509727	Home	6	4	0
265161	507511	481131		505494	Fix	6	0	1

266094	508135	482756		506838	Home	3	1	1
264961	502218	483875		501766	Home	9	2	1
266033	502441	482620		501764	Fix	6	4	1
265140	504084	480125		509727	Home	6	3	1
265161	507511	481131		505494	Fix	6	0	2
266094	508135	482756		506838	Home	3	1	2
264961	502218	483875		501766	Home	9	3	2
266033	502441	482620		501764	Fix	6	2	2
265140	504084	480125		509727	Home	6	4	2
265161	507511	481131		505494	Fix	6	0	3
266094	508135	482756		506838	Home	3	1	3
264961	502218	483875		501766	Home	9	3	3
266033	502441	482620		501764	Fix	6	4	3
265140	504084	480125		509727	Home	6	2	3

2.2.3 Load flow analysis (step 8)

The generators and load profiles that have been calculated in this step are then passed to the load flow calculator. The software architecture used in Platone calls the MATPOWER's Extensible Optimal Power Flow Architecture [13]. This tool is used only to perform the load flow analysis. The input needed to run the model are the following:

1) Load and generation profiles (combinations of generation and load profiles) (steps 5 and 6)
2) Network topology files
3) Limits for lines capabilities, voltage deviations; transformer limits (technical parameters fixed by national regulations)

The steps that the software architecture follows to run the load flows and to select the congested profiles that are sent to the Optimal Power Flows are illustrated in Figure 6. The software architecture creates different combinations of loads and generators daily profiles and sends them to Matpower that run the load flows. In a following step, the software architecture selects the OPF results in which a violation occurred and send this information to the OPF to perform the OPF and identify the new loads and generators set points that can allow the system to avoid congestions while leveraging on the local flexibility.

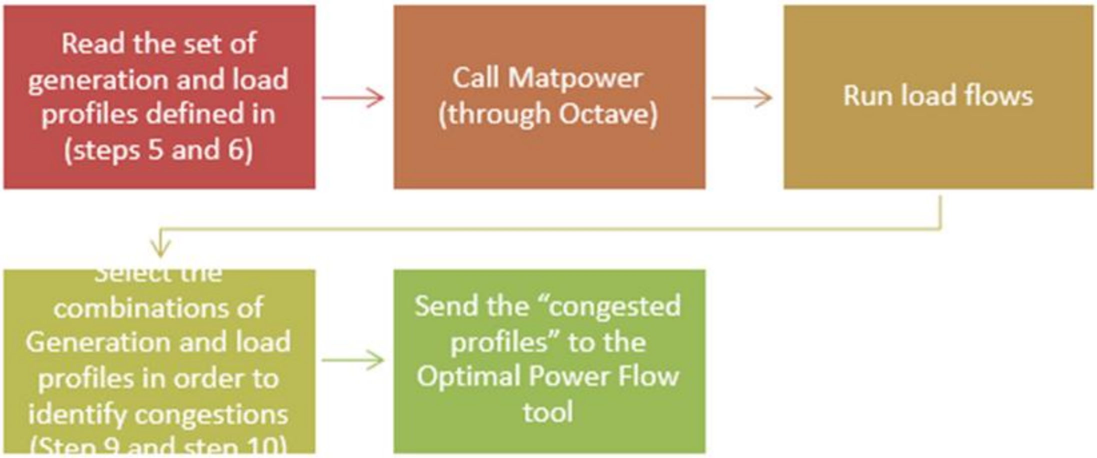


Figure 6: Steps of the load flow analysis

The information that the Load Flows transfer to the OPF is the following:

A. An input file that contains the basic information needed to run the OPF. Among these parameters we can list: the flexibility curtailment; the number of nodes in the network;
B. A "warm start" file that is used by the OPF to initialize the iterations;
C. An excel file that describe the characteristics of the network (including generators and loads profiles) that had caused the congestion detected by the Load Flow.

To identify the possible sources of flexibilities to solve the local congestion, we had assumed that each generator supplies power into the grid during the application of the 2 SRA UCs. Each generation can inject up to 1 per unit (p.u.) of active and reactive power in each time slice to supply the network. Each load connected to the grid can reduce its consumption by a specific percentage with respect to the consumption considered in the congested scenario. This percentage is an input parameter selected by the DSOs and included in the OPF parameter described in the indented A. It is important to underline that, in the simulations, each timeslice is considered as an independent timeslice with respect to the previous time slice, i.e., the available flexibility remains unchanged in each considered timeslice, regardless of whether there has been congestion in the previous timeslice. The specifications and input data requested in these files contain sensitive information that are reported in D7.4 [7].

2.2.4 Modified OPF problem (step 12)

2.2.4.1 Classical OPF problem

The classical OPF problem dispatches the total demand of a system among the conventional generators according to their operational costs. This goal forms the objective function of the optimisation problem, subject to:

- the balance between total generation and total demand in the system,
- the power flows in the lines,
- the operational limits of the voltage at the nodes of the system,
- the capacity limits of the power generation units of the system,
- the capacity limits of flows through the lines of the system.

To achieve faster execution of the OPF problem, fully distributed OPF algorithms have been proposed [14], [15]. This approach also ensures the scalability and modularity of the OPF algorithm, as the algorithm can be applied easily to any size of system, with any set of power generation units. The latter means that the distributed OPF algorithm can be modified easily, when units are integrated in the system that are not dispatched according to their operational costs, e.g., flexible loads. In addition, the algorithm can be easily modified to simulate certain scenarios of the system operation, e.g., for desired power generation from certain units or desired power injections from certain nodes. The aforementioned modifications can be performed easily thanks to the nodal formulation of the OPF problem for the fully distributed OPF algorithm, without changes in big data structures of the entire system.

2.2.4.2 Modifications to the classical OPF problem for the use-cases

The classical OPF problem, in its nodal formulation, is modified here for including flexible loads in the system and simulating the desired system operation of the two use-cases, i.e., zero power exchange with the external grid and desired power injection to the external grid, respectively.

For considering the integrated flexible loads in the demo systems, the corresponding power variables are introduced in the formulation of the OPF problem. These power variables are included in the objective function, with the relevant cost factors, as well as in the constraints of the power balance. Additional constraints for the limits of these power variables are introduced in the problem. The lower limit of the power variables of the flexible loads is determined as percentage of the upper limit, with this percentage corresponding to the acceptable curtailment of the flexible loads [16]. It should be mentioned that the cost factors of the flexible loads in the objective function of the OPF problem do not need necessarily to have a monetary interpretation; these can be used also as priority or penalty factors, to force or avoid the curtailment of the flexible loads.

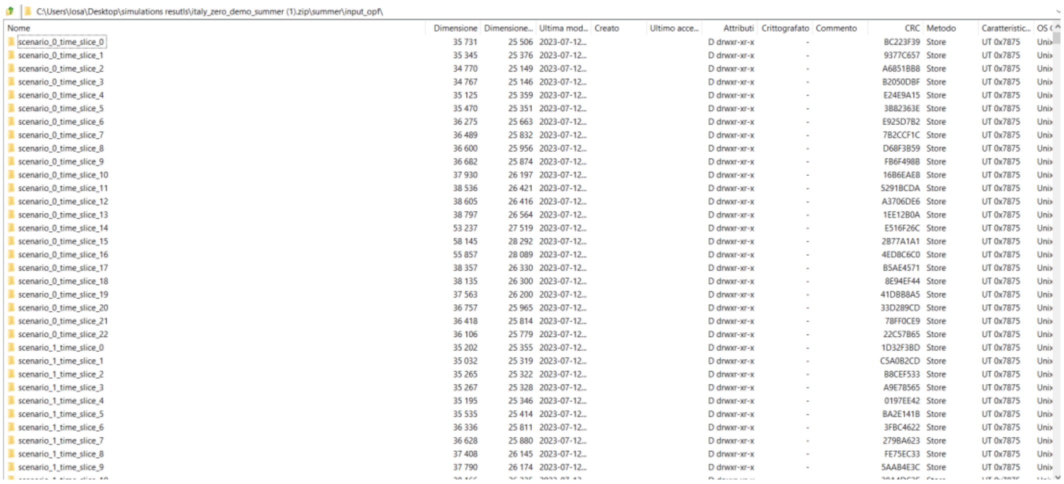
For simulating the use-case of the zero power exchange with the external grid of the demo systems, the parameters corresponding to the power generation unit that represents the external grid are set to particular values, to force this power variable to zero. Specifically, the lower limit of this power generation variable is set to zero and the corresponding cost factor in the objective function is set to a large value in comparison to the other cost factors. In this way, this power generation unit is considered as "expensive" in the OPF problem, and the algorithm assigns to this power variable its lowest possible value, which is zero.

For the use-case of the desired power injection to the external grid, the formulation of the OPF problem is modified to model negative power generated by the unit that represents the external grid, which is forced to a specific value. In particular, the constraint of the power balance at the node of the external grid is modified, to include negative power generation, i.e. variable of power absorption. Positive values of this power variable mean power absorption by this generation unit that represents the external grid. In other words, they mean injection from the system to the external grid. The lower limit of this power variable is set equal to the value of the desired amount of power injection from the demo system to the external grid. The cost factor corresponding to this power generation unit is set to a large value in comparison to the other cost factors in the objective function. Therefore, this power variable is forced to take its lowest possible value, which is equal to the desired amount of power injection from the system to the external grid.

2.2.5 Elaboration of OPF results

The outcomes of the OPF are used to estimate the amount of flexibility that is needed to resolve the expected congestions using local resources while maintaining the grid within the acceptable operational limits. To quantify this value, the following steps are followed:

1. The OPF calculates the new set points of active and reactive power of loads and distributed generators. To calculate the amount of flexibility needed, the results of the OPF are then subtracted by the same set points values that were indicate in the "warm start" files. These values describe the operational points of generators and loads connected to the grid during a congested timeslice. This calculation is performed for each congested timeslice in each scenario. An example of the outcomes that can be achieved after this step is illustrated in Figure 7. Each folder contains the input values of the JSON file, the outcomes of the OPF calculation and an excel files that calculate the differences of the parameters mentioned above in the congested scenarios and after the OPF calculations

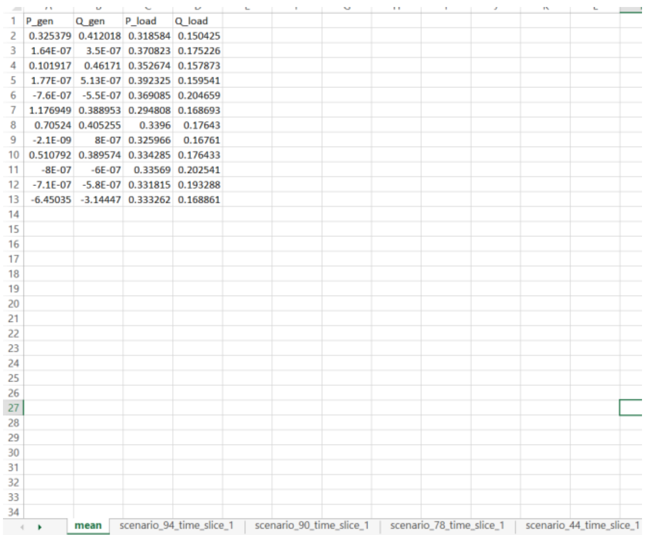


C:\Users\losa\Desktop\simulations resutls\italy_zero_demo_summer (1).zip\summer\input_opf\

Nome	Dimensione	Dimensione...	Ultima mod...	Creato	Ultimo acce...	Attributi	Crittografato	Commento	CRC	Metodo	Caratteristic...	OS (
scenario_0_time_slice_0	35 731	25 506	2023-07-12...			D drwxr-xr-x	-		BC223F39	Store	UT 0x7875	Unix
scenario_0_time_slice_1	35 345	25 376	2023-07-12...			D drwxr-xr-x	-		9377C657	Store	UT 0x7875	Unix
scenario_0_time_slice_2	34 770	25 149	2023-07-12...			D drwxr-xr-x	-		A6851BB8	Store	UT 0x7875	Unix
scenario_0_time_slice_3	34 767	25 146	2023-07-12...			D drwxr-xr-x	-		B2050DBF	Store	UT 0x7875	Unix
scenario_0_time_slice_4	35 125	25 359	2023-07-12...			D drwxr-xr-x	-		E24E9A15	Store	UT 0x7875	Unix
scenario_0_time_slice_5	35 470	25 351	2023-07-12...			D drwxr-xr-x	-		3B82363E	Store	UT 0x7875	Unix
scenario_0_time_slice_6	36 275	25 663	2023-07-12...			D drwxr-xr-x	-		E925D7B2	Store	UT 0x7875	Unix
scenario_0_time_slice_7	36 489	25 832	2023-07-12...			D drwxr-xr-x	-		7B2CCF1C	Store	UT 0x7875	Unix
scenario_0_time_slice_8	36 600	25 956	2023-07-12...			D drwxr-xr-x	-		D68F3B59	Store	UT 0x7875	Unix
scenario_0_time_slice_9	36 682	25 874	2023-07-12...			D drwxr-xr-x	-		FB6F498B	Store	UT 0x7875	Unix
scenario_0_time_slice_10	37 930	26 197	2023-07-12...			D drwxr-xr-x	-		16B6EAEB	Store	UT 0x7875	Unix
scenario_0_time_slice_11	38 536	26 421	2023-07-12...			D drwxr-xr-x	-		5291BCDA	Store	UT 0x7875	Unix
scenario_0_time_slice_12	38 605	26 416	2023-07-12...			D drwxr-xr-x	-		A3706DE6	Store	UT 0x7875	Unix
scenario_0_time_slice_13	38 797	26 564	2023-07-12...			D drwxr-xr-x	-		1EE12B0A	Store	UT 0x7875	Unix
scenario_0_time_slice_14	53 237	27 519	2023-07-12...			D drwxr-xr-x	-		E516F26C	Store	UT 0x7875	Unix
scenario_0_time_slice_15	58 145	28 292	2023-07-12...			D drwxr-xr-x	-		2B77A1A1	Store	UT 0x7875	Unix
scenario_0_time_slice_16	55 857	28 089	2023-07-12...			D drwxr-xr-x	-		4ED8C6C0	Store	UT 0x7875	Unix
scenario_0_time_slice_17	38 357	26 330	2023-07-12...			D drwxr-xr-x	-		B5AE4571	Store	UT 0x7875	Unix
scenario_0_time_slice_18	38 135	26 300	2023-07-12...			D drwxr-xr-x	-		8E94EF44	Store	UT 0x7875	Unix
scenario_0_time_slice_19	37 563	26 200	2023-07-12...			D drwxr-xr-x	-		41DBB8A5	Store	UT 0x7875	Unix
scenario_0_time_slice_20	36 757	25 965	2023-07-12...			D drwxr-xr-x	-		33D289CD	Store	UT 0x7875	Unix
scenario_0_time_slice_21	36 418	25 814	2023-07-12...			D drwxr-xr-x	-		78FF0CE9	Store	UT 0x7875	Unix
scenario_0_time_slice_22	36 106	25 779	2023-07-12...			D drwxr-xr-x	-		22C57B65	Store	UT 0x7875	Unix
scenario_1_time_slice_0	35 202	25 355	2023-07-12...			D drwxr-xr-x	-		1D32F3BD	Store	UT 0x7875	Unix
scenario_1_time_slice_1	35 032	25 319	2023-07-12...			D drwxr-xr-x	-		C5A0B2CD	Store	UT 0x7875	Unix
scenario_1_time_slice_2	35 265	25 322	2023-07-12...			D drwxr-xr-x	-		B8CEF533	Store	UT 0x7875	Unix
scenario_1_time_slice_3	35 267	25 328	2023-07-12...			D drwxr-xr-x	-		A9E78565	Store	UT 0x7875	Unix
scenario_1_time_slice_4	35 195	25 346	2023-07-12...			D drwxr-xr-x	-		0197EE42	Store	UT 0x7875	Unix
scenario_1_time_slice_5	35 535	25 414	2023-07-12...			D drwxr-xr-x	-		BA2E141B	Store	UT 0x7875	Unix
scenario_1_time_slice_6	36 336	25 811	2023-07-12...			D drwxr-xr-x	-		3FBC4622	Store	UT 0x7875	Unix
scenario_1_time_slice_7	36 628	25 880	2023-07-12...			D drwxr-xr-x	-		279BA623	Store	UT 0x7875	Unix
scenario_1_time_slice_8	37 408	26 145	2023-07-12...			D drwxr-xr-x	-		FE75EC33	Store	UT 0x7875	Unix
scenario_1_time_slice_9	37 790	26 174	2023-07-12...			D drwxr-xr-x	-		5AAB4E3C	Store	UT 0x7875	Unix

Figure 7: Example of the outcomes achieved in step 1

2. An excel file is created by collecting all the flexibility values quantified in each congested scenario at the same timeslice. Finally, the average value of flexibility needs for a given timeslice is quantified (see Figure 8)



	P_gen	Q_gen	P_load	Q_load
2	0.325379	0.412018	0.318584	0.150425
3	1.64E-07	3.5E-07	0.370823	0.175226
4	0.101917	0.46171	0.352674	0.157873
5	1.77E-07	5.13E-07	0.392325	0.159541
6	-7.6E-07	-5.5E-07	0.369085	0.204659
7	1.176949	0.388953	0.294808	0.168693
8	0.70524	0.405255	0.3396	0.17643
9	-2.1E-09	8E-07	0.325966	0.16761
10	0.510792	0.389574	0.334285	0.176433
11	-8E-07	-6E-07	0.33569	0.202541
12	-7.1E-07	-5.8E-07	0.331815	0.193288
13	-6.45035	-3.14447	0.333262	0.168861

Figure 8: Example of the outcomes achieved in step 2

3. Finally, an excel file is created. This file collects all the average flexibility needs calculated in step 2 for each node in each timeslice.
4. The final results are plotted. These results represent, in each node, for each timeslice the average flexibility needs but also the minimum and the maximum value calculated in the 100 scenarios that were analyzed.

3 Scalability and Replicability Analysis of the demo use cases

3.1 Italian demo

3.1.1 Scalability in density: Summer scenario

The characteristics of the scalability in density - Summer scenarios are:

- The load profiles that are used as input for the “as is” profiles are related to the Summer and Winter peak measured in an Areti primary substation in 2018. These values have been divided by number of total customers served by a single primary substation (based on input provided by Areti) and then multiplied by the number of customers served in the demo area (that includes only LV networks). The details calculations that were implemented to elaborate the LV profiles are reported in D7.4 [7]. The generation curves have been calculated by multiplying the values of PV generation (measured at the same day in which the Summer peak occurred) available in literature (calculated in p.u. by the average size and by the total number of PV panels installed in the demo area [17].
  The generation curves are referred to the Rome latitude. The gross load curves (winter/summer) are calculated by adding to the generation curves to the net load curves calculated at the secondary substations. These values have been labelled as sensitive information by the demo and therefore are reported in D7.4.
- The grid model used for the simulation of the demo area is the LV Urban grid model developed by Joint Research Center (JRC) [11]. This network model was considered as an accurate model of the LV grid that hosts the Italian demo. This model is composed of 12 nodes (0.4 kV) and a slack node. Each node of this model can host both a generator and a load that are considered as independent components of the network model. The parameters that describe the characteristic of this network and the results of the calculation are expressed in per unit. For this particular network model, the p.u. value is equal to 0.01 MVA.
- The input that describes the evolution of the grid in this scenario are summarized in Table 7. These data have been decided and validated during several iterations with the Italian demo to simulate a possible macro evolution of the distribution grid characteristics, however these values do not represent an official grid planning study of the distribution grid operated by Areti.

Table 7: Data describing the grid evolution of the Italian demo.

Variable	Value	Description
n_nodes	13	Number of nodes below the substation
perc_increase_load	55.08	%Expected increase of load with respect to the baseline scenario
uncertain_load	10.00	Error associated to the expected increase of load %forecast
perc_increase_gen	41.96	%Expected increase of generation with respect to the baseline scenario
uncertain_gen	10.00	%Error associated to the expected increase of gen. forecast
perc_nodes_gen	30.0	% of nodes equipped with generator in the target scenario
gen_types		Types of generators connected to the grid in target scenario [default: PV; PV and storage]
PV and storage	10.00	%
	90.00	%
load_types		Types of loads connected to the grid in target scenario [default: residential; EV; fixed; storage]
EV	30.00%	
residential	50.00%	

storage	10.00%	
fix	10.00%	
min_contracted_power	3	Minimum contracted power in the considered network in target scenario
med_contracted_power	6	Medium contracted power in the considered network in target scenario
max_contracted_power	10	Max contracted power in the considered network in target scenario
perc_min	0.6	% of loads equipped with meters that had the minimum contracted power in target scenario
perc_med	0.35	% of loads equipped with meters that had the medium contracted power in target scenario
perc_max	0.05	% of loads equipped with meters that had the max contracted power in target scenario
Load flexibility curtailment	50	%

The "scalability in density" simulations aim at replicating the use case "*UC-IT-2: Congestion Management*" when deployed in a representative feeder of the Areti network in 2030. For this purpose, the "desired power exchange" OPF is selected in the Software architecture and applied to 100 scenarios created with the "scenario generator" tool. In the desired power exchange scenario, it is assumed that, for each timeslice, the power injection from the MV into the LV is curtailed by 10% with respect to the baseline scenario. The calculations that were performed in the SRA analysis aim at assessing if the congestions caused by the reduction of the power imported from the MV network can be solved by leveraging only on local sources of flexibility.

The data obtained were then used to perform the calculations described in paragraph 2.2.5. The results of these simulations are reported in Figure 9 and Figure 10.

The SRA analysis of the Italian demo performed in WP7 complemented in WP2 with the assessment of the "technological Scalability" that assess how the performances of the Platone platforms and Platone Open Framework change when the number of customers served by the Platone architecture increases (Target scenario: 30% of total customers served by Areti participate to the flexibility market). The results of these analyses (reported in D2.16 [8]) proved that it is possible to ensure a high reusability and flexibility of the Platone Open Framework in a more realistic and extended context.

3.1.2 Replicability intranational

The characteristics of the replicability intranational scenario are:

- The load profiles that are used as input for the "as is" profiles are related to the Summer and Winter peak measured in an Areti primary substation in 2018. These values have been divided by the numbers of customers served in the entire primary substation and then multiplied by the number of customers served in the demo area to obtain the "gross" daily profile at the interface between MV and LV grids. The steps followed to compute the generation profiles and the net load profiles (measured at the MV/LV interface) are the same one as described in the previous step. These values have been labelled as sensitive information by the demo and therefore are reported in D7.4.
- The grid model used for the simulation of the demo area is the LV Semiurban grid model developed by Joint Research Center (JRC) [11]. This network model represents the average characteristics of a semi urban distribution network in Europe. Areti does not operate semi urban network, but these simulations could provide some results to the DSOs that are interested in implementing the SRA UCs in semi urban networks. This model is composed by 114 nodes (0.4 kV) and a slack node. The parameters that describe the characteristic of this network and the results of the calculation are expressed in per unit. For this particular network model the p.u. value is equal to 0.01 MVA
- The input that describes the evolution of the grid in this scenario are summarized in Table 8. These data have been decided and validated during several iterations with the Italian demo to simulate a possible macro evolution of the distribution grid characteristics, however these values do not represent an official grid planning study of the distribution grid operated by Areti.

Table 8: Data describing the grid evolution of the Italian replicability network

Variable	Value	Description
n_nodes	115	Number of nodes below the substation
Cosφ	0.9	Power factor
perc_increase_load	67.2	%Expected increase of load with respect to baseline scenario
uncertain_load	10.0	%Error associated to the expected increase of load forecast
perc_increase_gen	41.9	%Expected increase of generation with respect to baseline scenario
uncertain_gen	10.0	%Error associated to the expected increase of gen. forecast
perc_nodes_gen	50.0	% of nodes equipped with generator in the target scenario
gen_types		Types of generators connected to the grid in target scenario [default: PV; PV and storage]
PV	10.0	%
PV and storage	90.0	%
load_types	labels	Types of loads connected to the grid in target scenario
EV	15.0	%
residential	65.0	%
storage	10.0	%
fix	10.0	%
min_contracted_power	3	Minimum contracted power in the considered network
med_contracted_power	6	Medium contracted power in the considered network
max_contracted_power	10	Max contracted power in the considered network
perc_min	0.5	% of loads equipped with meters that had the min. contracted power
perc_med	0.4	% of loads equipped with meters that had the med contracted power
perc_max	0.1	% of loads equipped with meters that had the max contracted power
Load flexibility curtailment	50	%

The "replicability intranational" simulations aim at replicating the use case "UC-IT-2: Congestion Management" when deployed in a semi urban network in 2030. For this purpose, the "desired power exchange" OPF is selected in the Software architecture and applied to 100 scenarios created with the "scenario generator" tool. In the desired power exchange scenario, it is assumed that, for each timeslice, the power injection from the main grid (MV) to the LV grid investigated in these simulations is curtailed by 10% with respect to the baseline scenario. The results of this simulation are reported in Figure 11 and Figure 12.

3.1.3 Replicability international: Summer and winter scenario

The replicability international simulations aim at investigating the behaviour of the networks described in the previous subchapter when the zero power exchange use case in selected in the OPF algorithm. Currently this SRA – UC cannot be implemented in the Areti distribution networks since its application is not allowed by the Italian regulatory system. For this reason, these simulations are classified as "international replicability". The goal of this set of simulations is to investigate the performances of the networks in the most challenging operational conditions for the grid represented by the daily profile measured during the Summer and Winter peak days.

In the simulations it was assumed that the entire import from the MV grid is set equal to 0 in each of the considered timeslice. The calculations were performed to estimate how different types of grids (urban/semiurban) were able to operate in virtual islanding mode. The input data to calculate the different load and generation profiles are the ones reported in D7.4.

The use case was also applied to the semiurban network, that is characterized by a higher number of nodes and a higher dispersion of distributed generations and loads. The input data to calculate the different load and generation profiles are the ones reported in Table 8, while the network model used in these simulations is the JRC LV semiurban network. However, in this scenario, the OPF tool could not reach the convergence even in scenarios in which high level of loads flexibility were simulated (loads could be curtailed up to 90% w.r.t their baseline consumption). In fact, the voltage convergence criteria could not be satisfied and the distributed resources were not able to provide enough reactive power to compensate the voltage losses caused by the increased amount of power flows in the network.

This use case was applied to the urban network with Summer and Winter profiles and the results are reported from Figure 13 to Figure 16.

3.1.4 Public results

In the network models considered for the SRA of the Italian demo, 1 p.u. is equal to 0.01 MVA.

In these calculations it was assumed that each generator could offer up to 1kW and 1KVA of flexibility, while each load absorbed be cut up to 50% with respect to its baseline profile.

In all the results reported in this paragraph, it can be noticed that the slack nodes (node 13 for urban networks and node 115 for the semiurban networks) is characterized by a negative value of P_{gen} Q_{gen} that is significantly higher with respect to the other values measured in the grid. In fact, this value represents the amount of energy that, in the baseline scenarios, was imported from the MV grid. These curtailments have been compensated by the flexibility provided by the local generators and flexible loads.

The results reported in the present paragraph illustrate the amount of flexibility needed to solve the local congestions. This parameter is calculated as the difference of the observed parameter in the baseline scenario (warmstart) and the same value calculated by the OPF tool. This computation was performed for all the 100 scenarios generated by the “scenario generator” tool. The graphs report, for each timeslice characterized by a congestion the mean, the minimum and the maximum values of the observed parameter: P_{gen} and Q_{gen} represent the active and reactive power of the generators connected to the grid while P_{load} and Q_{load} represent the active and reactive power of the loads connected to the grid.

Figure 9 and Figure 10 summarize the results of the simulations related to the “scalability in density” SRA-UC. In these simulations the “desired power exchange” SRA-UC is used to calculate the amount of flexibility needed to solve the congestion (in terms of active and reactive power of each generator and each load connected to the grid). To simulate a congestion, the power injected from the MV grid into the slack node was curtailed by 10% with respect to the baseline scenario. The amount of flexibility needed is calculated as the difference of the observed parameter in the baseline scenario (warmstart) and the same value calculated by the OPF tool. This computation was performed for all the 100 scenarios generated by the “scenario generator” tool. The graphs reports, for each timeslice characterized by a congestion the mean, the minimum and the maximum values of the observed parameter: P_{gen} Q_{gen} (reported in Figure 9) represent the active and reactive power of the generators connected to the grid while P_{load} Q_{load} (reported in Figure 10) represent the active and reactive power of the loads connected to the grid.

Figure 11 and Figure 12 summarize the results of the simulations related to the “replicability intra national” SRA-UC. In these simulations the same approach described for the “scalability in density” was used but it was applied to the network model selected for the replicability analysis: the JRC semiurban LV network (115 nodes). Figure 13 to Figure 16 summarize the results of these simulations of the “SRA international” simulations. For these analyses, the “zero power exchange” SRA-UC was used in order to evaluate the possibility to implement the “virtual islanding” operation also in the Italian context. In fact, the current Italian regulatory framework does not allow the DSO to set the power exchange between MV and LV network equal to 0 and this use case is not included in the tests performed in the Italian demo. This set of simulations represent a pure theoretical exercise aimed at estimating how much flexibility will be needed to implement the "zero power exchange" in the representative networks related to the Italian demo if a different regulatory scheme that allow the "zero power exchange" would be implemented. When the “zero power exchange” SRA-UC was applied to the replicability network models, the OPF simulations failed to find a solution.

SCALABILITY IN DENSITY - DEMO NETWORK - DESIRED POWER EXCHANGE

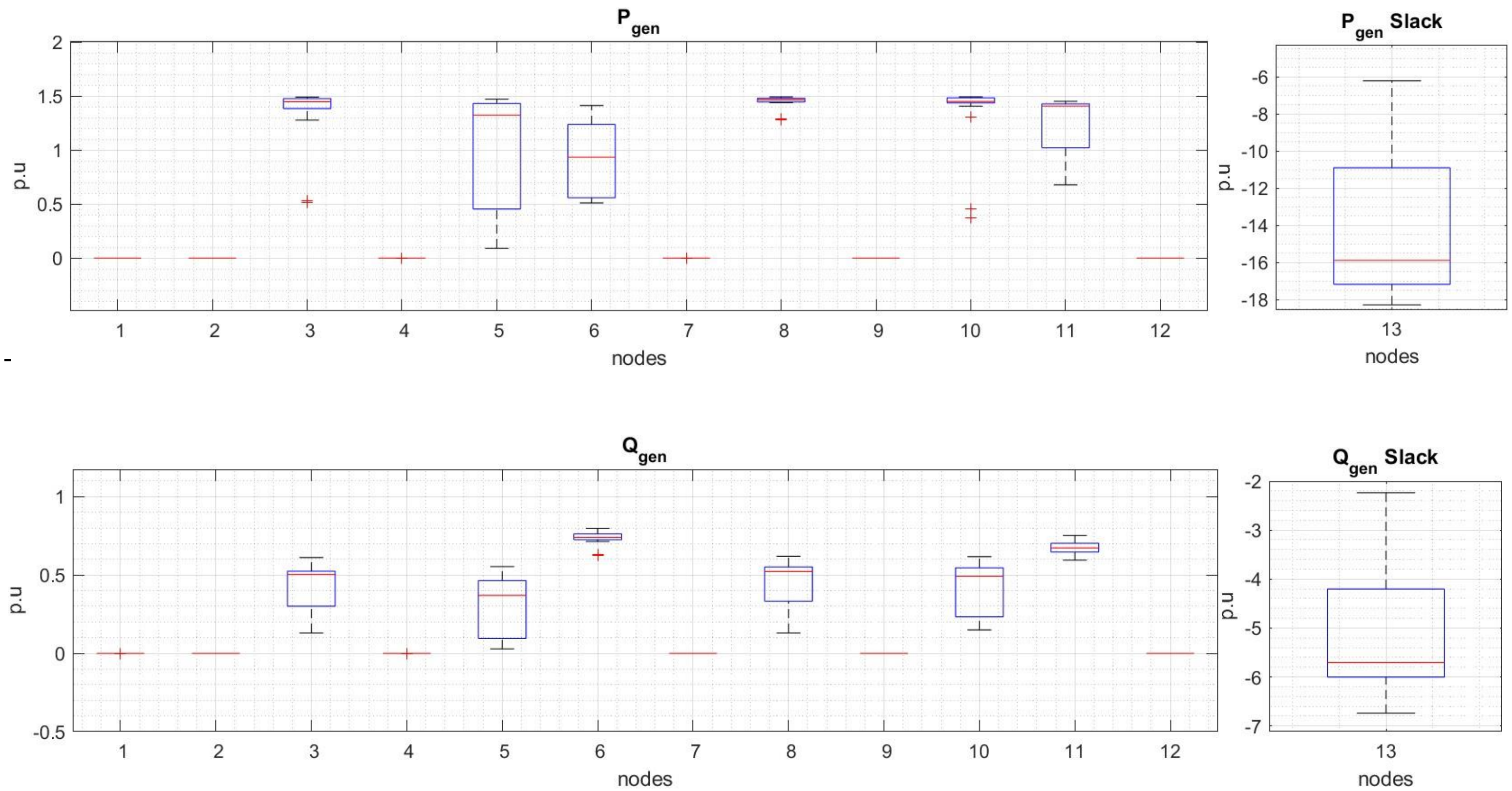


Figure 9: Flexibility (in terms of Active and Reactive power) of the generators in the scenario scalability in density, demo network, desired power exchange

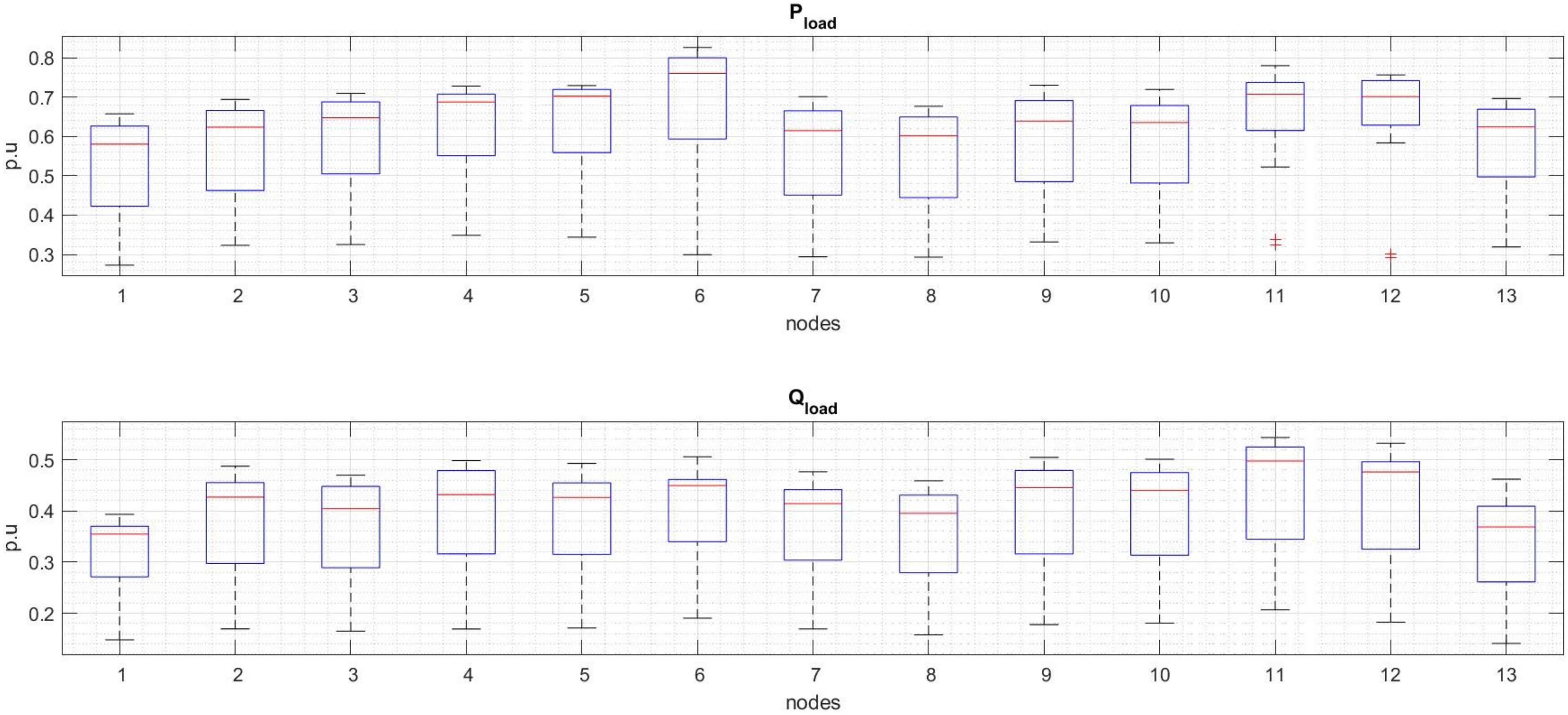
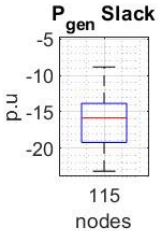
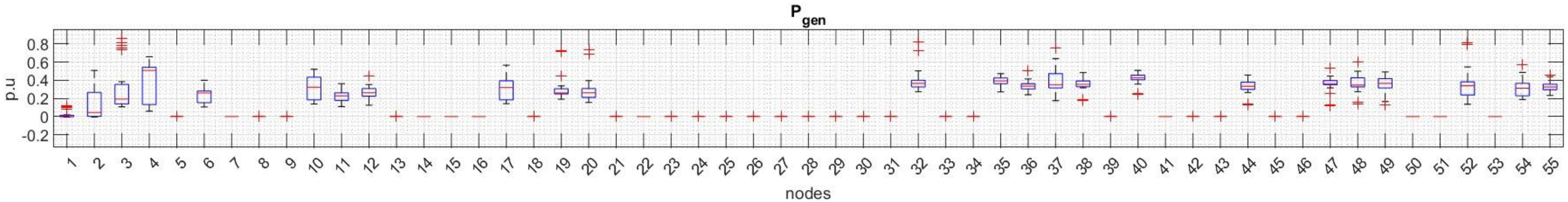
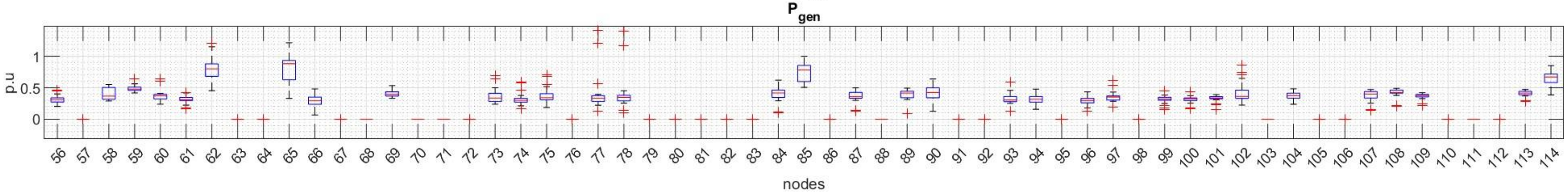


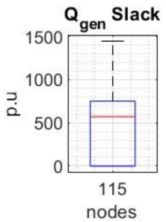
Figure 10: Flexibility (in terms of Active and Reactive power) of the loads in the scenario scalability in density, demo network, desired power exchange

REPLICABILITY INTRANATIONAL - DESIRED POWER EXCHANGE – SEMIURBAN NETWORK - SUMMER









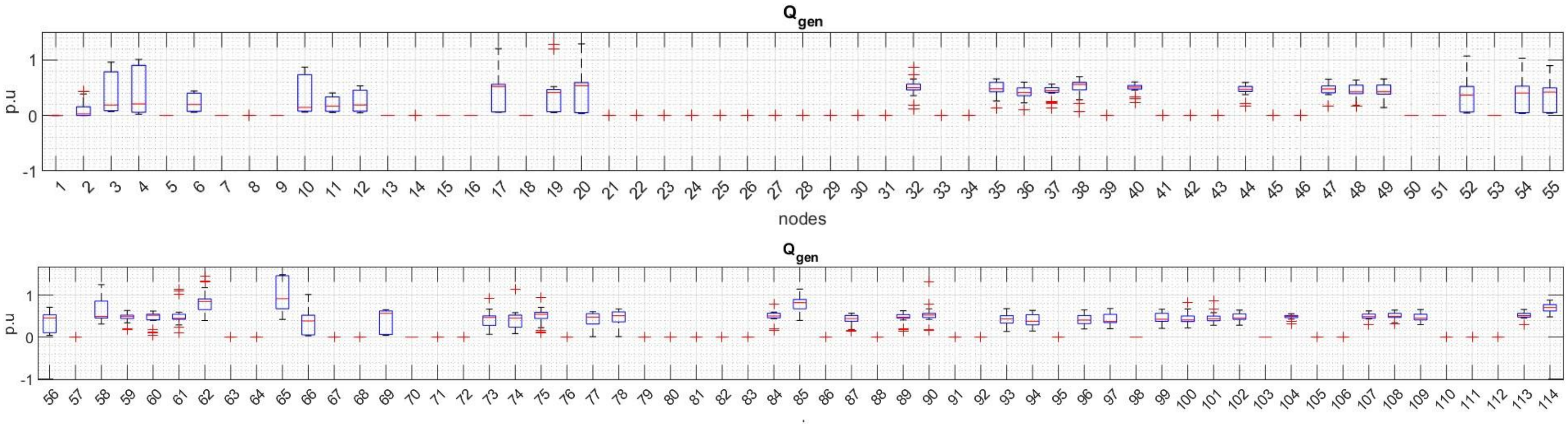
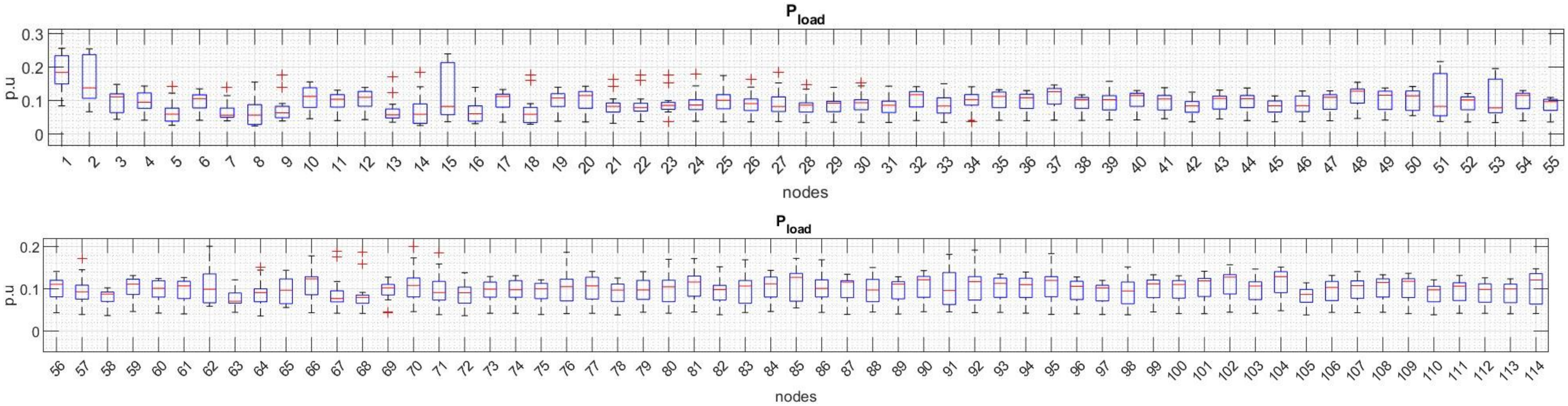


Figure 11: Flexibility (in terms of Active and Reactive power) of the generators in the scenario replicability intranational, semiurban network, desired power exchange



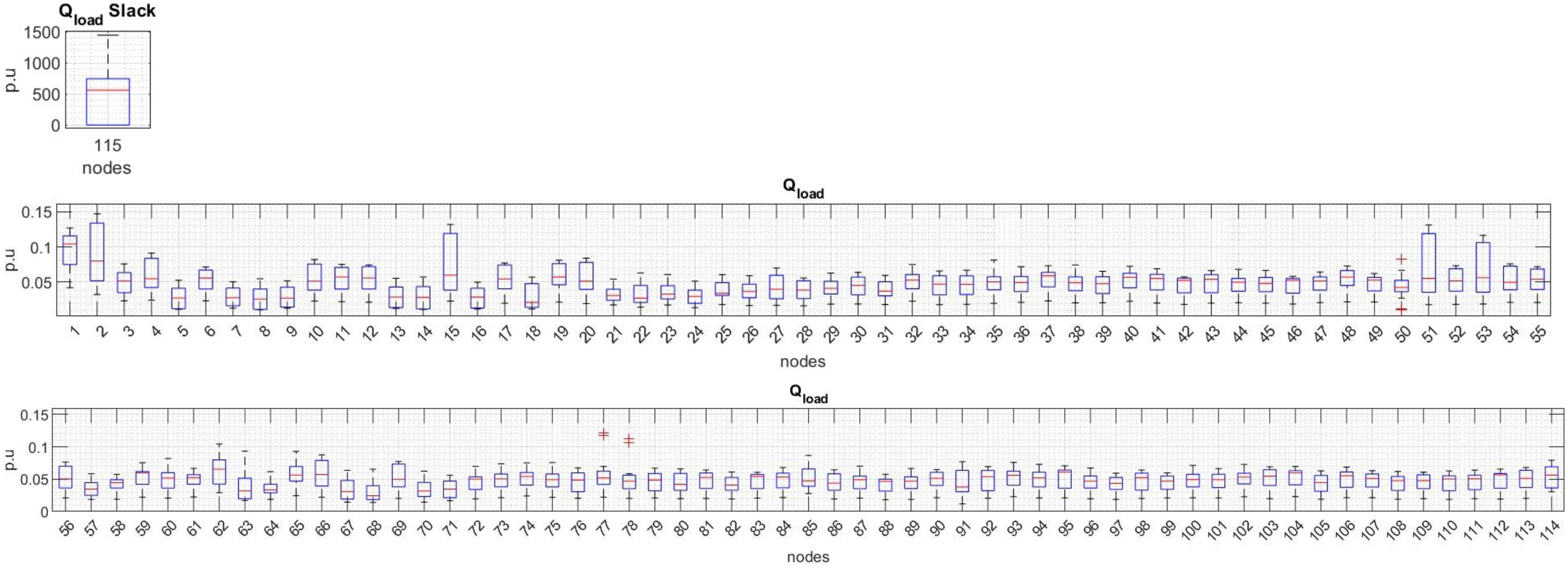


Figure 12: Flexibility (in terms of Active and Reactive power) of the loads in the scenario replicability intranational, semiurban network, desired power exchange

REPLICABILITY INTERNATIONAL - ZERO POWER EXCHANGE – DEMO NETWORK - SUMMER

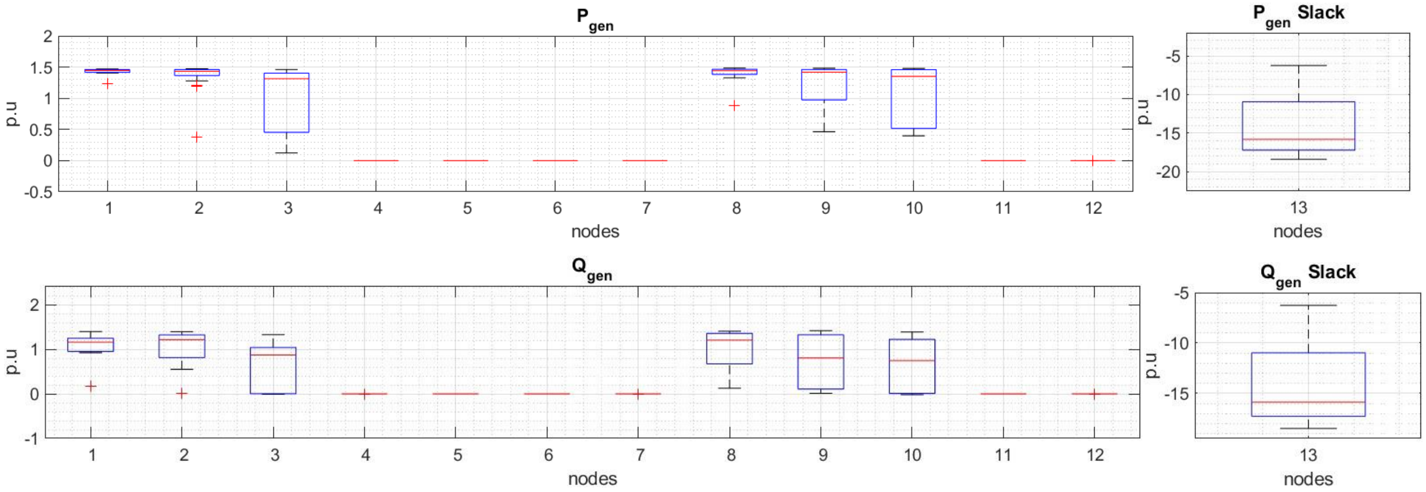


Figure 13: Flexibility (in terms of Active and Reactive power) of the generators in the scenario replicability international, demo network, summer profile, zero power exchange

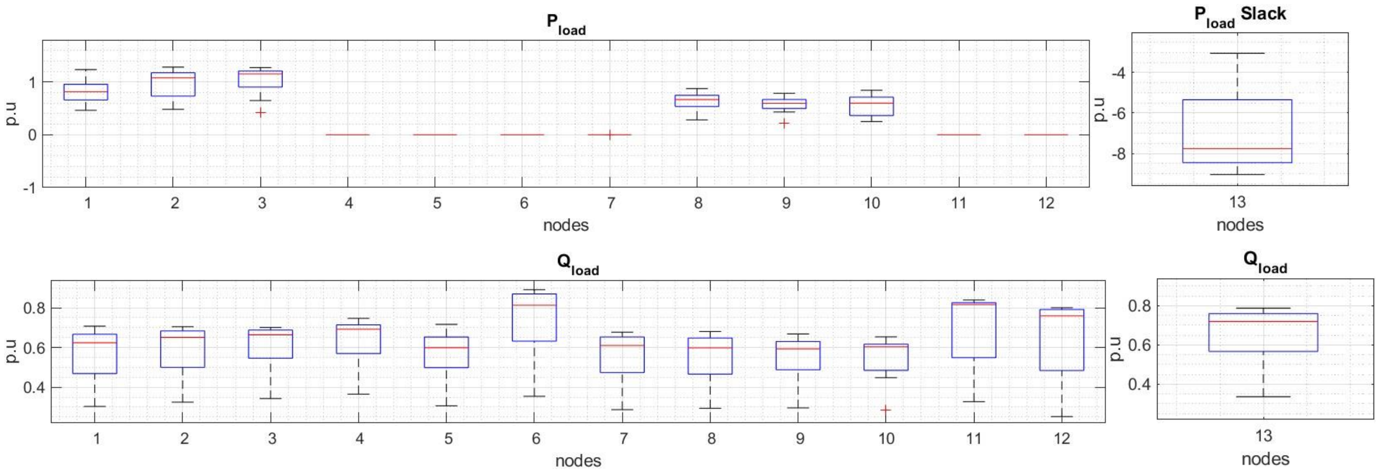


Figure 14: Flexibility (in terms of Active and Reactive power) of the loads in the scenario replicability international, demo network, summer profile, zero power exchange

REPLICABILITY INTERNATIONAL - ZERO POWER EXCHANGE – DEMO NETWORK - WINTER

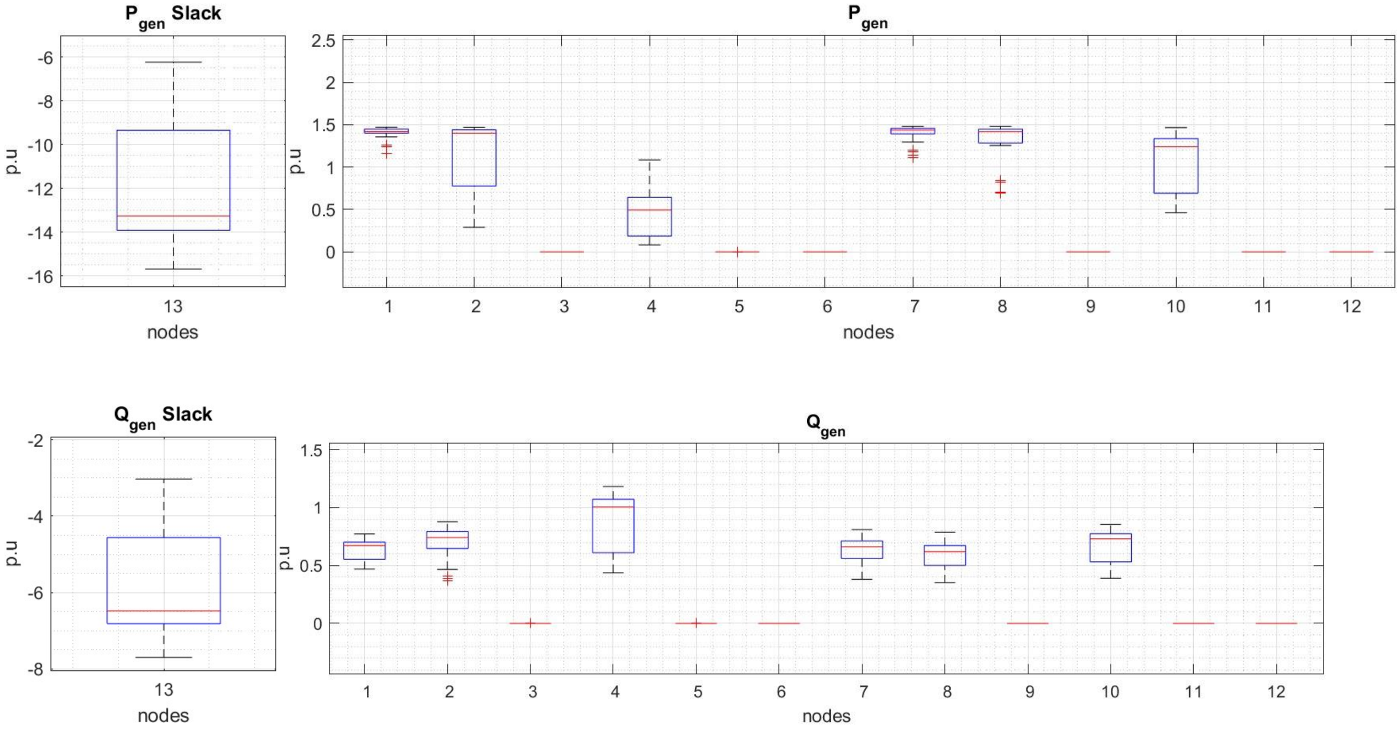


Figure 15: Flexibility (Active and Reactive power) of the loads in the scenario scalability replicability international - demo network, summer profile, zero power exchange

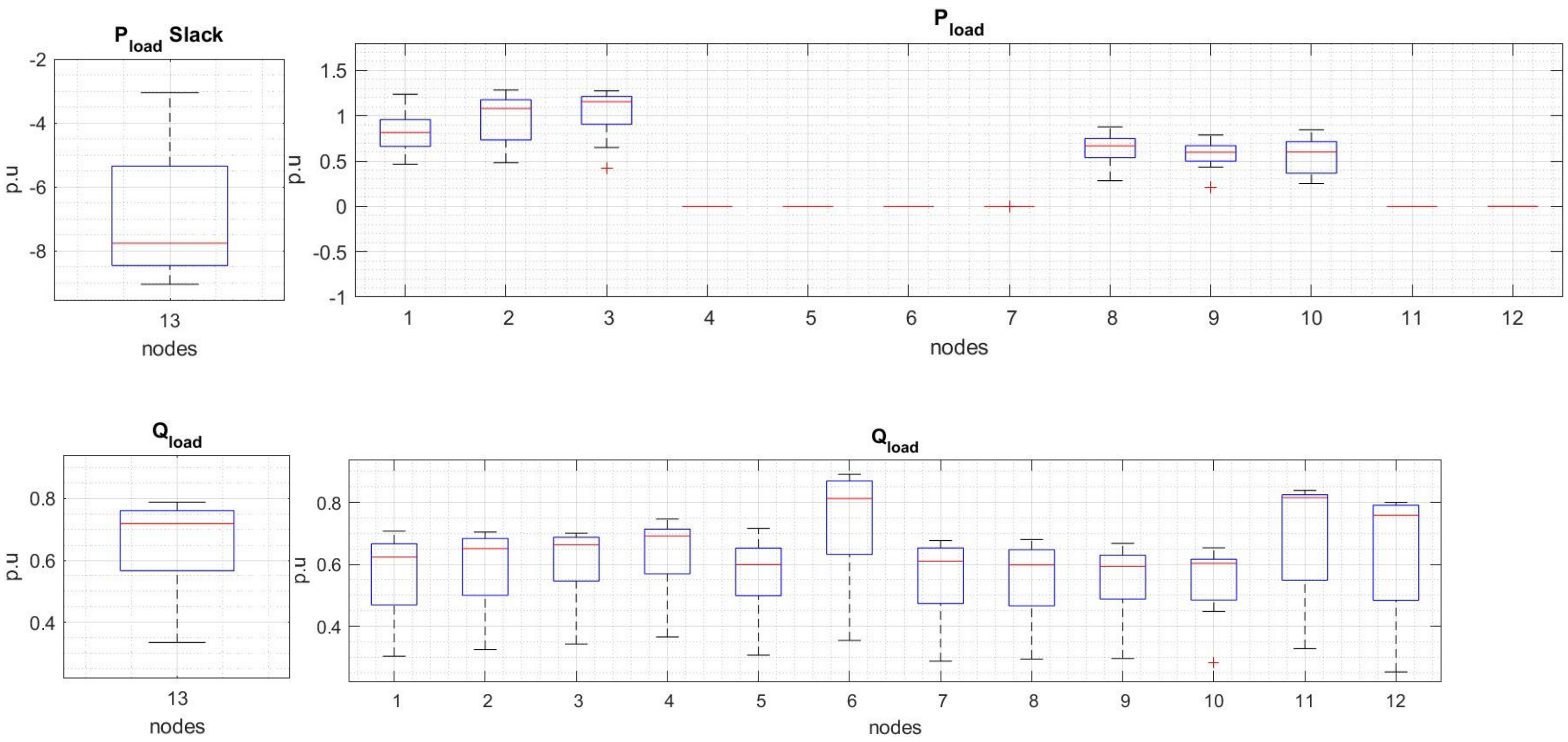


Figure 16: Flexibility (Active and Reactive power) of the loads in the scenario scalability replicability international, demo network, winter profile, zero power exchange

3.1.5 Lessons learnt

The graphs included in the previous subchapter report, for each node of the network the mean, the minimum and the maximum values of the observed parameters in all the time slices that represent the daily load and generation curves in a peak day.

The SRA analysis aim at simulating the KPI PR03 Flexibility Availability when deployed in different conditions.

- The KPI measures the potential flexibility provided by flexible PODs connected to the grid:

$$Flexibility\_Availability\_Up = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i=1}^{N}|Available\_Flexibility\_Up_{i,t}|}{\sum_{i=1}^{N}|Baseline_{i,t}|}\cdot 100$$

$$Flexibility\_Availability\_Down = -\frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i=1}^{N}|Available\_Flexibility\_Down_{i,t}|}{\sum_{i=1}^{N}|Baseline_{i,t}|}\cdot 100$$

The SRA analysis is targeting a future scenario of grid development that consider different evolutions of load and generations curves but does not simulate the impact of different tariffs schemes. This KPI will be therefore calculated by comparing the amount of energy from RES that must be curtailed to avoid the congestions that have been identified in the load flow calculations. This result can be then used to estimate the amount of flexibility that shall be procured in the future to rely on the provision of flexibility services to resolve the expected congestions without no further changes on the current grid topology.

This KPI is therefore calculated by comparing the amount of flexible generation that must be curtailed in order to avoid the congestions that have been identified in the load flow calculations, using the following formula:

$$FLEX\_GEN = \frac{max(median\_of\_gen_{flex}@target_{year})}{gen_{peak}@target_{year}} * 100$$

Where:

- $max(median\_of\_gen_{flex}@target_{year})$ represents the maximum value of $median\_of\_gen_{flex}@target_{year}$, which are the median values of P_{gen}, and Q_{gen} of the flexibility services provided by the distributed generators calculated for the summer peak of the target year (reported in D7.4 [7])
- $gen_{peak}@target_{year}$ represents the maximum value of the generation curve in the target year

The SRA KPI $FLEX\_LOAD$ load curtailment is calculated using the following formula:

$$FLEX\_LOAD = \frac{max(median\_of\_load_{flex}@target_{year})}{load_{peak}@target_{year}} * 100$$

Where:

- $max(median\_of\_load_{flex}@target_{year})$ represents the maximum value of $median\_of\_load_{flex}@target_{year}$, which are the median values of P_{load}, and Q_{load} of the flexibility services provided by the flexible loads calculated for the summer peak of the target year (reported in D7.4 [7])
- $load_{peak}@target_{year}$ represents the maximum value of the load curve in the target year.

The flexibility values considered in the formulas reported above and in the results reported in this sub chapter are the median flexibility values of the observed parameter calculated for a specific node in all the 2200 observed congested time slice. Therefore, this KPI is calculated by dividing the maximum values among the median values of active and reactive flexibility of generators calculated in the scalability in density analysis by the peak value of generator and load curves.

As illustrated in Figure 9 and Figure 10, to resolve the local congestions caused by the application of the desired power exchange, each generator connected to the grid shall increase their production up to 0.015 MW and up to 0.008 MVAR. These values correspond to a value of SRA KPI $FLEX\_GEN$ equal to 52.46% (when referred to active power) equal to 22.20% if calculated w.r.t the reactive power. Each load shall provide a maximum value of flexibility equal to 0.00860 MW and 0.00569 MVAR. These values correspond to a value of SRA KPI $FLEX\_LOAD$ equal to 5.40% (when referred to active power) and equal to 2.83% when referred to reactive power.

It is important to notice that, based on the results published in D2.16 related to the technical SRA of the Platone platform in the Italian demo, the Platone platform can guarantee the correct execution of the whole process in an expected penetration of flexibility sources equal to 30% of the total customers served by the Italian demonstrator geographical area. It could be therefore interesting, in the framework of the prosecution of Platone, to evaluate the performance of the Platone platform considering the results of the SRA simulations, with a penetration of flexibility sources equal to 50-60% of the total customers, value that represents the amount of flexibility needed in the "SRA in density" simulations.

This latter value is calculated by multiplying the peak value of the generator curve in the target year (reported in D7.4) by the expected growth of generation in the demo scenario, reported in Table 7.

Figure 11 and Figure 12 report the results of the “replicability intra national” SRA use case. In these simulations, the amount of curtailed injection of active power is the same as the “scalability in density” simulations, 0.16 MW and 0.16 MVAR. To solve these congestions, the generators shall provide a maximum flexibility equal to 0.0149 MW and 0.0149 MVAR, while the loads shall provide a maximum flexibility of 0.00262 MW and 0.00137 MVAR

The results illustrated in Figure 9, Figure 10, Figure 11, Figure 12 prove that the application of the use case “desired power exchange” (with a curtailment factor equal to 10% of the gross demand) can be successfully implemented during summer peaks days in the urban distribution grids even in future scenarios characterized by a significant penetration of distributed generations. In fact, the results reported in the previous section and the relevant simulations proved that, in the 2200 scenarios that have been observed in each simulation, the local congestions could be resolved leveraging on the contributions of local sources of flexibility. These results report the minimum, maximum and median values of the active and reactive power that must be provided by local sources of flexibility to safely resolve the congestions. These use cases can be safely integrated in both rural and urban networks: in both cases the flexibility services that can be provided by local sources of flexibility is sufficient to compensate the curtailed withdrawal from the MV grid. However, when a rural network is analysed, it is important to notice that the request of reactive power in the slack node is significantly high, therefore the distributed resource shall provide high values of flexibility to compensate the lack of reactive power and many resources are providing an amount of flexibility that is closer to technical boundaries (0.015 MVAR). These values are comparable with the request of flexibility of active power and are higher than the flexibility request of reactive power that was observed in the urban networks. To help the network to resolve these congestions, the common sources of local flexibility shall be supported by specific solutions aimed at compensating specifically the local request of reactive power.

Similarly the results reported in Figure 13, Figure 14, Figure 15, Figure 16 prove that the “zero power exchange” SRA use case can also be safely implemented in the future urban distribution grids characterized by high penetration of flexible sources, both in Winter and Summer peak days.

In particular, Figure 13 and Figure 14 report the results of the application of the SRA-UC “zero power exchange” to the demo network with summer profiles. In these simulations, the maximum amount of flexibility needed to resolve the expected congestions is equal to

- 0.0149 MW and 0.0127 MVAR for the distributed generators
- 0.0077MW and 0.0045 MVAR for the flexible loads.

Figure 15 and Figure 16 show the results of the “zero power exchange” to the demo network with winter profile. In these simulations, the maximum amount of flexibility needed to resolve the expected congestions is equal to:

- 0.0149 MW and 0.0119 MVAR for the distributed generators
- 0.0066 MW and 0.0033 MVAR for the flexible loads.

When the “zero power exchange” SRA-UC is applied to the urban networks, the available sources of flexibility are adequate to solve the expected congestions both in Winter and Summer scenarios, however many distributed generators are operating close to their technical boundaries, since they are providing the maximum values of active and reactive flexibility.

However, when the two use cases are deployed in rural networks (characterized by longer length of distribution lines and by a significant number of loads and distributed generators) the system needs to exploit a huge amount of reactive power to solve the congestions that arise in the network and, in case of “zero power exchange”, the OPF cannot find a solution to resolve local congestions leveraging only on local sources of flexibility. This result is in line with the results related to replicability intranational. In this scenario the import from the MV grid was curtailed by 10% with respect to the baseline scenario (instead of 100%) however the local sources of flexibility had to provide a large amount of reactive power to resolve the local congestions and many resources were operating close to the technical limits included in the model. As a conclusion from these simulations, it might be suggested that, when applying the “zero power exchange” and “desired power exchange” use cases in semirural network characterized by a significant penetration of dispersed generation and loads and longer lines, there is a significant need to compensate the local voltage drops in order to be able to operate the network in a secure and stable way. In these situations, the provision of flexibility services by distributed grids could be also complemented with the installation of distributed devices that help the system compensate the increased need of reactive power (e.g., inverters, distribution static compensators (D-STATCOMs) [18] etc.) that are traditionally installed in HV networks.

3.2 Greek demo

The scenarios selected for the SRA analysis of the Greek demo are characterized by the following:

- Scalability in density: Summer scenario;
- Replicability intranational: Summer Scenario;
- Replicability international: Summer scenario.

It is assumed that each RES generator, to compensate the lack of centralized generation caused by the curtailment, can inject in the network up to 1 MW and 1 MVA of active and reactive power, while the loads can curtail their active and reactive demand by a fixed percentage of curtailment (reported in the input data list).

3.2.1 Scalability in density: Summer scenario

The characteristics of the scalability in density - summer scenarios are:

- The load profiles that are used as input for the “as is” profiles are related to the summer peak measured in an HEDNO primary substation in 2018. These values have been divided by the numbers of customers served in the entire primary substation and then multiplied by the number of customers served in the demo area. The generation curves have been calculated by multiplying the values of PV generation (measured at the same day in which the summer peak occurred) available in the literature [17] (calculated in p.u.) by the average size and by the total number of PV panels installed at the same latitude of Athens. The generation curves are referred to the Athens latitude. The gross load curves (summer) are calculated by adding to the generation curves to the net load curves calculated at the secondary substations. These values have been labelled as sensitive information by the demo and therefore are reported in D7.4 [7].
- The grid model used for the simulation of the demo area is a network model that represents a MV feeder included in the CIM network model developed in the framework of WP6 [19]. This model is composed by 63 nodes (20 kV) and a slack node. According to the analysis reported in D7.2 [2], this network was classified as “semi urban”. The parameters that describe the characteristic of this network and the results of the calculation are expressed in p. u. For this network model, the p.u. value is equal to 5 MVA.
- The input that describes the evolution of the grid in this scenario are summarized in Table 9. These data have been selected and validated during several iterations with the Greek demo, partly based on the NPEC [20], in order to simulate a possible macro evolution of the distribution grid characteristics. The values that concern grid expansion do not represent an official grid planning study of the distribution grid operated by HEDNO.

Table 9: Data describing the grid evolution of the Greek demo network

Variable	Value	Description
n_nodes	64	Number of nodes below the substation
Cosφ	0.9	Power factor
perc_increase_load	30	Expected increase of load with respect to baseline scenario
uncertain_load	10	%Error associated to the expected increase of load forecast
perc_increase_gen	100	%Expected increase of generation with respect to baseline scenario
uncertain_gen	10.0	%Error associated to the expected increase of gen. forecast
perc_nodes_gen	25.0	% of nodes equipped with generator in the target scenario
gen_percs	[%]	Percentage of each type of generator
PV	10.0	%
pvs	90.0	%
load_types		Types of loads connected to the grid in target scenario

EV	10.00	%
residential or industrial	50.00	%
storage	10.00	%
fix	30.00	%
min_contracted_power	50	Minimum contracted power in the considered network in target scenario
med_contracted_power	400	Medium contracted power in target scenario
max_contracted_power	500	Max contracted power in target scenario
perc_min	50	% of loads equipped with meters that had the min contracted power
perc_med	30	% of loads equipped with meters that had the med.contracted power
perc_max	20	% of loads equipped with meters that had the max contracted power

The “scalability in density” simulations aim at replicating the KPIs “KPI_GR_07 - Generation curtailment” and “KPI_GR_08 - Demand curtailment” when deployed in a representative feeder of the HEDNO network in 2030. For this purpose, the “desired power exchange” SRA use case is selected in the Software architecture and applied to 100 scenarios created with the “scenario generator” tool. In the desired power exchange SRA use case, it is assumed that, for each timeslice, the power injection from the HV into the MV is curtailed by 10% with respect to the baseline scenario.

3.2.2 Replicability intra national: Summer scenario

The characteristics of the replicability intranational summer scenarios are:

- The load profiles that are used as input for the “as is” profiles are related to the summer peak measured in an HEDNO primary substation in 2018. These values have been divided by the numbers of customers served in the entire primary substation and then multiplied by the number of customers served in the demo area to obtain the “gross” daily profile at the interface between HV and MV grids. The steps followed to compute the generation profiles and the net load profiles (measured at the HV/MV interface) are the same one as described in the previous step. These values have been labelled as sensitive information by the demo and therefore are reported in D7.4.
- The grid model used for the simulation of the demo area is the JRC MV RURAL grid model developed by Joint Research Centre (JRC) [21]. This network model represents the average characteristics of an urban MV distribution network in Europe. This model is composed by 116 nodes (20 kV) and a slack node. The parameters that describe the characteristic of this network and the results of the calculation are expressed in per unit. For this network model the p.u. value is equal to 1MVA.

The input that describes the evolution of the grid in this scenario are summarized in Table 10. These data have been decided and validated during several iterations with the Greek demo to simulate a possible macro evolution of the distribution grid characteristics, however these values do not represent an official grid planning study of the distribution grid operated by HEDNO.

Table 10: Data describing the grid evolution of the Greek replicability network

Variable	**Value**	**Description**
n_nodes	117	Number of nodes below the substation
Cosφ	0.90	Power factor
perc_increase_load	30	Expected increase of load with respect to baseline scenario
uncertain_load	10.0	Error associated to the expected increase of load forecast
perc_increase_gen	120	Expected increase of generation with respect to baseline scenario

uncertain_gen	10.00	Error associated to the expected increase of gen. forecast
perc_nodes_gen	40.0	% of nodes equipped with generator in the target scenario
gen_percs	[%]	Percentage of each type of generator
PV	10.00	%
pvs	90.00	%
load_percs	[%]	Percentage of each type of load (sum must be equal to 100%]
EV	5.00	%
residential	50.0	%
storage	5.00	%
fix	40.0	%
min_contracted_power	50	Minimum contracted power in the considered network in target scenario
med_contracted_power	400	Medium contracted power in the considered network in target scenario
max_contracted_power	500	Max contracted power in the considered network in target scenario
perc_min	30	% of loads equipped with meters that had the min. contracted power
perc_med	35	% of loads equipped with meters that had the med contracted power
perc_max	35	% of loads equipped with meters that had the max contracted power

The "replicability intra national" simulations aim at replicating the KPIs "KPI_GR_07 - Generation curtailment" and "KPI_GR_08 - Demand curtailment" when deployed in a representative typical feeder of a rural MV grid in 2030. For this purpose, the "desired power exchange" OPF is selected in the Software architecture and applied to 100 scenarios created with the "scenario generator" tool.

In the desired power exchange scenario, it is assumed that, for each timeslice, the power injection from the HV into the MV is curtailed by 10% with respect to the baseline scenario.

3.2.3 Replicability international: Summer scenario

The replicability international simulations aim at investigating the behaviour of the networks described in the previous subchapter when the "zero power exchange" use case is selected in the OPF algorithm. The latter use case represents the most challenging operational condition for the grid because the local generators and batteries shall compensate the entire demand of the loads connected to the grid. To facilitate the OPF convergence in the scenario "Replicability international, zero power exchange, demo network", (whose results are reported in Figure 21) it is assumed that the local loads could be curtailed up to 90% of the load calculated in the baseline scenario.

In the simulations it was assumed that the entire import from the HV grid is set equal to 0 in each of the considered timeslice. The calculations were performed to estimate how different types of grids (rural/semiurban) were able to operate in virtual islanding mode.

In the simulations it was assumed that the entire import from the HV grid is set equal to 0 in each of the considered timeslice. The calculations were performed to estimate how different types of grids (rural/semiurban) were able to operate in virtual islanding mode. The input data to calculate the different load and generation profiles are the ones reported in Table 9 and Table 10.

3.2.4 Public results

In the network models considered for the Scalability and Replicability Analyses of the Greek demo, 1 p.u. is equal to 1 MVA.

In these calculations it was assumed that each generator could offer up to 1MW and 1MVA of flexibility, while each load absorbed be cut up to 50% (90% for the "scalability in density" case) with respect to its baseline profile.

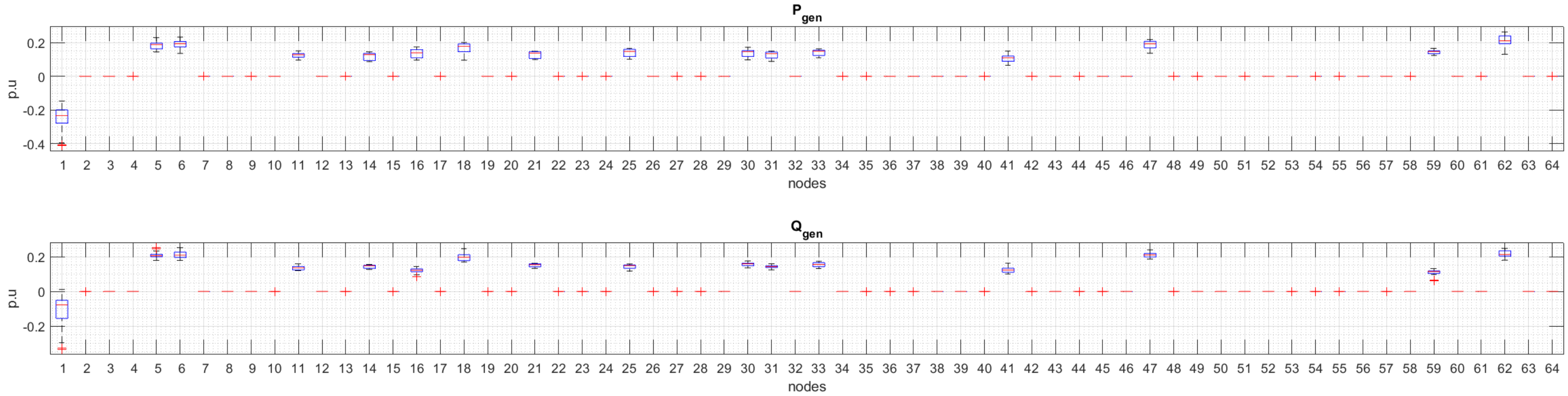
The results reported in the present paragraph illustrate the amount of flexibility needed is calculated as the difference of the observed parameter in the baseline scenario (the load and generation profiles in the target year that had caused the congestions) and the same value calculated by the OPF tool.

Figure 17 summarizes the results of the simulations related to the "scalability in density" use case. In these simulations the "desired power exchange" use case is used to calculate the amount of flexibility needed to solve the congestion (in terms of active and reactive power of each generator and each load connected to the grid). To simulate a congestion, the power injected from the HV grid was curtailed by 10% with respect to the baseline scenario.

Figure 18 and Figure 19 summarize the results of the simulations related to the "replicability intra national" simulations. In these simulations the same approach described for the "scalability in density" was used but it was applied to the network model selected for the replicability analysis: the JRC semiurban LV network (115 nodes)

Figure 20, Figure 21, Figure 22 and Figure 23 summarize the results of the "replicability international" simulations. For these analyses, the "zero power exchange" use case was used in order to evaluate the possibility to implement the "zero power exchange" operation also in the Greek context. The current regulatory framework does not allow the DSO to set the power exchange between HV and MV network equal to 0 and this use case is not included in the tests performed in the Italian demo, for these reasons this set of simulations, that simulate the performance of the networks when deployed in a different regulatory system, are classified as "international replicability". The use case is applied to the set of data used to simulate the "replicability intra national" and to simulate the "scalability in density" use case**.**

SCALABILITY IN DENSITY - DESIRED POWER EXCHANGE DEMO NETWORK (Scalability in density)



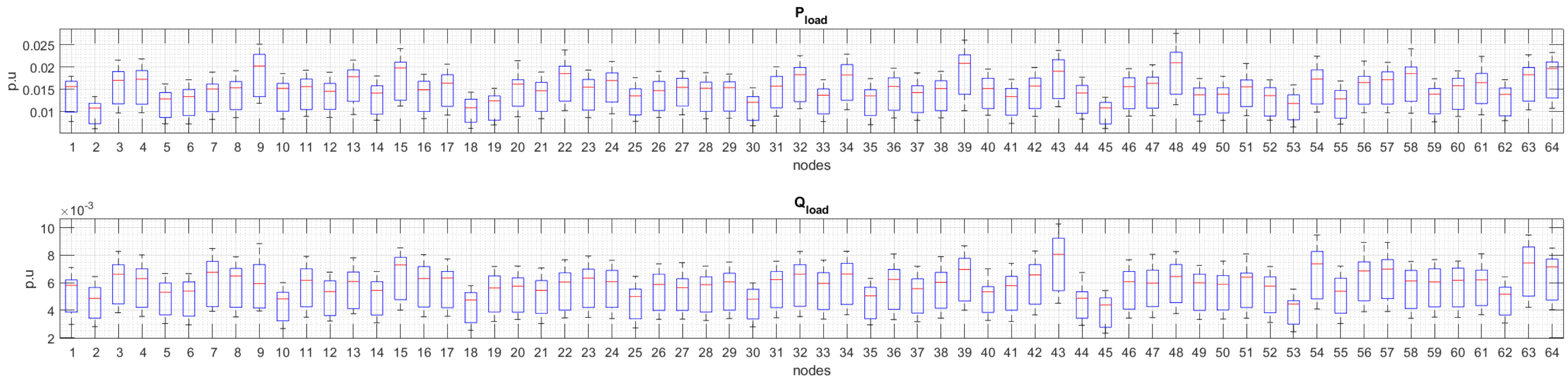
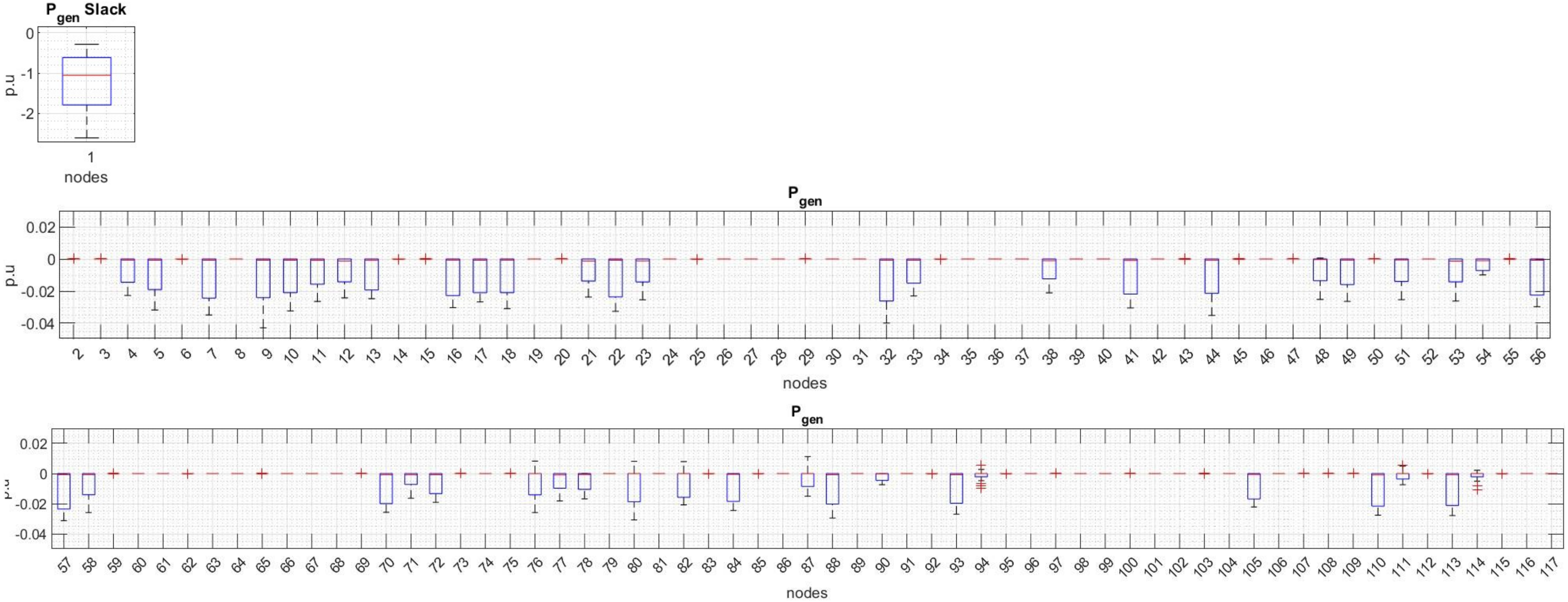


Figure 17: Flexibility (Active and Reactive power) of the generators and loads in the scenario scalability in density, demo network, desired power exchange

REPLICABILITY INTRA NATIONAL - DESIRED POWER EXCHANGE- RURAL NETWORK



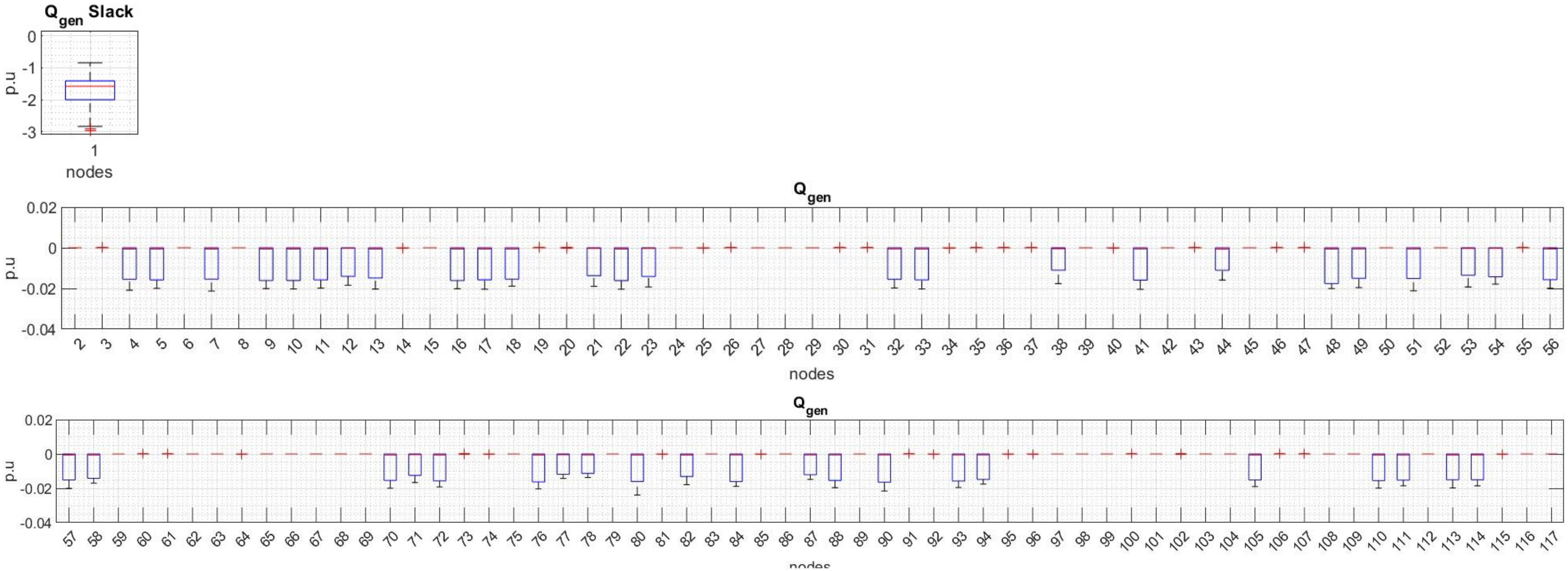


Figure 18: Flexibility (Active and Reactive power) of the generators in the scenario scalability replicability intra national, rural network, desired power exchange

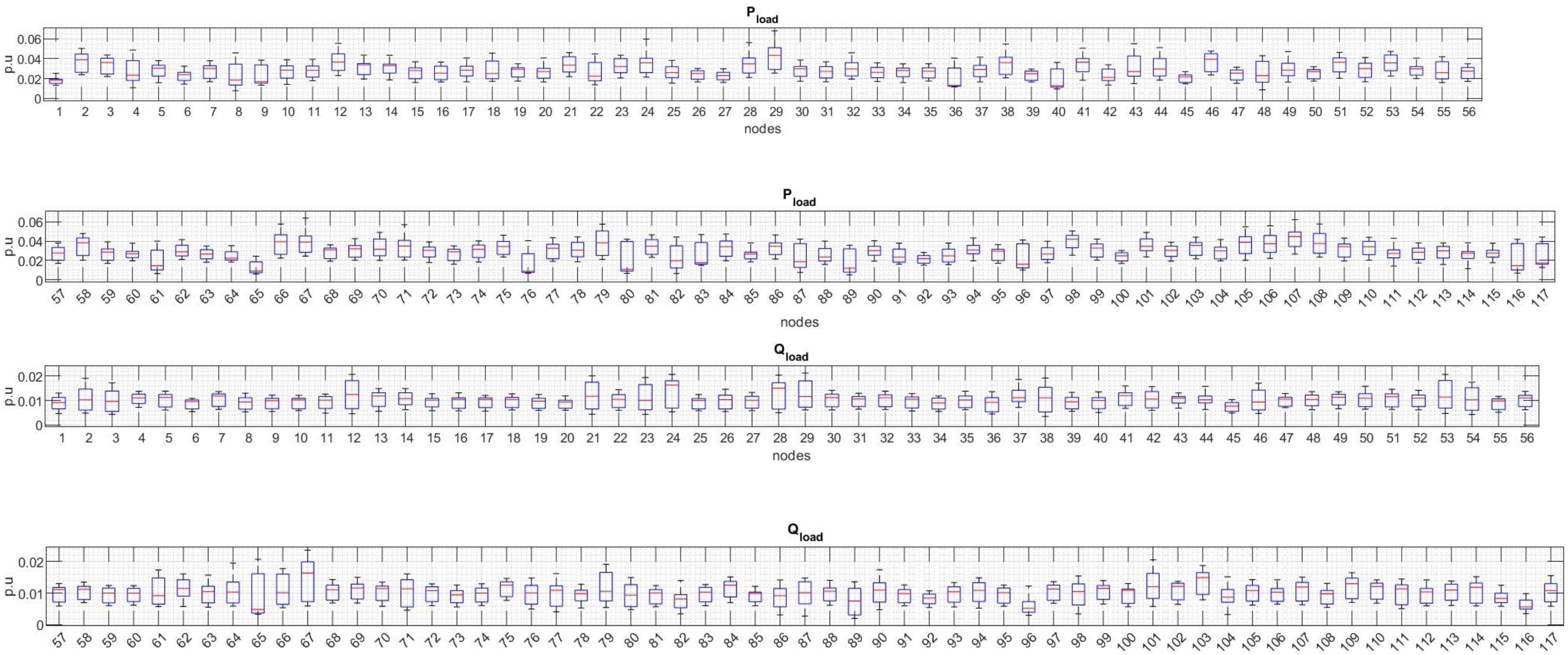
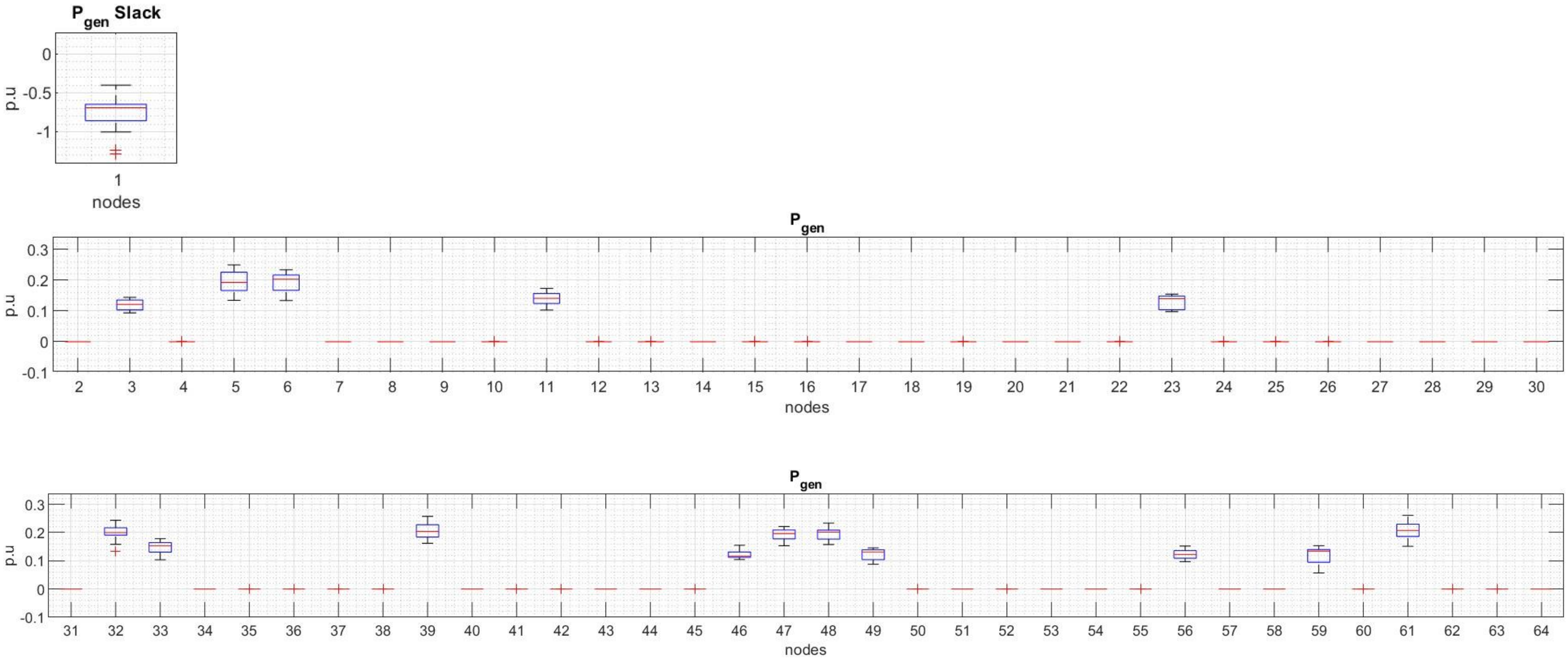


Figure 19: Flexibility (Active and Reactive power) of the loads in the scenario scalability replicability intra national, rural network, desired power exchange

REPLICABILITY INTERNATIONAL - ZERO POWER EXCHANGE - DEMO NETWORK



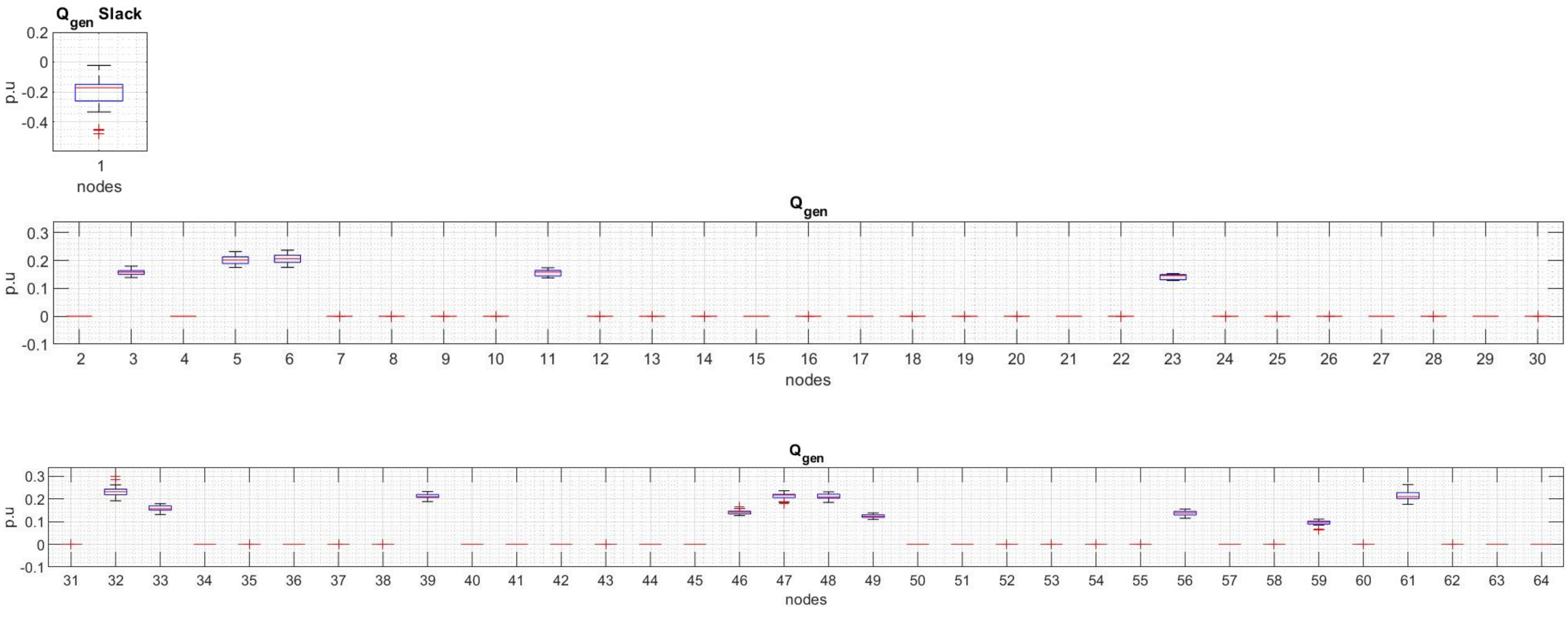


Figure 20: Flexibility (Active and Reactive power) of the generators in the scenario scalability replicability international, demo network, zero power exchange

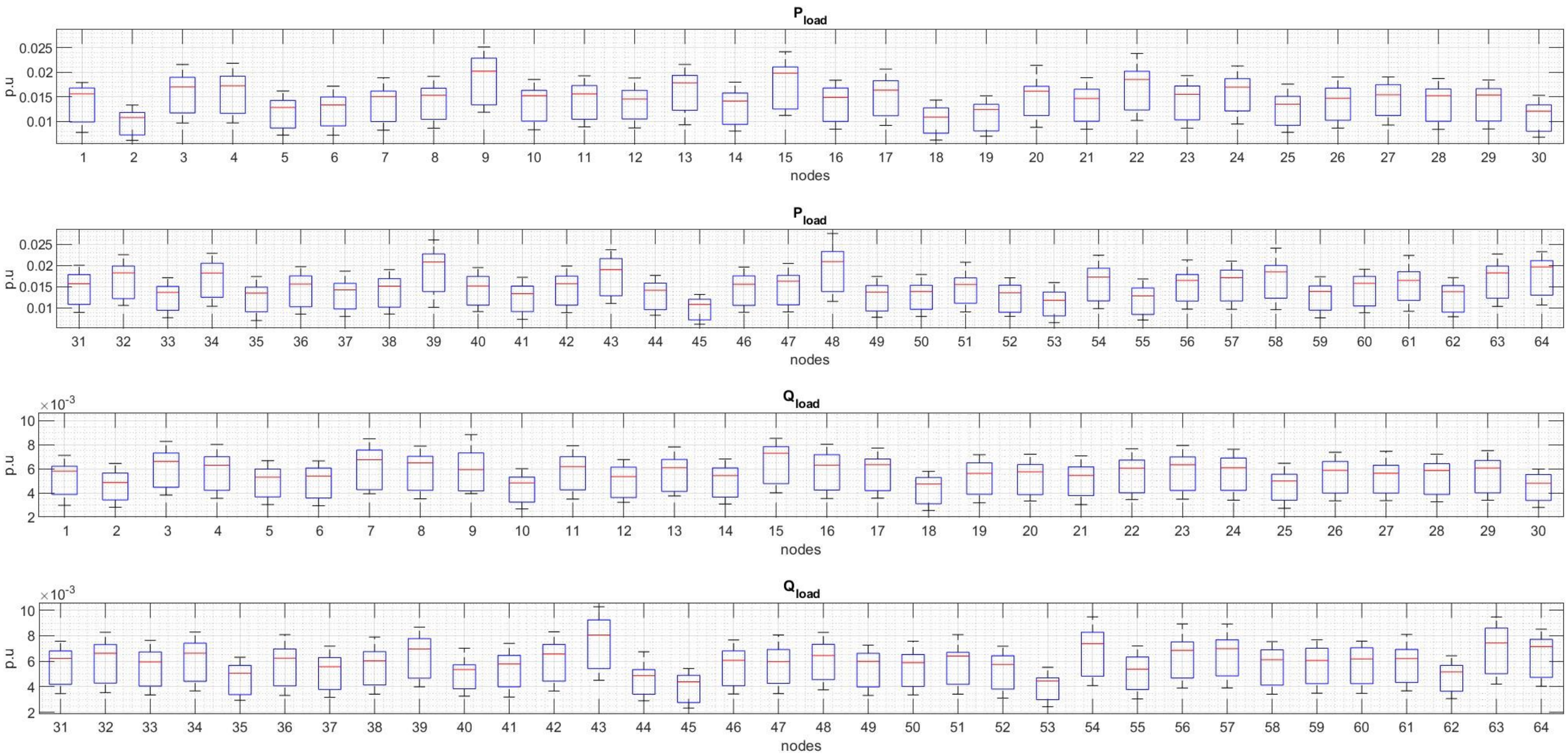


Figure 21: Flexibility (Active and Reactive power) of the loads in the scenario scalability replicability international, rural network, zero power exchange

REPLICABILITY INTERNATIONAL - ZERO POWER EXCHANGE– RURAL NETWORK

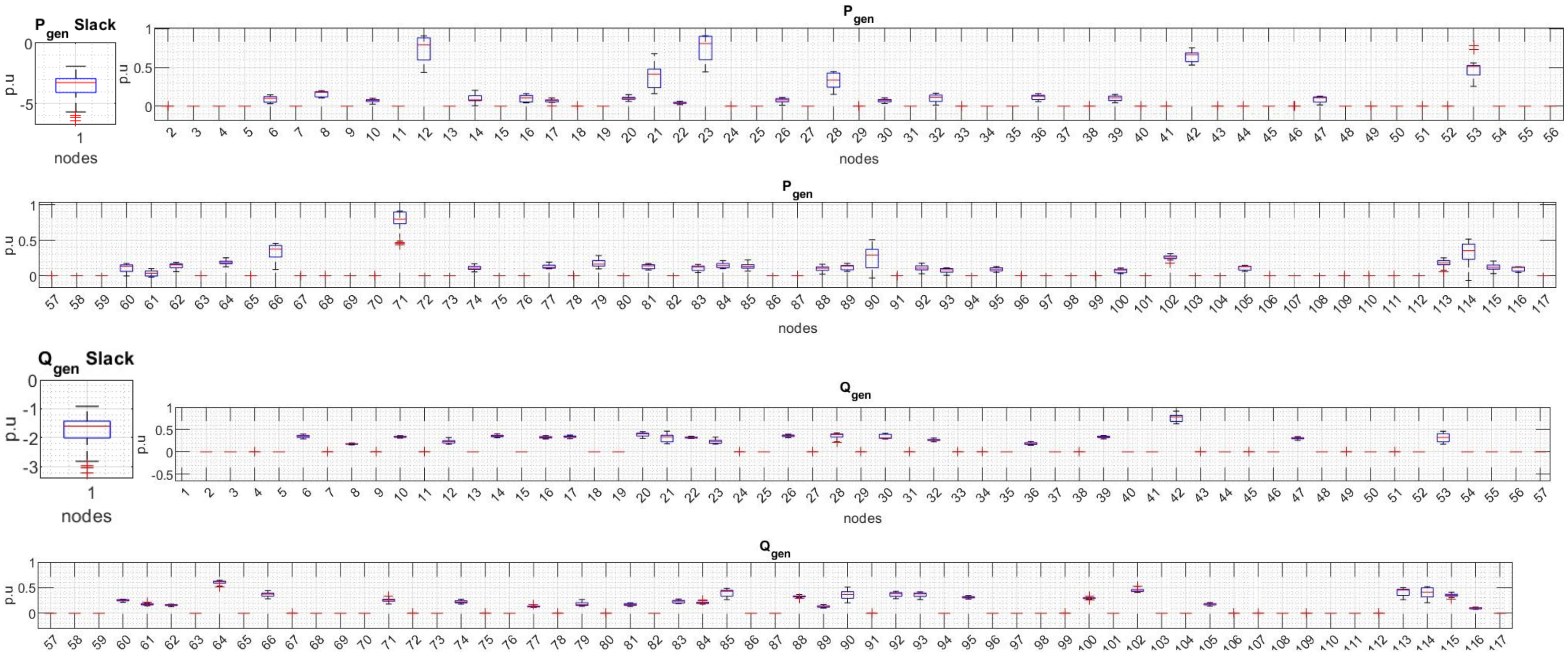


Figure 22: Flexibility (Active and Reactive power) of the generators in the scenario scalability replicability international, rural network, zero power exchange

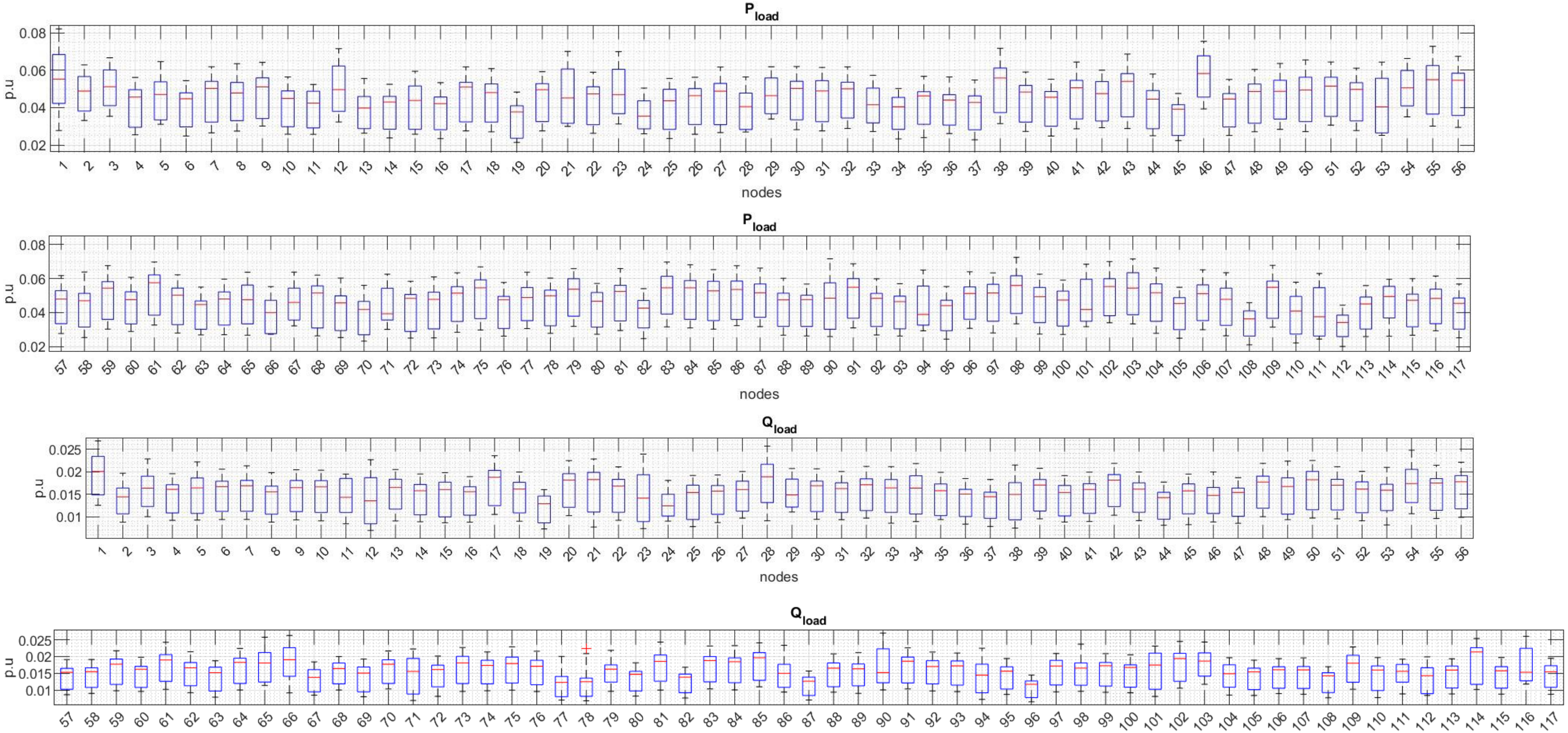


Figure 23: Flexibility (Active and Reactive power) of the loads in the scenario scalability replicability international, rural network, zero power exchange

3.2.5 Lessons learnt

The results illustrated in paragraph 3.2.4 prove that the application of the use case “desired power exchange” (with a curtailment factor equal to 10% of the gross demand) and “zero power exchange” can be successfully implemented during summer peaks days in the urban distribution grids even in future scenarios characterized by a significant penetration of distributed generations. These use case can be safely integrated in both rural and urban networks: in both cases the flexibility services that can be provided by local sources of flexibility is sufficient to compensate the curtailed withdrawal from the HV grid.

The desired power exchange SRA UC aims at replicating the following demo KPIs: KPI GR 07 - Generation curtailment and KPI GR 08 - Demand curtailment.

KPI GR 07 is defined as “KPI GR 07, ΔC_{RES}, compares the amount of energy from Renewable Energy Sources (RES) that is not injected to the grid (even though it is available) due to operational limits of the grid, between the Variable Network Tariff scenario and the Business as Usual (BaU) scenario. The formula used to calculate this KPI is as follows:

$$KPI\_GR\_07 = \frac{\sum_{t\in T}\sum_{i\in I} E_{g_{i,t}}^{BaU} - \sum_{t\in T}\sum_{i\in I} E_{g_{i,t}}^{R\&I}}{\sum_{t\in T}\sum_{i\in I} E_{g_{i,t}}^{BaU}} \times 100$$

where $E_{g_{i,t}}^{BaU}$ is the energy curtailment of the i-th RES facility at period t in the BaU – Flat Network Tariff scenario (kWh), $E_{g_{i,t}}^{R\&I}$ is the energy curtailment of the i-th RES facility at period t in the Variable Network Tariff scenario (kWh), I is the set of RES facilities under consideration, and T is the set of time intervals of the period under consideration (excluding periods of scheduled maintenance and outages), see D3.9 [9].

The SRA analysis is targeting a future scenario of grid development that consider different evolutions of load and generations curves but does not simulate the impact of different tariffs schemes. This KPI is therefore calculated by comparing compares the amount of energy from Renewable Energy Sources that must be curtailed to avoid the congestions that have been identified in the load flow calculations. This result can be then used to estimate the amount of flexibility that shall be procured in the future to rely on the provision of flexibility services to resolve the expected congestions without no further changes on the current grid topology. Therefore, this KPI, in the SRA analysis il calculated by dividing the median values of active and reactive flexibility of generators in the “scalability in density” scenario by the peak value of generator curves. This latter value is calculated by multiplying the peak value of the generator curve in the target year (reported in D7.4 [7]) by the expected growth of generation in the demo scenario, reported in Table 9.

KPI GR 08 – Demand curtailment, compares the amount of energy consumption that needs to be curtailed due to operational limits of the grid, between the Variable Network Tariff and the Business-as-Usual scenario. The formula used to calculate the KPI is as follows:

$$KPI\_GR\_08 = \frac{\sum_{t\in T}\sum_{i\in I} E_{d_{i,t}}^{BaU} - \sum_{t\in T}\sum_{i\in I} E_{d_{i,t}}^{R\&I}}{\sum_{t\in T}\sum_{i\in I} E_{d_{i,t}}^{BaU}} \times 100$$

where $E_{d_{i,t}}^{BaU}$ is the demand curtailment of the i-th flexible customer facility at period t in the BaU – Flat Network Tariff scenario (kWh), $E_{d_{i,t}}^{R\&I}$ is the demand curtailment of the i-th flexible customer facility at period t in the Variable Network Tariff scenario (kWh), I is the set of flexible customers under consideration, and T is the set of time intervals of the period under consideration.

The SRA analysis is targeting a future scenario of grid development that consider different evolutions of load and generations curves but does not simulate the impact of different tariffs schemes. Therefore, in order to calculate the amount of curtailed generations and loads in a future scenario, the KPIs proposed by the Greek demo have been adapted as follows:

$$FLEX\_GEN = \frac{max(median\_of\_gen_{flex}@target_{year})}{gen_{peak}@target_{year}} * 100$$

While the SRA KPI $FLEX\_LOAD$ is calculated using the following formula

$$FLEX\_LOAD = \frac{max(median\_of\_load_{flex}@target_{year})}{load_{peak}@arget_{year}} * 100$$

The flexibility values considered in the formulas reported above and in the results reported in this sub chapter are the median flexibility values of the observed parameter calculated for a specific node in all the 2200 observed time slice.

As illustrated in Figure 17, in order to resolve the local congestions caused by the application of the desired power exchange, each generator connected to the grid shall increase their production up to 0.326 MW and up to 0.2379 MVAR. These values correspond to a value of KPI $FLEX\_GEN$ equal to 9.26% (when referred to active power) and equal to 7.35% if calculated w.r.t the reactive power. Each load shall provide a maximum value of flexibility equal to 0.0296 MW and 0. 0.0132 MVAR. These values correspond to a value of KPI $FLEX\_LOAD$ equal to 0.76% (when referred to active power) and equal to 0.27% when referred to reactive power.

This latter value is calculated by multiplying the peak value of the generator curve in the target year (reported in D7.4) by the expected growth of generation in the demo scenario, reported in Table 9.

The data need to calculate these parameters are sensitive and therefore they are reported in D7.4 [7].

Figure 18 and Figure 19 report the results of the application of the SRA use case “desired power exchange” to the replicability network (rural) with summer profiles. In these simulations, the maximum amount of flexibility needed to resolve the expected congestions is equal to

- 0.01364 MW and 0.002546 kVAR for the distributed generators
- 0.0577 MW and 0.0301 MVAR for the flexible loads.

These results prove that the desired power exchange SRA UC can be safely implemented in the Greek MV network (both demo network and replicability network). The amount of flexibility provided by the local sources of flexibility is compatible with the flexibility ranges that can be provided by the distributed resources.

Figure 20 and Figure 21 report the results of the application of the SRA-UC “zero power exchange” to the demo network with summer profiles. In these simulations, the maximum amount of flexibility needed to resolve the expected congestions is equal to

- 0.321 MW and 0.0346 MVAR for the distributed generators
- 0.0298 MW and 0.0125 MVAR for the distributed loads

Finally, Figure 22 and Figure 23 report the results of the application of the SRA use case “zero power exchange” to the replicability network (rural network) with summer profiles.

In these simulations, the maximum amount of flexibility needed to resolve the expected congestions is equal to:

- 0.911 MW and 0.937 MVAR for the distributed generators
- 0.087 MW and 0.0345 MVAR for the distributed loads

The results related to the “zero power exchange” SRA UC prove that this SRA UC can be safely deployed in the future Greek network since the amount of local flexibility is adequate to compensate the congestions that are caused by its application. However, when a rural network is considered, the amount of active and reactive flexibility that the distributed generators must provide to balance the network increases significantly and it approaches to the maximum amount of flexibility that could be provided by local resources (that in the Greek scenarios is equal to 1MW and 1MVA). This result is like the results obtained for the replicability intranational analysis performed for the Italian demo. Therefore, it could be concluded that, when there is the need to curtail significant amount of power in rural network, to avoid grid congestions, the local sources of flexibility typically connected to the distribution grids might be complemented with the support of specific devices aiming at compensating specifically the lack of reactive power.

3.3 German demo

The scenarios selected for the SRA analysis of the German demo are characterized by the following:

- Scalability in density: Summer scenario;
- Replicability intranational: Summer Scenario;

The scalability in density of the German demo aims at modelling the implementation of the UC1 (virtual islanding) and UC2 (Flexibility provision) when deployed in a network model that represents the future evolution of the German demo network (a rural LV distribution network). The network model used for the scalability in density was provided by Avacon and represents the demo area. The network model is composed of 189 nodes but only 76 of these nodes are connected to a load or a generator. In the SRA analysis the expected increase of loads and generators will be spread over 76 nodes. In the German demo model, 1 p.u. is equal to 100 MVA.

The Replicability intranational aims studying the implementation of these two demo use cases when deployed in an urban network model. The load and generation curves used in these studies are the same curves used in the scalability in density analysis. The network model used in the German replicability analysis is the JRC LV urban network, characterized by 12 LV nodes and 1 slack node. In the replicability network model 1 p.u. is equal to 0.01 MVA

It is assumed that each generator, to compensate the lack of generation caused by the curtailment, can inject in the network up to 1 MW and 1 MVAR of active and reactive power, while the loads can curtail their active and reactive demand by a fixed percentage of curtailment (reported in the input data list).

The load and generation profiles considered in the German demo analysis are referred to the summer peak. This scenario differs from the Greek and Italian scenarios because, due to the high presence of distributed generators, in several timeslice, the LV network is exporting power to the MV grid instead of importing power. Therefore, when the desired power exchange SRA UC is applied, the optimization criteria included in the software architecture will curtail:

- the power imported from the MV grid, in the time slices in which the local generation is lower than the local demand
- the power exported to the MV grids in the time slices in which the local generation exceed the local demand

When the zero-power exchange SRA UC is simulated, the optimization criteria included in the software will compensate the excess of local generation leveraging on local sources of flexibility.

3.3.1 Scalability in density: Summer scenario

The characteristics of the scalability in density - summer scenarios are:

- The load profiles that are used as input for the “as is” profiles are related to the summer peak measured in an Avacon secondary substation in 2018. The aggregation of these values in the 24 timeslice observed in the present study represent the “net load curve”. These values have been divided by the numbers of customers served in the entire primary substation and then multiplied by the number of customers served in the demo area. Avacon had also provided information about the total energy consumption measured by the meters installed in the customers’ households. This information was used to create the gross load curve that represent the total energy demand requested by the customers during the day in which the summer peak occurred. The generation curves have been calculated by subtracting the gross load energy curve by the net load curve. The scenarios considered in the SRA of the German case are based on the daily profiles measured during the 2018 summer peak. In that day, the network had experienced two different configurations: exporting the excess of local generation to MV grid from 7 a.m. to 8 p.m. and importing power from the MV grid during the remaining hours of the day. These values have been labelled as sensitive information by the demo and therefore are reported in D7.4.
- The input that describes the evolution of the grid in this scenario are summarized in Table 11. These data have been decided and validated during several iterations with the Greek demo to

simulate a possible macro evolution of the distribution grid characteristics, however these values do not represent an official grid planning study of the distribution grid operated by AVACON.

Table 11: Data describing the grid evolution of the German demo network.

Variable	unit	description
n_nodes	189 (76)	Number of nodes below the substation. In this model only 76 of 189 nodes are connected to loads or generators
Cosφ	0.90	Power factor
perc_increase_load	478	Expected increase of load with respect to baseline scenario
uncertain_load	25	%Error associated to the expected increase of load forecast
perc_increase_gen	150	%Expected increase of generation with respect to baseline scenario
uncertain_gen	25	%Error associated to the expected increase of gen. forecast
perc_nodes_gen	75	% of nodes equipped with generator in the target scenario
gen_perc		Types of generators connected to the grid in target scenario [default: PV; PV and storage]
PV	20.00	%
PVs	80.00	%
load_percs	[%]	Percentage of each type of load (sum must be equal to 100%]
EV	15	%
residential or industrial	40	%
storage	45	%
fix	0	
min_contracted_power	0.3	Minimum contracted power in the considered network in target scenario
med_contracted_power	3	Medium contracted power in the considered network in target scenario
max_contracted_power	8	Max contracted power in the considered network in target scenario
perc_min	15	% of loads equipped with meters that had the minimum contracted power in target scenario
perc_med	35	% of loads equipped with meters that had the medium contracted power in target scenario
perc_max	50	% of loads equipped with meters that had the max contracted power in target scenario

The “replicability intra national” simulations aim at replicating the UC2 – flexibility provision (implemented in the German demo) when deployed in a representative typical feeder of a urban LV grid in 2030. For this purpose, the “desired power exchange” SRA-UC is selected in the Software architecture and applied to 100 scenarios created with the “scenario generator” tool. In the desired power exchange scenario, it is assumed that, for each timeslice, the power exchange from the MV into the LV is curtailed by 10% with respect to the baseline scenario.

The input that describes the evolution of the grid in this scenario are summarized in Table 12.

Table 12: Data describing the grid evolution of the German Replicability network.

Variable	Unit	description
n_nodes	13	
Cosφ	0.90	Power factor
perc_increase_load	478	Expected increase of load with respect to baseline scenario (changed from 478 because it could not converge
uncertain_load	25	%Error associated to the expected increase of load forecast
perc_increase_gen	150	%Expected increase of generation with respect to baseline scenario
uncertain_gen	25	%Error associated to the expected increase of gen. forecast
perc_nodes_gen	75	% of nodes equipped with generator in the target scenario
gen_perc		Types of generators connected to the grid in target scenario
PV	20	%
PVs	80	%
load_percs		Percentage of each type of load
EV	25.00	%
residential or industrial	55.00	%
storage	20.00	%
fix	0.00	
min_contracted_power	0.3	Min contracted power in the considered network in target scenario
med_contracted_power	3	Med contracted power in the considered network in target scenario
max_contracted_power	8	Max contracted power in the considered network in target scenario
perc_min	10	% of loads equipped with meters that had the minimum contracted power in target scenario
perc_med	35	% of loads equipped with meters that had the medium contracted power in target scenario

The data reported in Table 11 and Table 12 show that Avacon expects to face in 2030 an extremely high increase of loads and distributed generators connected to the distribution grids in the upcoming years. These figures are in fact ten times larger with respect to similar data provided by other DSOs (e.g. Table 7 and Table 9).

These values were used as input data to perform the simulations with the SRA software tools. In these simulations, the scenarios created by the scenario generator tools were significantly congested and characterized by high voltage values. Under these conditions, the OPF tool included in the SRA architecture, despite several iterations, could not find a solution that complies with the convergence criteria for the 2200 scenarios considered in each SRA scenario related to the German case study. In fact the OPF could not find a solution that, in each node of the network, complies with the first criteria of the OPF convergence criteria: i.e. voltage node $V_{node} < V_{threshold}$ where $V_{threshold} = \sqrt{n\_nodes} * 10^{-4}$ [22] (see Figure 24).

OPF_check.log

```
2023-08-03 09:19:52,947 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_2_time_slice_13
2023-08-03 09:19:52,950 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_3_time_slice_16
2023-08-03 09:19:52,950 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_6_time_slice_3
2023-08-03 09:19:52,951 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_5_time_slice_18
2023-08-03 09:19:52,951 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_7_time_slice_9
2023-08-03 09:19:52,952 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_1_time_slice_7
2023-08-03 09:19:52,953 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_1_time_slice_4
2023-08-03 09:19:52,954 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_3_time_slice_6
2023-08-03 09:19:52,954 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_7_time_slice_6
2023-08-03 09:19:52,955 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_2_time_slice_7
2023-08-03 09:19:52,956 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_2_time_slice_12
2023-08-03 09:19:52,957 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_8_time_slice_18
2023-08-03 09:19:52,957 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_4_time_slice_15
2023-08-03 09:19:52,958 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_7_time_slice_14
2023-08-03 09:19:52,959 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_7_time_slice_1
2023-08-03 09:19:52,959 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_3_time_slice_22
2023-08-03 09:19:52,960 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_1_time_slice_3
2023-08-03 09:19:52,961 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_0_time_slice_18
2023-08-03 09:19:52,962 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_9_time_slice_13
2023-08-03 09:19:52,962 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_1_time_slice_2
2023-08-03 09:19:52,963 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_3_time_slice_0
2023-08-03 09:19:52,964 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_2_time_slice_0
2023-08-03 09:19:52,965 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_3_time_slice_7
2023-08-03 09:19:52,965 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_2_time_slice_22
2023-08-03 09:19:52,966 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_0_time_slice_21
2023-08-03 09:19:52,967 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_9_time_slice_16
2023-08-03 09:19:52,967 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_4_time_slice_3
2023-08-03 09:19:52,968 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_5_time_slice_6
2023-08-03 09:19:52,969 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_4_time_slice_5
2023-08-03 09:19:52,969 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_3_time_slice_9
2023-08-03 09:19:52,970 - MainThread - DEBUG - Failed Simulation Germany/desired_power_exchange/demo/summer  scenario_0_time_slice_17
2023-08-03 09:19:52,970 - MainThread - INFO - Simulation Germany/desired_power_exchange/demo/summer Number of tasks 220. To do: 0.0%, converged: 0.0%, not converged 0.0%,  failed 100.0%
```

Figure 24: Results of the SRA simulations for the German case for the 2030 scenario (desired power exchange SRA UC)

These preliminary results suggests that, in the long term (10 years) it is not possible to rely only on the provision of flexibility services by distributed resources to safely integrate expected increase of loads and generators predicted by Avacon in the grid planning study. Therefore, it was decided to modify the expected increase of generators and loads stated in Table 10 and Table 11 to simulate a short-term scenario in which both generations and loads will grow by 77% compared to the baseline scenario. These targets, even if they are not specified in the long-term development plans published by Avacon, have been agreed with the WP5 members and represent a shorter-term evolution of the loads and DGs.

These new targets for the growth of generation and loads were simulated. In the simulations that involved the demo grid model (189 nodes and 76 generators/loads) the OPF could converge in 85% of the analysed timeslice when the desired power exchange is applied and in 97% of the time slices when the zero-power exchange SRA-UC is applied, as shown in Table 13.

Table 13: Report on the convergence of the German SRA simulations

simulation_id	n_time_slices	Converged [%]	Not converged	Not_started [%]
germany_desired_demo_summer_new	2200	84.73	0	15.28
germany_desired_replicability_summer_new	2300	100	0	0
germany_zero_demo_summer	2200	97.23	0	2.73

In these calculations it was assumed that each generator could offer up to 1MW and 1MVA of flexibility, while each load absorbed be cut up to 10% with respect to its baseline profile.

3.3.2 Public results

The timeslice analysed in these simulations are considered as independent and non-consecutive timeslice: it is considered that in each timeslice all generators and loads can provide the maximum amount of flexibility available. The present simulations did not model the state of charges of the different generators and storage units included in the model.

Figure 25 and Figure 26 summarize the results of the simulations related to the “scalability in density” use case. In these simulations the “desired power exchange” SRA-UC is used to calculate the amount of flexibility needed to solve the congestion (in terms of active and reactive power of each generator and each load connected to the grid). In these simulations the power injected into the MV grid was curtailed by 10% with respect to the baseline scenario.

Figure 27 and Figure 28 summarize the results of the simulations related to the “scalability in density” use case. In these simulations the “zero power exchange” SRA use case is used to calculate the amount of flexibility needed to solve the congestion (in terms of active and reactive power of each generator and each load connected to the grid).

Finally, Figure 29 and Figure 30 summarize the outcomes of the simulations for the “replicability intranational” SRA, when the “desired power exchange” SRA UC is applied, while Figure 31 and Figure 32 illustrate the results for the “replicability intra national” SRA, “zero power exchange” SRA-UC.

SCALABILITY IN DENSITY - DESIRED POWER EXCHANGE DEMO NETWORK

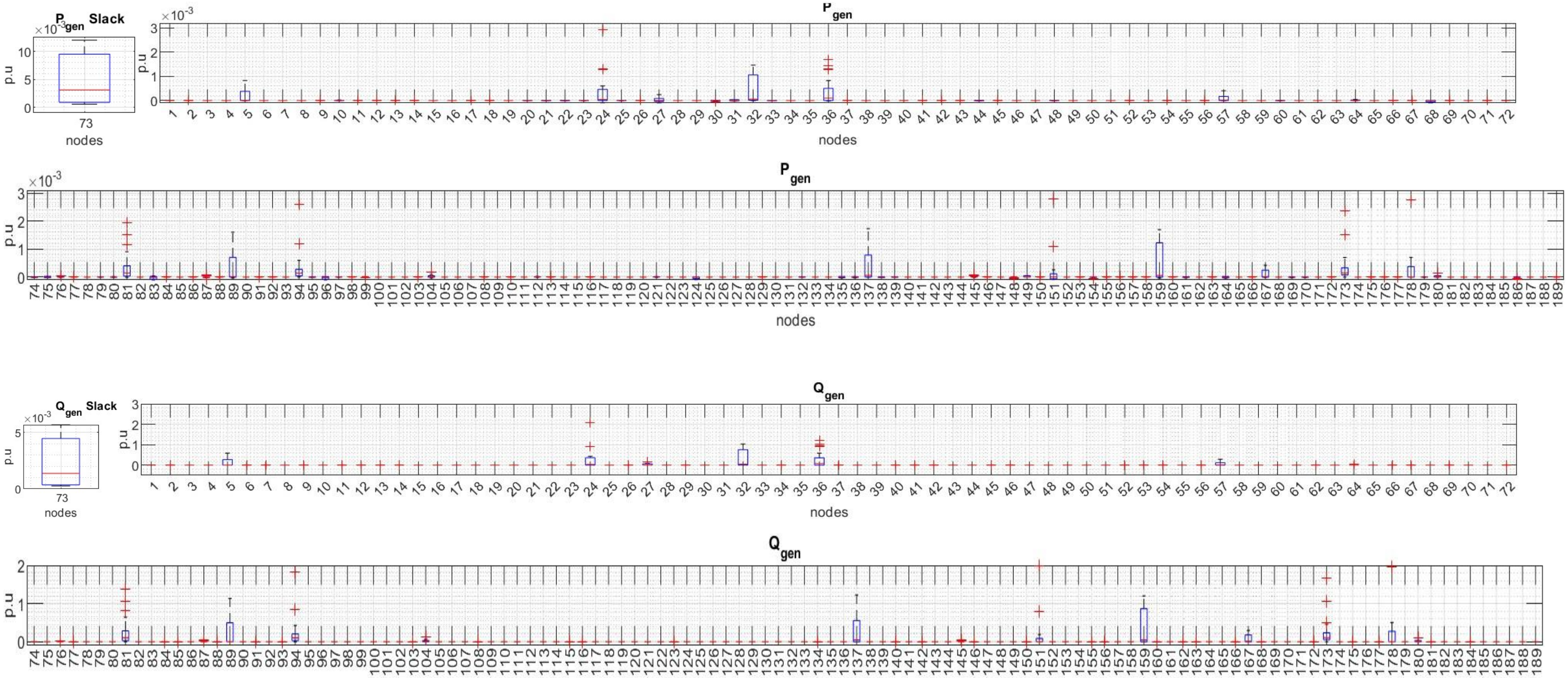


Figure 25: Flexibility (Active and Reactive power) of the generators in the scenario scalability in density, demo network, desired power exchange

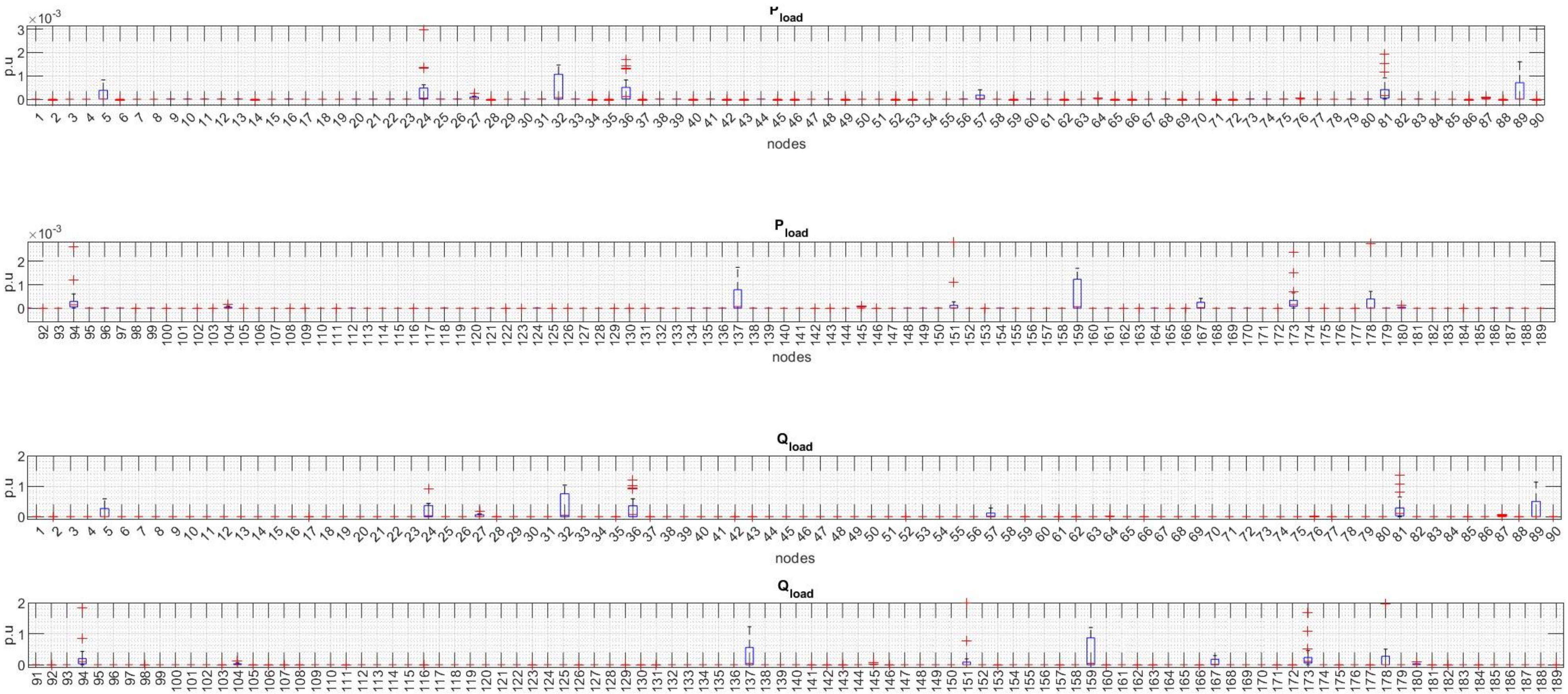


Figure 26: Flexibility (Active and Reactive power) of the loads in the scenario scalability in density, demo network, desired power exchange

SCALABILITY IN DENSITY – ZERO POWER EXCHANGE DEMO NETWORK

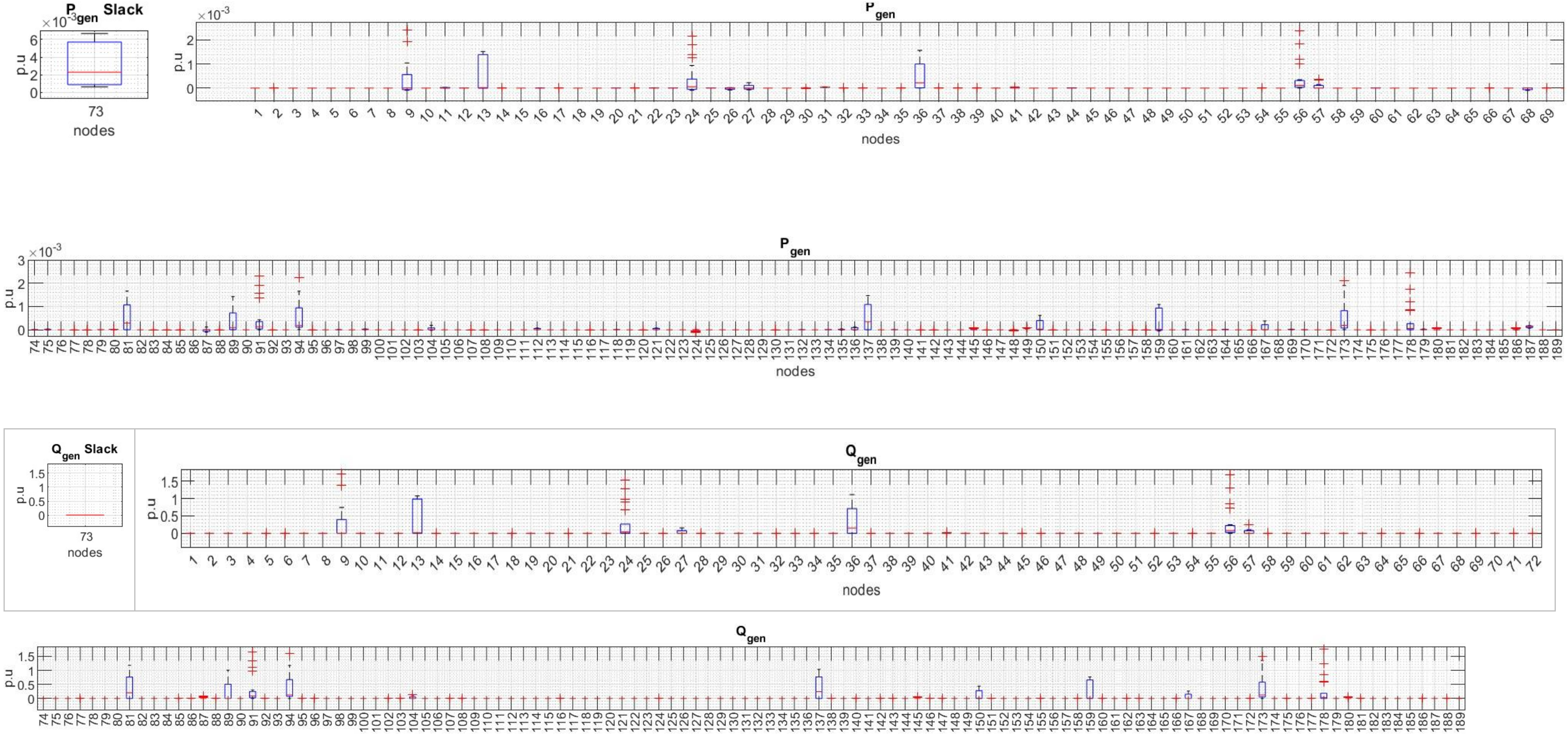


Figure 27: Flexibility (Active and Reactive power) of the generators in the scenario scalability in density, demo network, zero power exchange

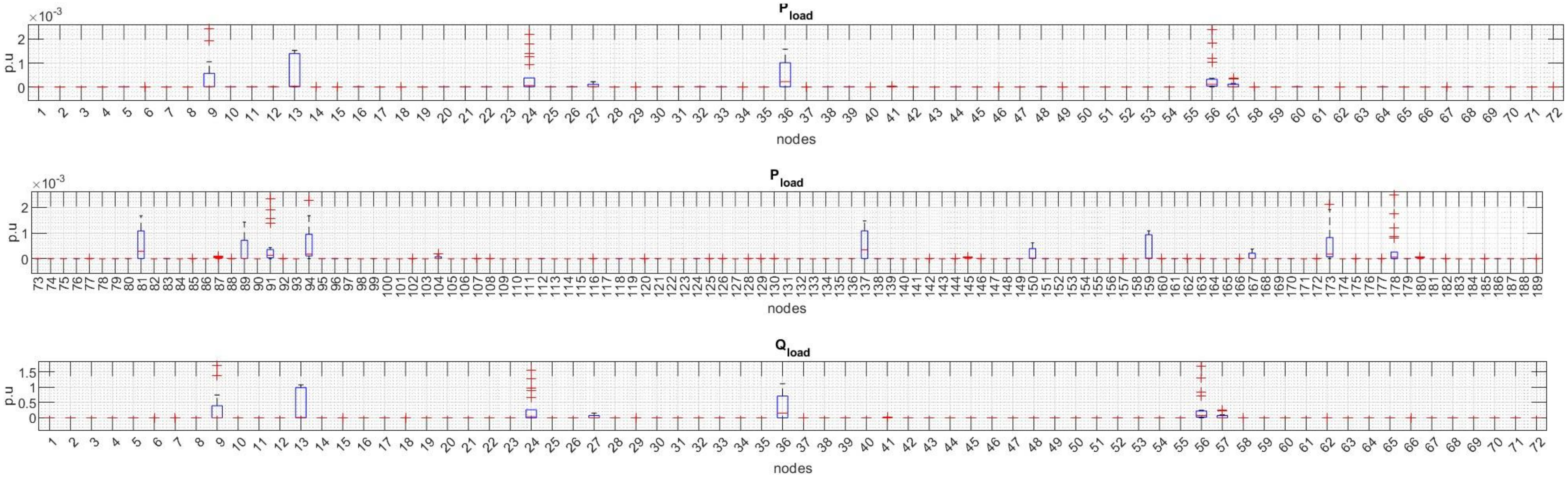


Figure 28: Flexibility (Active and Reactive power) of the loads in the scenario scalability in density, demo network, zero power exchange

REPLICABILITY INTRA NATIONAL - DESIRED POWER EXCHANGE URBAN NETWORK

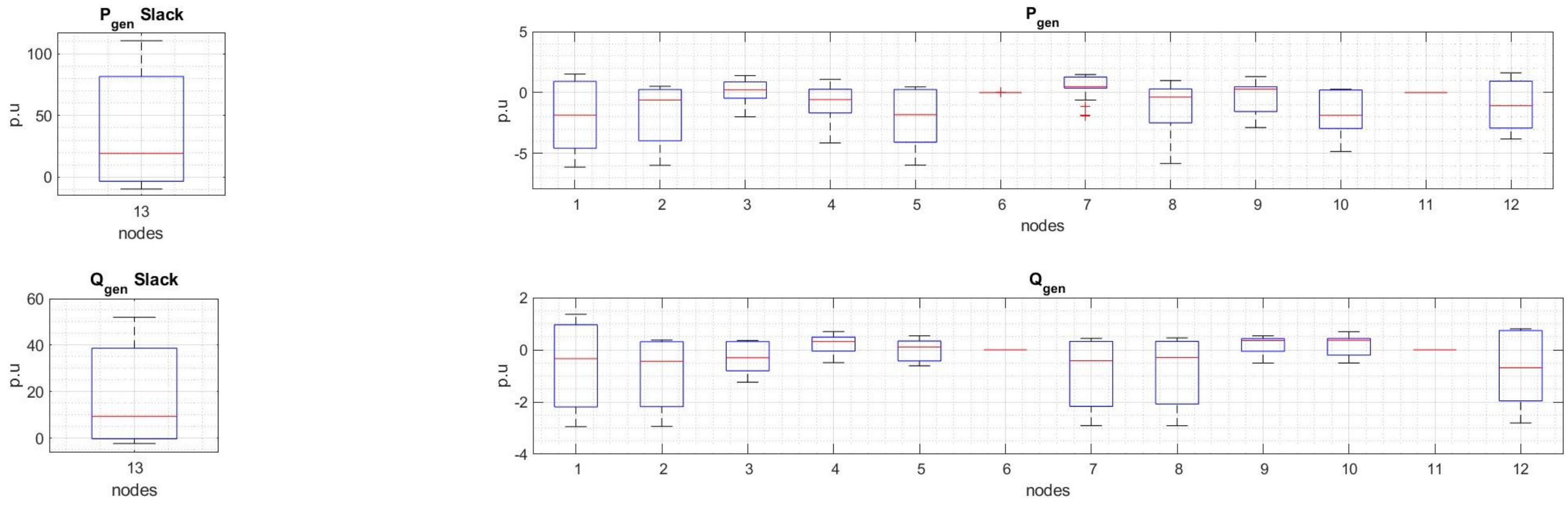


Figure 29: Flexibility (Active and Reactive power) of the generators in the scenario replicability intra national, urban network, desired power exchange

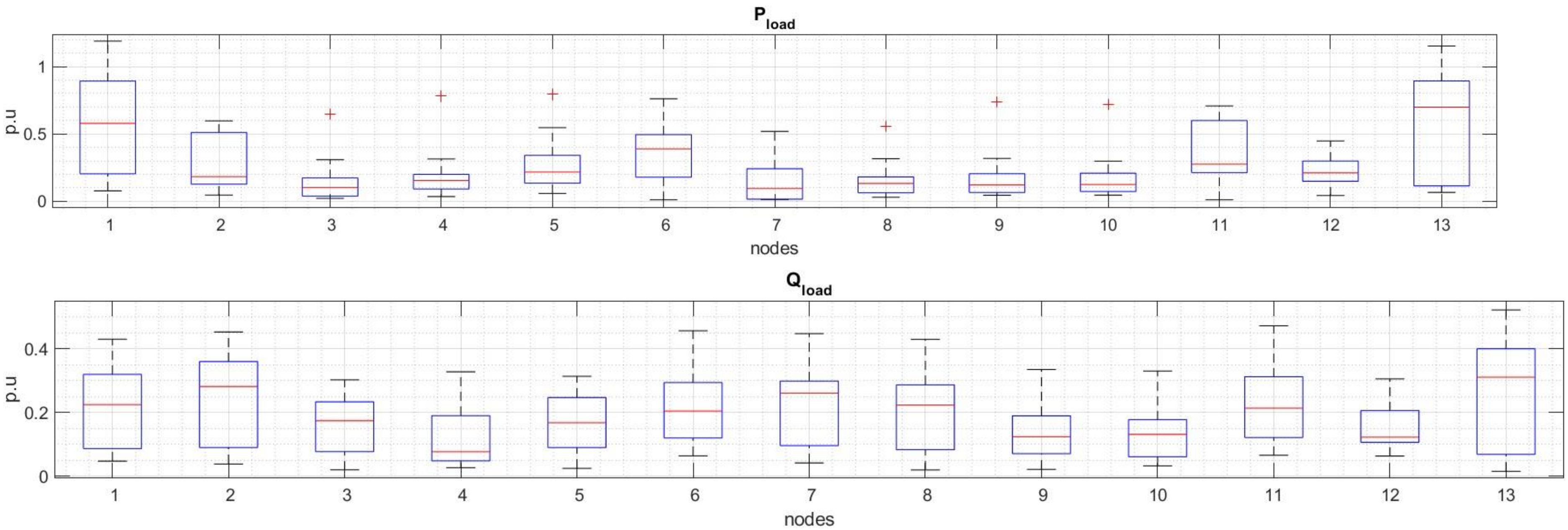


Figure 30: Flexibility (Active and Reactive power) of the loads in the scenario replicability intra national, urban network, desired power exchange

REPLICABILITY INTRA NATIONAL – ZERO POWER EXCHANGE DEMO NETWORK

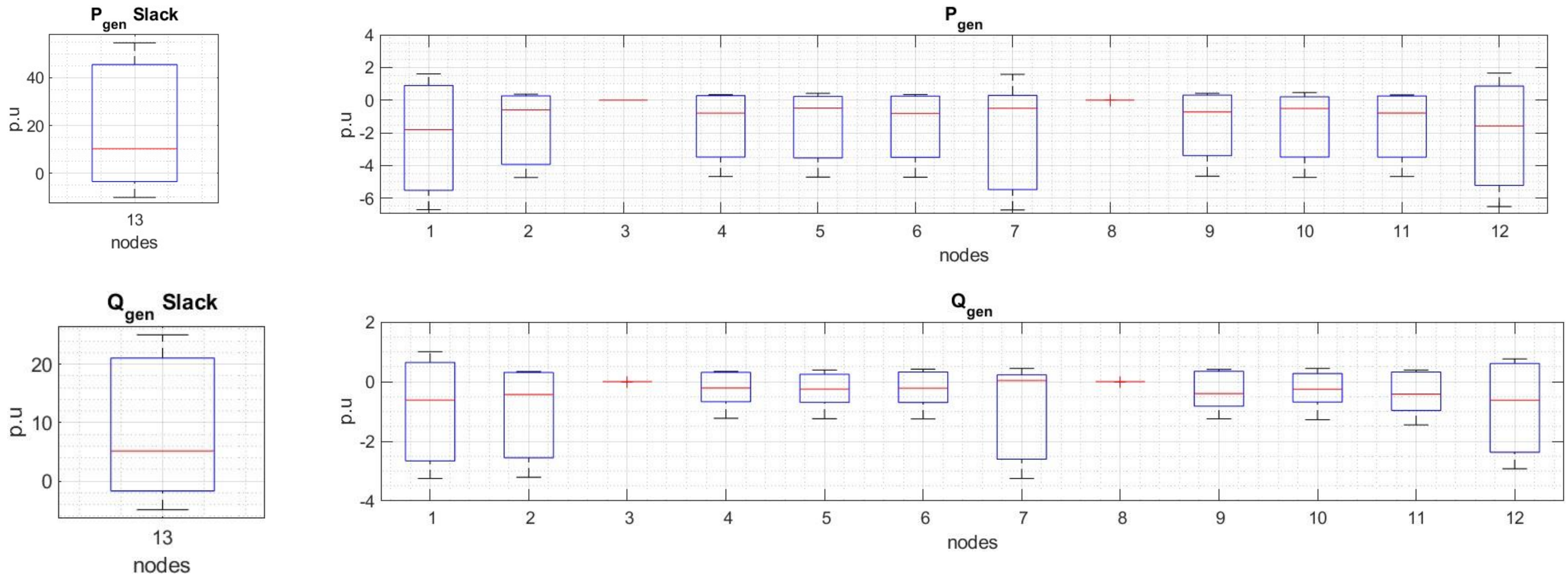


Figure 31: Flexibility (Active and Reactive power) of the generators in the scenario replicability intra national, urban network, zero power exchange

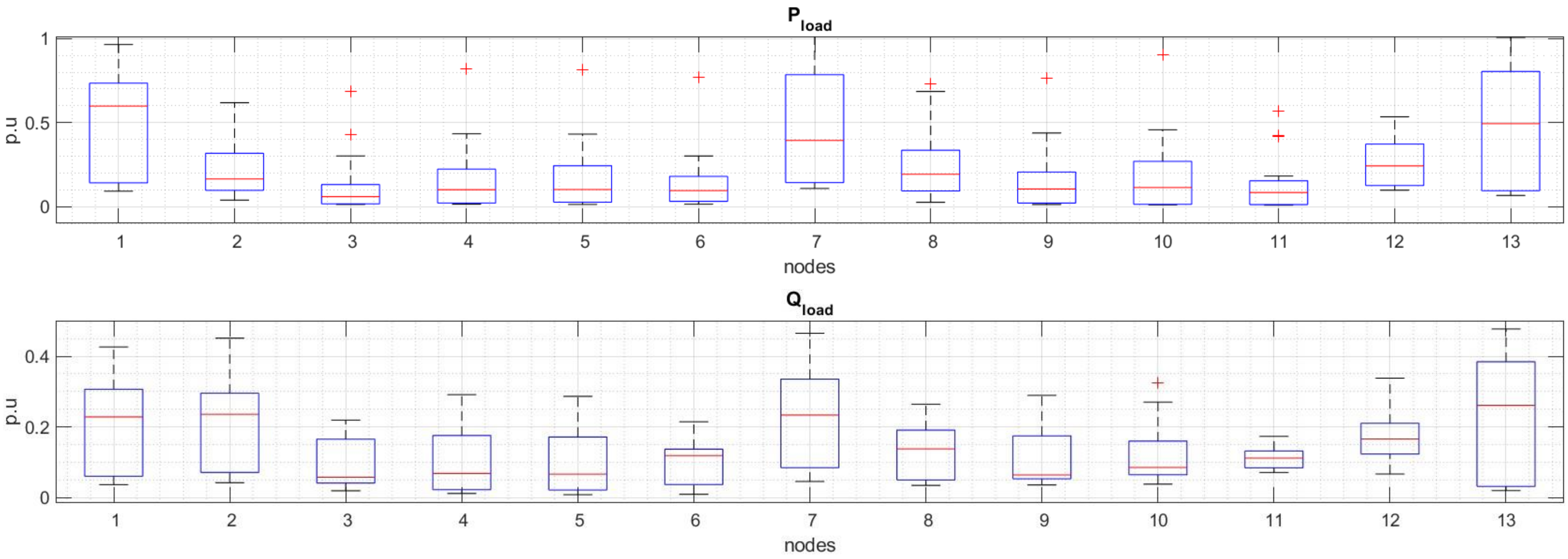


Figure 32: Flexibility (Active and Reactive power) of the loads in the scenario replicability intra national, urban network, desired power exchange

3.3.3 Lessons learnt

The results of the SRA simulations applied to the German demo are illustrated in paragraph 3.3.2.

The data provided by Avacon regarding the expected growth of loads and distributed generators by 2030 are significantly larger with respect to similar data provided by other DSOs. The scenarios that were created in the SRA based on these data were significantly congested and characterized by high voltage values. Under these conditions, the OPF tool included in the SRA architecture, despite several iterations, could not find a solution that complies with the convergence criteria for the 2200 scenarios considered in each SRA scenario related to the German case study. This result proved that it is not possible to rely on flexibility services provided by distributed resources to cope with a significant penetration of distributed renewable energy sources. However, further simulations aimed at studying the impact of a shorter-term scenario, characterized by lower increase of growth of loads and generation growths, proved that for an expected growth of generation units and loads equal to 77% of the baseline scenario, it is possible to rely on flexibility services provided by distributed resources to resolve most of the expected congestions on the network.

However, in the simulations focused on the German demo network (both "desired power exchange" and "zero power exchange" SRA UCs), 15% and 2% of the scenarios simulated could not be resolved using local flexibility.

The SRA analysis aims at simulating the KPI PR03 Flexibility Availability when deployed in different conditions.

The KPI measures the potential flexibility provided by flexible PODs connected to the grid:

- $Flexibility\_Availability\_Up = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i=1}^{N}|Available\_Flexibility\_Up_{i,t}|}{\sum_{i=1}^{N}|Baseline_{i,t}|}\cdot 100$
- $Flexibility\_Availability\_Down = -\frac{1}{T}\sum_{t=1}^{T}\frac{\sum_{i=1}^{N}|Available\_Flexibility\_Down_{i,t}|}{\sum_{i=1}^{N}|Baseline_{i,t}|}\cdot 100$

The SRA analysis is targeting a future scenario of grid development that consider different evolutions of load and generations curves. The approach followed to adapt KPI PR03 to the specific characteristics of the SRA is the same approach adopted in the subchapter dedicated to the German demo. For the SRA KPI assessment, an expected increase of load and generation equal to 77% with respect to the baseline scenarios is considered.

This KPI is therefore calculated by comparing compares the amount of flexible generations that must be curtailed in order to avoid the congestions that have been identified in the load flow calculations, using the following formula:

$$FLEX\_GEN = \frac{max(median\_of\_gen_{flex}@target_{year})}{gen_{peak}@target_{year}} * 100$$

While the SRA KPI $FLEX\_LOAD$ load curtailment is calculated using the following formula

$$FLEX\_LOAD = \frac{max(median\_of\_load_{flex}@target_{year})}{load_{peak}@target_{year}} * 100$$

The flexibility values considered in the formulas reported above and in the results reported in this sub chapter are the median flexibility values of the observed parameter calculated for a specific node in all the 2200 observed time slice.

Therefore, this KPI in the SRA analysis is calculated by dividing the maximum values among the median values of active and reactive flexibility of generators calculated in the "scalability in density – desired power exchange" SRA UC by the peak value of generator and load curves. In particular, as illustrated in Figure 25 and Figure 26 in order to resolve the local congestions caused by the application of the desired power exchange, each generator connected to the grid shall increase their production up to 0.345 MW and up to 0.567 MVAR. These values correspond to a value of SRA KPI $FLEX\_GEN$ equal to 81.24% (when referred to active power) equal to 105.88% if calculated with respect to the reactive power. Each load shall provide a maximum value of flexibility equal to 0.00197 MW and 0.00103 MVAR. These values correspond to a value of SRA KPI $FLEX\_LOAD$ equal to 2.63% (when referred to active

power) and equal to 1.10% when referred to reactive power. This latter value is calculated by multiplying the peak value of the generator curve in the target year (reported in D7.4) by the expected growth of generation in the demo scenario, (+77% with respect to the "as is" load and generation curves).
Figure 27 and Figure 28 report the results of the "scalability in density – zero power exchange" SRA use case. To solve these congestions, the generators shall provide a maximum flexibility equal to 0.345 MW. The flexible loads shall provide a maximum flexibility of 0.246 MW and 0.346 MVAR. This result highlights the need to use the flexible resources connected to the grid to compensate the lack of reactive power when analysing congestions that occur on rural networks.
The results of the intranational SRA are illustrated in Figure 29, Figure 30, Figure 31 and Figure 32. The first two figures summarize the results of the application of the "desired power exchange" UC to the JRC urban network (replicability intra national) while the last two figures are related to the application of the "zero power exchange" SRA-UC to the urban network.
When the desired power exchange SRA-UC is applied, it can be noticed the maximum amount of flexibility needed to resolve the expected congestions both positive and negative: this value ranges from -0.06097 MW to 0.01847 MW and the reactive power varies from positive 0.00171 MVAR to negative values -0.033 MVAR. The maximum amount of load flexibility is equal to 0.014 MW and 0.0068 MVAR.

In addition, in the "zero power exchange" UC it can be noticed the maximum amount of flexibility needed to resolve the expected congestions both positive and negative: this value ranges from -0.068 MW to 0.01847 MW and also the reactive power varies from positive 0.0019 MVAR to negative values -0.033 MVAR. The maximum amount of load flexibility is equal to 0.0119 MW and 0.0063 MVAR.
Based on the above-mentioned results, the following conclusions can be draws:

- When the characteristics of the German demo scenarios in 2030 are applied to rural network grid models, similar to the demo grid models, severe congestions can be noticed. In fact, these grid models are characterized by longer lines, with a lower degree of undergrounding, and a more radial structure with ramifications. In these networks, where lines are generally longer and therefore conductors have a higher impedance, the significant growth of DG and flexible loads causes higher voltage rises and consequently leads to significant congestions. To mitigate this impact, the use of local sources of flexibility might be complemented with the adoption of complementary strategies of local voltage control (e.g: Distribution STATCOM, Static Var Compensators, On Load Tap Changer transformers etc. [20], [17])
- On the contrary, when the characteristics of the German demo 2030 scenarios are applied to urban network, the SRA UCs "desired power exchange" (with a curtailment factor equal to 10% of the gross demand) and "zero power exchange" can be successfully implemented during summer peaks days in the urban distribution grids even in future scenarios characterized by a significant penetration of distributed generations. The urban networks are characterized by are characterized by lower levels of ramifications, shorter lines, and higher density of energy demand. The SRA of the German SRA simulates scenarios in which the LV network is exporting power to the MV grid during some time slices and importing power from MV network when the PV production decreases. The OPF algorithm, in order to solve the expected congestions of the German scenarios while respecting the constraints that are associated to the characteristics of the urban grids, activate both the negative and positive flexibility of the distributed generators, as illustrated in the "SRA intra national" simulations .This result highlights the needs to invest in solutions that can offer both positive and negative flexibility services when considering the application of the German demo scenarios in urban networks.

3.4 Main findings from the SRA

From the results and findings illustrated in Chapters 2 and 3 the following conclusions and recommendations can be drawn:

- To develop a comprehensive software architecture that can be used to perform the scalability and replicability analysis it is not possible to rely only on commercial tools. In fact, to simulate the potential flexibility services offered by flexible loads an ad hoc OPF tools had to be developed. This tool has the possibility to include in the lists of variables that can be optimized, also a percentage of the active and reactive loads connected to the grid. Moreover, the customized OPF tool offers the possibility to modify the optimization criteria, to simulate the application of the use cases that were implemented in the demos.

- An ad hoc software was also developed to elaborate several scenarios that could describe the potential evolution of the load and generation curves in a given portion of the network. These scenarios were created with the scope of considering the uncertainties related to the potential location, typologies and sizes of distributed generators and loads that will be implemented in the distribution grids in the target year. This software tool represents a preliminary attempt to incorporate Monte Carlo approaches in the grid planning studies for quantifying the potential contribution of flexible loads and generations for solving local congestions and grid problems.
- On the one hand, the development of these innovative tools for the grid studies falls into the recommendations issued by the EC directive 944/2019 [23] to elaborate "network development plan that provides transparency on the medium and long-term flexibility services needed" but on the other hand these tools have introduced further variables to the classical OPF algorithms: as a consequence of the increased numbers of variables that the algorithm can handle, the computational time and the iterations that are needed to identify results of the OPF calculation increase and, in the most congested scenarios, the OPF calculations can fail. To improve the computational capabilities of the software architecture developed in Platone, future research programs might investigate the possibility to introduce the Optimal Power Flow Using Genetic Algorithm in the existing OPF algorithm.
- Both the "desired power exchange" and "zero power exchange" SRA-UC can be implemented in most of the scenarios considered in the SRA reported in Chapter 3. The amount of local sources of flexibilities included in these scenarios are sufficient to compensate most of the congestions caused by the application of the SRA UCs. These results prove that the provision of flexibility services could be a viable solution to resolve the congestions that will occur during peak days in 2030, provided that the penetration of flexible loads and generators in the distribution networks can be compared to the target identified in the results of the SRA.
- However, the scenarios that describe the behaviour of rural networks are characterized by longer lines, with a lower degree of undergrounding, and a more radial structure with ramifications. In these networks, where lines are generally longer and therefore conductors have a higher impedance, the significant growth of DG and flexible loads causes higher voltage rises and consequently leads to significant congestions. To mitigate this impact, the use of local sources of flexibility might be complemented with the installation of special devices that can compensate the local lack of reactive power.
- When the SRA is applied to scenarios in which the observed network is exporting power to the main grid during some time slices and importing power when the local production decreases, the OPF algorithm, to solve the expected congestions, might activate both the negative and positive flexibility of the distributed generators. This behaviour is observed especially in urban networks. This result highlights the needs to invest in solutions that can offer both positive and negative flexibility services.

In order to complete all the steps of the general methodology for the scalability and replicability analysis illustrated in D7.2 [2], the last set of simulations shall investigate how the performances of the solutions tested in the demos are deployed in larger network with similar of different boundary conditions (e.g. rural/ urban networks). WP7 partners evaluated the possibility to also perform these simulations, using other JRC representative networks that describe distribution networks with up to 1000 nodes. However, as demonstrated in the results shown previously, the modifications of the custom OPF algorithm that were introduced to simulate the zero-power exchange and desired power exchange SRA-UCs, increase the complexity of the algorithm: in fact, the flexible loads are now additional variables that the solver can activate to find the solution. This additional complexity results in an increase of the iterations that the OPF tool must perform to resolve the simulated congestions in a grid model characterized by high penetration of DG and high demand (Summer peak day). As shown in the results that describe the behaviour of urban networks, when the congestion is simulated in a network model characterized by limited number of nodes, the OPF tool manages to find a solution within an acceptable number of iterations (1000). However, when the analysed network models include more than 180 nodes (e.g., the network model used for the SRA analysis of the German demo networks) the iterations needed by the OPF to find a solution significantly increase and, in some scenarios, the OPF fails to identify the solutions within the acceptable computational times. Moreover, large networks characterized by dispersed generation and flexible loads distributed randomly along the LV lines are subjected to larger voltage drops and lack of reactive power with respect to urban networks and therefore, to resolve the expected congestions in these contexts, the provision of flexibility services by distributed loads and generators must be complemented with the support provided by special solutions that can provide reactive power and voltage support.

Based on these observations, it can be concluded that, to perform the Scalability/Replicability analysis in size, the Software architecture that has been developed in the Platone project shall be further complemented and shall include additional features like Optimal Power Flow Using Genetic Algorithm [24] [25] that can help the solver to limit the number of iterations needed to identify the solutions or the possibility to model, among the potential sources of flexibility, additional type of users that can inject significant amount of reactive power.

3.5 Qualitative assessment

The results of the quantitative SRA reported in the previous paragraphs have demonstrated the feasibility to implement the selected SRA-UCs in specific network models and have assessed the amount of local flexibility that shall be procured to resolve the expected congestions while avoiding the need to invest in grid reinforcements. The results of the technical SRA are now complemented with a qualitative assessment based on the main findings are recommendations elaborated in cooperation with other WPs. This analysis aims at identifying the potential barriers that might prevent the large-scale implantation of the SRA-UCs (and consequently of the demo UCs) addressed in the present deliverable in the three countries that host the Platone demo. In particular, the following set of barriers be identified:

- Regulatory: identification of the optimal regulatory schemes that could better support the deployment of the solutions tested in the demos;
- Stakeholders' engagement: suggestions to optimise stakeholders' participation in the management of the tested SRA - UCs.

The technical barriers (standardization needs, interoperability) have been described in WP2.
The regulatory aspects that have an impact on the potential deployment of the Platone solutions are summarized in Figure 33 (as stated in D8.10 [26] and D1.5 [27])

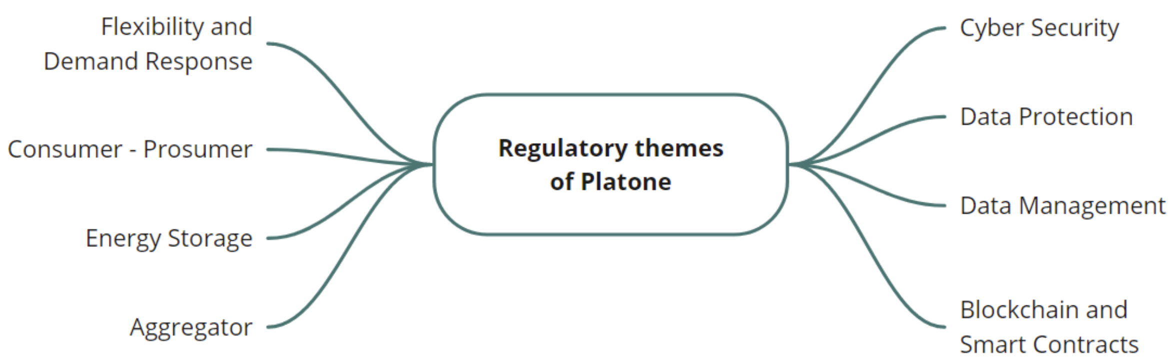


Figure 33: Identified Platone themes for the description of the regulatory and legislative framework [26]

Based on the outcomes of "Table 1: Use Case Mapping: Use Cases vs. thematic areas analysed" reported in D1.5, the regulatory parameters that impact on the "desired power exchange" (UC2- DE, UC IT -2 and on the Greek KPIs 08 and 07) are: flexibility services; consumer prosumer; functionalities allowed to the energy storage owners; aggregation; blockchain and smart contracts in the energy sector; data management, protection and cybersecurity. The regulatory parameters that impact on the Zero power exchange SRA-UC include, on top of the ones already considered in the desired power exchange SRA-UC, also DSO ownership of storage units and local energy communities' regulation.

Based on information reported in D1.5 [27] the WP7 summarized in Table 14 the current status of the regulatory aspects that impact on the SRA-UCs. Based on the analysis of the regulatory aspects summarized in Table 14 the following conclusions can be derived.

The regulatory barriers that might hinder the large-scale deployments of the two SRA-UCs significantly vary among the three countries that hosts the Platone demo.

In Italy, one of the main regulatory gaps in the Italian context is represented by the lack of a definitive definition of the roles and responsibilities of DSOs, aggregators, and other market players. The National Regulatory Agency has published several resolutions to enable the new two roles of the DSO in the flexibility market (market enabler and flexibility buyer), but the process of a full framework definition is still ongoing. The recommendation goes to ARERA to gather the findings from the National and European demos on this topic and formulate laws and resolutions to close this gap.

In Greece, the main obstacle is represented by the lack of regulation in terms of Blockchain technology in the energy sector poses an obstacle, even more since many legislative steps are still expected to be taken. Moreover, in the Greek legislation, the role of the aggregator is not clearly stated, especially when it comes to the representation of RES producers and high efficiency CHP units in the Greek energy market.

Finally, the regulatory landscape of Germany's energy sector, primarily encompassing the Renewable Energy Act and Energy Industry Act, has undergone significant expansion. However, the implementation and functioning of the German demonstration have uncovered challenges and deficiencies. Initially, there is a requirement for a more defined regulatory structure concerning flexibility mechanisms, particularly in cases involving devices like remote controllers for control methodologies. Secondly, enhancements are necessary in the regulatory framework governing DSOs' use of batteries. This should encompass both streamlining processes and introducing incentives for diverse functionalities, such as grid management. Such adjustments would stimulate battery proprietors to become more engaged and offer their flexibility to the DSO.

Table 14: Summary of the current regulation implemented in DE, GR and IT (source [27])

	DE	GR	IT
Flexibility services	the Energy Industry Act (§14) [28] by German legislation, states that DSOs are obliged to offer a discount on grid charges for customers who offer flexibilities to the System Operator. An additional technical option is the curtailment of RES, regulated by the German Renewable Energy Act [29].	Only the EU directives: e-Regulation [30] and the e-Directive [31] of the Clean Energy Package are enforced	ARERA Consultation Documents: 322/2019/R/eel [32] and 685/2022/R/eel [33] establish the new rules for the wholesale electricity market and launch the process of reforming the current electricity dispatching market to enable the participation of DER
Consumer - prosumer	Under DE legislation, as outlined in the Energy Industry Act (§14) [28], network operators are required to provide grid charge discounts to customers who provide flexibilities to the System Operator.	DSOs are mandated to equip 80% of their customers with telemetering systems that enable the creation of “prosumers”. Energy communities are outlined in Greek law 4513/2018, that also defines their role in energy markets.	The RED II Directive was transferred into national legislation with the Legislative Decree 199/21 November 2021. The Decree Law n.34 in April 2022 has partially amended the Legislative Decree implementing the «Renewable Energy Directive 2018/2001 - RED II» (legislative decree 199/21). The amendment implies that self-consumers now, can also sell the self-produced electricity and offer ancillary and flexibility services. The e-directive has been transferred into national legislation with the Legislative Decree 210/21 November 2021 [34].
Functionalities allowed to the Energy Storage owners	The governing framework is outlined within directive 2019/944/EU, which stipulates that DSOs are prohibited from possessing, developing, managing, or running energy storage facilities	Not relevant	ARERA Decision 574/2014/R/EEL [35] implements the integration of the battery storage in the electrical system. Decision 642/2014/R/EEL [36] defines the functional requirements for storage systems and their proper connection to the grid
Aggregation	the regulatory framework is given by the e-Directive [31] and the Electricity Balancing Guideline	the regulatory framework is given by the e-Directive [31] and the Electricity	The aggregation of small energy resources is regulated in the Decision 300/2017/R/EEL [37].

		Balancing Guideline	
Blockchain and Smart Contracts in the energy sector	Blockchain and Smart Contracts" in the energy sector are not clearly regulated by the EC.	Blockchain and Smart Contracts" in the energy sector are not clearly regulated by the EC.	Blockchain and Smart Contracts" in the energy sector are not clearly regulated by the EC.
Data Management	Germany has issued a variety of different laws, ensuring a high level of cyber security and data protection. For the German demo, only the GDPR and Federal Data Protection Act are relevant	This is subject to the national Law 4342/2015.	Customer's energy and personal data is protected by the GDPR [38] as well as the national legislation Legislative Decree no. 196 of 2003 [39].
Protection and cybersecurity	The pertinent regulations consist solely of the GDPR and the Federal Data Protection Act.	These aspects are regulated by the Council Directive 2008/114/EC, addressing the recognition and classification of European Critical Infrastructures.	The transposal of the EU directive 2016/1148 [40] dealing with "Cybersecurity" into national law led to Legislative Decree 65/2018. Furthermore, Italy adopted a National Plan for cyberspace protection and ICT security [41]. The Italian government has taken another step towards the implementation of an extensive national cyber-security framework through the adoption of the Law Decree n. 105 [42].
DSO ownership of storage units	The governing framework is outlined within directive 2019/944/EU, which stipulates that DSOs are prohibited from possessing, developing, managing, or running energy storage facilities		
Local Energy Communities regulation	Starting on 1st January, the new law called EEG 2023 enter into force, establishing a new regulatory framework for energy communities.	Energy communities are outlined in Greek law 4513/2018, that also defines their role in energy markets.	Energy communities are regulated by the Law decree n. 199/2021 [43]

The categories of stakeholders that are impacted by the deployment of the SRA UCs have been identified in D8.10 [26] are reported in Figure 34

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Figure 34: Target groups of the Platone Open Framework

The technical SRA analysis demonstrated that the two SRA-UCs can be used in the future distributed grids as solutions that can solve local congestions and voltage problems. Unlike traditional methods that call for grid reinforcement, this inventive approach empowers users to exert flexibility bidirectionally, effectively precluding potential grid congestions.

However, based on the insights and lessons learnt in WP8 [26], in order to integrate the SRA-UCs in the daily activities of the above-mentioned stakeholders, several barriers shall be removed.

DSOs are one of the most important stakeholder categories that can benefit from implementation of the implementations of the SRA-UCs to address grid congestions and imbalances. However, to integrate these SRA-UCs in their daily operations, new market design in the form of market platforms or innovative network tariffs and net billing schemes shall be allowed by the national regulatory frameworks. The current regulatory frameworks shall be further modified to remove the barriers illustrated in Table 14 and to allow small-scale DER and loads to provide ancillary services. The network codes currently implemented in the countries that host the Platone demos shall be revised to allow for innovative cooperative mechanisms between TSOs and DSOs. Finally, the process of digitalization of the distribution grids shall be further accelerate in order to enable the current distribution networks to accommodate the innovative digital components that constitutes the Platone architecture. The digitalization process enables the DSOs to control and manage flexibility services, to improve the grid observability and to ensure the processes of data collection and storage.

TSOs are also key stakeholders that would benefit from the implementation of the two SRA-UCs, however they have to resolve the same barriers identified for the DSOs. Moreover, the TSOs play the role of Balance Responsible Party and are therefore in charge of ensuring the system stability and the provision of the adequate amount of ancillary services needed to safely operate the system. The implementation of innovative market schemes aimed at procuring flexibility services from distributed sources require further adaptations of the dispatching codes that are currently implemented in the Countries that host the Platone demos.

Aggregators are a key player for the successful implementation of the SRA-UCs, however their role is not clearly defined in the national regulatory frameworks. Moreover, to perform their activities, aggregators need to exploit a fully digitalized energy systems that integrates secure and false-proof bidirectional communication technology and platforms to pool and coordinate a huge number of flexible units. Finally, a clear mechanism to remunerate the provision of the aggregator services shall be established, to enable the aggregators to develop reliable business cases.

Customers lie at the heart of Platone's vision and are fundamental players that provides the flexibility services that were modeled in the two SRA-UCs. A notable barrier was the necessity for easy and uncomplicated solutions and components that enable customers to offer their flexibility. These solutions shall not represent an economic barrier that prevent the access of new customers to the local flexibility markets. To motivate customers to actively provide the flexibility services, a clear and fair remuneration for the provision of flexibility services shall be established and innovative approaches to involve customers shall be developed. Data security and confidentiality have been highlighted as major concerns for the end users.

In research, the Platone project identified barriers and fostered a dynamic knowledge exchange across diverse scientific fields and sectors, underpinning the vital energy transition. The project recognized the pressing need for an open-source and freely accessible approach to facilitate the seamless interchange of tools, information, and insights. This necessity was particularly pronounced in the absence of a clear-cut SRA methodology tailored to Platone's distinctive use cases, as highlighted in D7.2. [2] and D7.3 [3]. To address these challenges, Project Platone took proactive measures to forge solutions that bridge these knowledge gaps. The SRA framework was developed and rigorously tested, marking a significant stride toward addressing the dearth of tailored methodology. Furthermore, the project exhibited adaptability by tailoring the general CBA framework to align with Platone's specific needs. These accomplishments lay a strong foundation for future research endeavours, as the project envisions further investigations and inquiries to continue advancing the energy transition landscape.

The industrial sector shall be able to develop solutions that respond to the technological challenges highlighted by the other stakeholders. To achieve this goal, close cooperation and knowledge transfer between science and industry must be ensured and open systems software and components shall be developed.

As illustrated in Table 14, the regulatory authorities shall introduce significant changes in the current regulatory schemes to support the deployment of the SRA – UCs. The most urgent adaptations identified by the WP8 analysis are:

- Adaption of regulation according to new market schemes for ancillary services to encourage participation from DER owners and aggregators.
- Change regulation to foster new network tariffs reflecting the changing use of the network across various customer groups.
- Change of regulatory framework to incentivize the reinforcement and digitalization of the grid infrastructure.

Adaption of regulatory framework to the new roles and responsibilities of new and existing players in the grid e.g. DSOs and flexibility providers.

4 Multi Criteria Cost Benefit Analysis

In D7.3 [3], a hybrid Multi-Criteria and Cost-Benefit Analysis (MC-CBA) has been elaborated to combine the strengths of two methodologies, i.e., the CBA approach proposed in 2012 by the European Union Joint Research Centre (JRC) [44] and the MCA developed by the ISGAN (International Smart Grid Action Network) [45]. If on the one hand the JRC methodology provides guidelines and best practices to identify and monetise benefits and costs related to Smart Grid projects, on the other hand the ISGAN approach complement the former with a multi-criteria feature, so that different impacts other than the economic ones (such as environmental, societal, etc.) can be effectively considered and assessed under a common framework. The MC-CBA, which can provide investors and governments with an ex-ante assessment of design and development options for large projects, aim at assessing and identifying the benefits (and the beneficiaries) of the project under different viewpoints, namely economic, social and environmental.

This section is organized as follows. Section 4.1 provides a short recap of the MC-CBA developed in [3]. Section 4.2 describes the Smart Grid Evaluation toolkit developed in [45] and adopted in this deliverable to elaborate the data collected for each project demo as well as to report the CBA results in a unified and effective format.

4.1 Overview of the MC-CBA methodology

The MC-CBA devised in [3] includes the following steps:

1. The assets newly introduced in the three project demos or those already existing which are essential for the project are identified.
2. The assets identified in 1 are mapped into corresponding Smart Grid functionalities, based on the objectives set for each demo Use Case (UC).
3. Functionalities and KPIs of each UC are mapped into benefits (both monetary and non-monetary) from an economic, social, and environmental viewpoint.
4. For each KPI, the Business as Usual (BaU) condition is established so to have a baseline against which comparisons may be performed after a given new asset is introduced.
5. The costs of the assets are identified and quantified, including both CapEx (i.e., initial investments costs related to the purchase and installation of the new assets) and OpEx (i.e., their costs for operation, maintenance, etc.).
6. Formulas for the benefits expected after the assets implementation are determined under a monetary viewpoint.
7. The BaU condition is compared with each of the project alternative scenarios foreseen after the assets' full deployment to evaluate the project cost-effectiveness, by accounting for both monetary and non-monetary (e.g., societal) impacts.

The application of the CBA methodology to all the Platone demos is extensively described in [3], which the reader is referred to for further details.

4.2 Description of the Smart Grid Evaluation toolkit

The elaboration of the data collected from each demo (needed as input for the MC-CBA) as well as the presentation of the MC-CBA results are performed by using the Smart Grid Evaluation toolkit developed by ISGAN in [45] to assess the impact of a smart grid project considering economic and non-economic factors.

In a nutshell, the ISGAN toolkit assists in the identification of the "best" alternative among a set of smart grid development options (under different but not mutually exclusive viewpoints) by means of an automated comparison procedure which prevents subjective biases while retaining stakeholder-oriented interests.

More in detail, the ISGAN toolkit performs a decomposition of the decision-making problem by dividing the impacts of a given smart grid alternative in three main areas: (i) economic impacts, (ii) contribution towards the smart grid realisation, and (iii) externality impacts. Figure 35 depicts the generic hierarchical structure assumed for the decision-making problem.

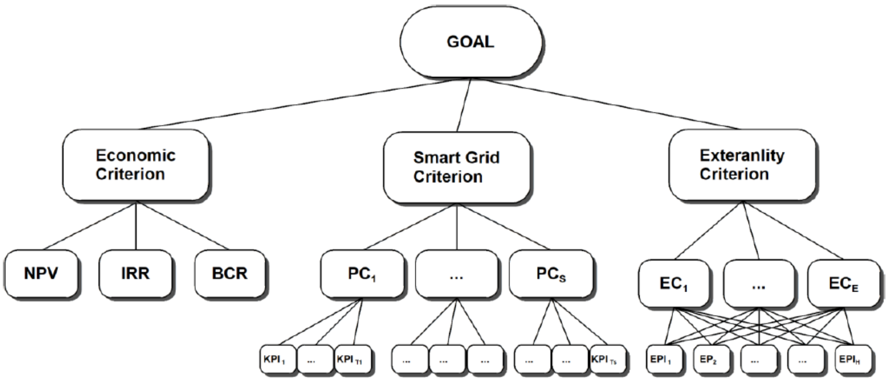

Figure 35: General tree of the structure of the decision-making problem according to [45].

In particular, the decision-making problem is divided in three independent branches:

- the *economic* criterion focuses on the economic assessment and evaluates each alternative in terms of monetary impacts; three criteria can be considered for the second hierarchy level, namely the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Cost-Benefit Ration (CBR). All the three criteria are aimed to be maximized: the higher their values, the bigger the economic impact of the alternative.
- the *smart grid deployment merit evaluation* criterion focuses on the impact that each alternative provides towards the smart grid realization. A set of independent Policy Criteria (PCs) are defined by the JRC to provide common assessment guidelines for smart grid project, and form the second hierarchy level; the fulfilment of each of them is appraised by resorting to outcome-oriented Key Performance Indicators (KPIs), which form the third hierarchy level. The list of PCs and related KPIs defined by the JRC is reported in Table 15. Each KPI is independent from each other.
- The *externality impact assessment* criterion concerns the evaluation of the project alternatives considering externalities, which are divided into thematic areas (e.g., social area), each of them measured via terminal criteria (e.g., consumer satisfaction). Unlike the PCs of the smart grid branch, the externality criteria are allowed to be dependent, i.e., an impact related to a given thematic area can influence also other areas, as shown in Figure 35.

Table 15: Policy criteria (left) and related KPIs (right) as defined by the JRC.

Policy criterion	KPI
Level of sustainability	- Reduction of greenhouse gas emissions (GHG) - Environmental impact of electricity grid infrastructure
Capacity of transmission and distribution grids	- Installed capacity of distributed energy resources in distribution networks - Allowable maximum injection of power without congestion risks in transmission networks - Energy not withdrawn from renewable sources due to congestion or security risks
Network connectivity	- Methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both - Operational flexibility provided for dynamic balancing of electricity in the network
Security and quality of supply	- Ratio of reliably available generation capacity and peak demand

	- Share of electricity generated from renewable sources - Stability of the electricity system - Duration and frequency of interruptions per customer, including climate related disruptions - Voltage quality performance
Efficiency and service quality	- Level of losses in transmission and in distribution networks - Ratio between minimum and maximum electricity demand within a defined time period - Demand side participation in electricity markets and in energy efficiency measures - Percentage utilisation (i.e. average loading) of electricity network components - Availability of network components (related to planned and unplanned maintenance) and its impact on network performances - Actual availability of network capacity with respect to its standard value
Contribution to cross-border electricity markets	- Ratio between interconnection capacity of a Member State and its electricity demand - Exploitation of interconnection capacities - Congestion rents across interconnections

Once a set of alternatives is available, they are evaluated taking into consideration any of the three branches of Figure 35. This is performed via the Analytic Hierarchy Process (AHP), which is a multi-attribute decision-making technique able to handle simultaneously quantitative and qualitative data, using a standardized judgement scale [46].

The ISGAN toolkit is implemented in a web application (https://smartgrideval.unica.it), which can be accessed after requesting user-specific credentials.

The data needed as input for the toolkit are:

1. The hierarchical structure of the decision-making problem;
2. The qualitative/quantitative performance values of the alternatives in terms of terminal criteria of the hierarchy (e.g., NPV for the economic branch or KPIs values of the PCs);
3. The preference information (in terms of weights) regarding the relevance of each of the three evaluation criteria;

whereas the data produced as output depend on the algorithm chosen to solve the decision making problem. For example, if the “Subjective weights” method is chosen, the toolkit produces:

4. The overall merit score of each alternative;
5. The partial merit score of each alternative.

4.2.1 Example of MC-CBA using the Smart Grid Evaluation toolkit

The Smart Grid Evaluation toolkit is employed in this section to exemplify the application of the MC-CBA methodology to the distribution grid planning UC presented in [46], to which the reader is referred for more details.

Five planning alternatives consisting in different grid reinforcement plans are considered (A1 to A5) for the analysis.

The hierarchical structure of the decision-making problem (Input-1) yields the tree in Figure 36: only the NPV is adopted as economic branch criterion and no externality branch is considered.

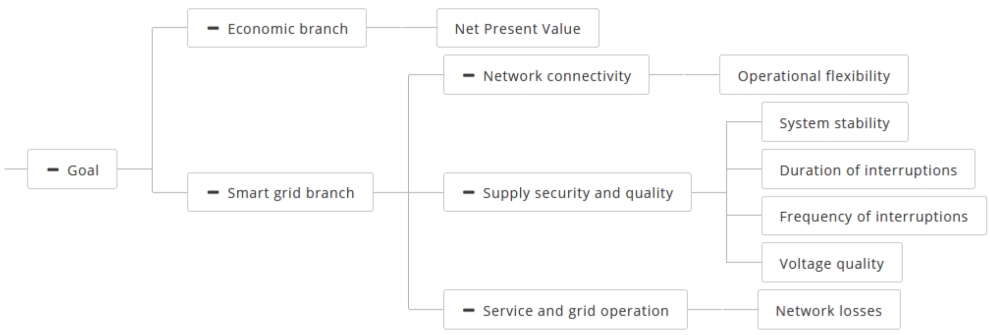

Figure 36: Tree structure of the decision-making problem of the sample UC.

The quantitative performance of the alternatives (Input-2) is reported in Table 16.

Table 16: Performance for the terminal criteria (quantitative values).

Alternative	Economic branch	Smart Grid branch					
	NPV [EUR*1000]	Operational flexibility [MW]	System stability [MW]	Frequency of interruptions [number/year]	Duration of interruptions [hour/year]	Voltage quality [p.u.]	Network Losses [MWh]
A1 (BaU)	0	0	0	2.026	0.837	11.48	11216.1
A2	4.257	66.2	1269.2	2.017	0.751	10.68	10677.7
A3	3.371	184.2	2903.9	2.017	0.751	10.68	10701.3
A4	12.905	48.4	984.6	2.017	0.751	10.68	10661.3
A5	88.587	38.2	574.1	2.017	0.751	10.69	10682.4

The weights of each of the considered evaluation criteria (Input-3) are set to 0.5 for the Economic branch and the Smart Grid branch.

By running the web application with the “Subjective weights” method, the following outputs are produced.

The overall merit score of each alternative (Output-4) is reported in Figure 37.

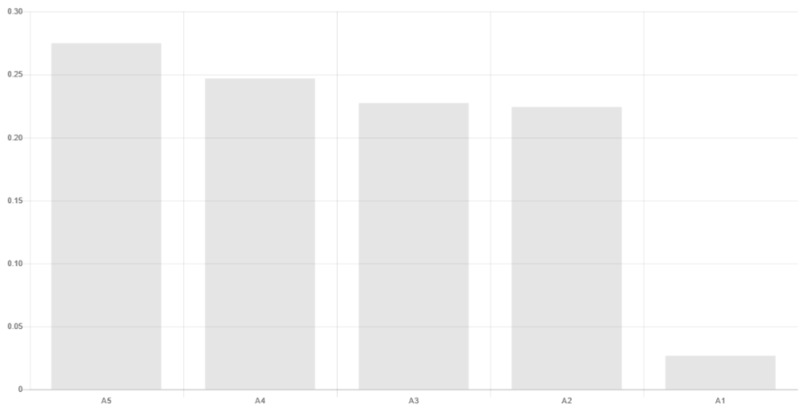

Figure 37: Overall ranking merit score for the five alternatives

The partial merit scores (Output-5) for the economic branch and the smart grid branch are reported in Figure 38 and Figure 39, respectively.

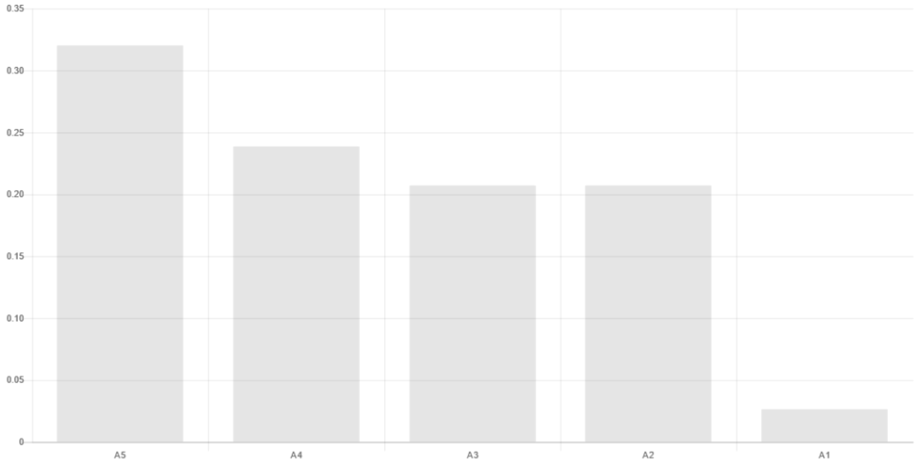

Figure 38: Partial merit score for the Economic branch

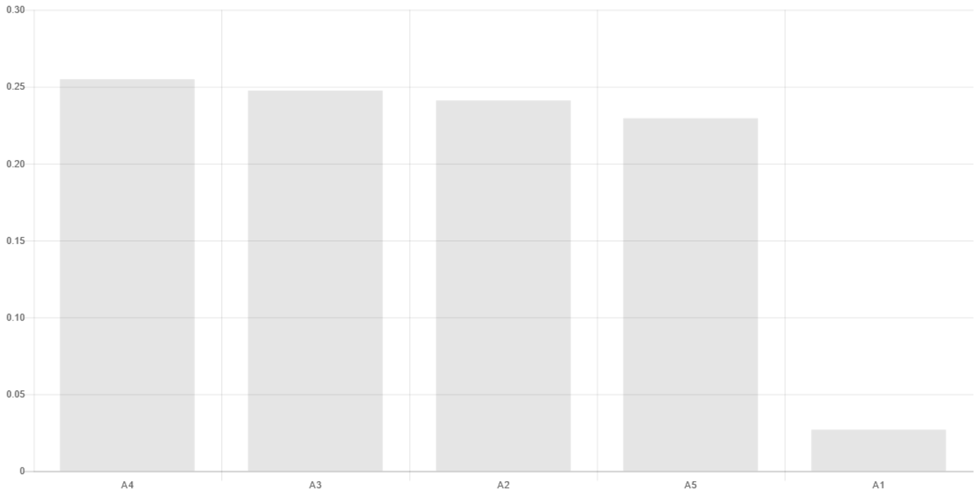

Figure 39: Partial merit score for the Smart Grid branch

The results show that the alternative achieving the highest overall score is A5, which is then the best option according to the MC-CBA assessment made in this UC. The worst alternative is the Baseline option, A1. If the partial scores are looked at, A5 performs the best under the economic branch, whereas A4 has the best partial score by considering the Smart Grid branch.

5 Multi Criteria Cost Benefit Analysis of the demo use cases

In this section, the results of the application of the MC-CBA methodology to each of the three demos is described. Section 5.1, Section 5.2 and Section 5.3 report the CBA application, public results and conclusions for the Italian, Greek and German demos, respectively.

It is noteworthy that the terminal criteria (KPIs) for the Smart Grid branch have not been chosen among those suggested by the JRC and reported in Table 15. Instead, the KPIs selected for performing the CBA of different alternatives of each of the three demos are selected among those identified in D7.3. For this reason, in the ISGAN toolkit, custom criteria have been manually created by using the "Manage custom" palette of the web application. In other words, project- and demo-specific KPIs are employed for the CBA (not resorting to those preliminary defined by the JRC), and the ISGAN toolkit is used only to create the branch tree, to perform the automatized AHP technique in order to compare each of the alternatives of interest under a multi-criteria framework, and to produce the results in a uniform format across demos.

During the fourth and final year of the project, each demo leader has been asked to fill out a dedicated excel sheet specifically created for collecting the performance values of the needed input data. For privacy concerns, the performance values of all the considered terminal criteria and the quantitative scores of the considered alternatives are reported in the confidential deliverable D7.4.

5.1 Italian demo

The objective of the Italian Demo is to develop and test a complete system supporting TSOs and DSOs to use the DERs flexibility in the management of the grid.

The Italian demo have executed two main use cases in the target project areas regarding "Voltage management in transmission and distribution systems" (UC-IT-1) and "Congestion management in transmission and distribution systems" (UC-IT-2), both of which are briefly recalled hereafter.

UC-IT-1: Voltage Management

This use case describes the main steps to avoid voltage violations in transmission and distribution systems by exploiting flexibility resources, focusing on the phase of procurement and forecasting in the day-ahead and real time flexibility market. The DSO can use flexible resources connected to the distribution system and the TSO can use flexible resources connected to distribution systems under the DSO's approval. The state estimation is assessed and monitored by the DSO to keep the electrical quantities within admissible ranges.

UC-IT-2: Congestion Management:

This use case describes the steps to prevent congestion issues in transmission and distribution systems, by using flexible resources, contemplating all the phases concerned (procurement, activation, and settlement) in the day-ahead and real time flexibility market. The DSO can use flexible resources connected to the distribution system and the TSO can use flexible resources connected to distribution systems under the DSO's approval. The state of the grid is assessed and monitored respectively by the DSO to keep the electrical quantities of the system within admissible ranges.

In detail, the demo makes available to Service Operators (SOs) the flexibility services Voltage Management and Congestion Management offered by DERs, by means of market processes that consider also technical constrains of the grids. This will guarantee that activation of the flexibility services will not generate issues in any grid.

Technology Adopted:

For the implementation of the above mentioned Use Cases a multi-platform system architecture was adopted, enabling SOs the possibility to cater flexibility services from local DERs. The technologies involved were:

- A market platform for the matching of Flexibility requests and Flexibility offers, based on an open-source technology and consistent with the requirements and functionalities defined and developed in WP2;

- A DSO platform for the elaboration of Flexibility requests, developed by the partner Siemens. This platform, integrated into the company's legacy systems, allows the forecasting of loads and productions on the distribution grids in line with the day ahead and real time market timeframes defined in the project;
- An aggregator platform, developed by Siemens, for the processing of Flexibility offers. This platform is also integrated with smartphone applications to facilitate the communication and involvement of end customers in the experimentation;
- A shared customer database to facilitate the storage of data and the necessary measures for the Flexibility market;
- A device to enable end customers to the market, allowing them to receive activation signals, as well as to take measurements in real time from the meters for the evaluation of the services provided.

Boundary Conditions:

- A shared market between DSO and TSO is assumed for the demand for Flexibility services;
- A short-term market with day ahead session and six real time sessions has been implemented;
- A liquid market is assumed open to all the utilities connected in medium and especially low voltage;
- Smart meters are required at the point of delivery;
- Offers are defined for Point of Delivery (PoD) to respect the dynamics of the Distribution grid and the location of resources;
- A market giving priority to local demand is envisaged;
- A dynamic verification of the technical limits of the distribution grid has been hypothesized to avoid that the movements violate the network constraints.

Time horizon for the rollout of the smart grid alternatives:

The solution implemented in the Italian demo has reached a high level of maturity, therefore it has been used for the national experimentation promoted by the Italian authority to test the local ancillary services. It is assumed that at the end of the three-year trial, the solution could be ready for the production environment.

5.1.1 CBA application

Three different scenarios (or alternatives) are considered in the CBA of the Italian demo:

Table 17: Set of scenarios considered for the CBA of the Italian demo

Alternative name	Alternative description
Fully reinforcement	The increase of the loads is faced only with the grid reinforcement
Only flexibility	The increase of the loads is faced only with the flexibility
Reinforcement + flexibility	The increase of the loads is faced with a mix solution of grid reinforcement and flexibility

The branch tree of the decision-making problem of the Italian demo is reported in Figure 40. The economic branch is composed of only one terminal criterion (Cost Benefit Ratio, CBR). The smart grid branch contains three independent terminal criteria. No externality branch is present.

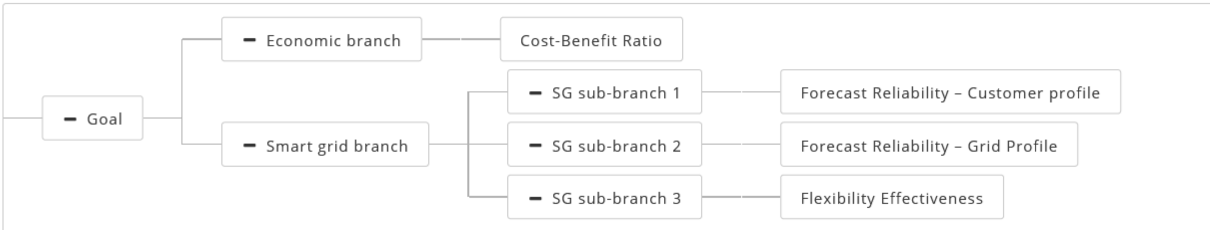

Figure 40: Branch tree of the decision-making problem of Italian demo

The formulas and definitions of the terminal criteria of the branch tree of Figure 40 are reported in Table 18 and Table 19.

Table 18: KPI for the economic branch for the Italian demo

Economic branch	
Economic KPI	**Formula**
CBR	$\sum_{t=1}^{T} \frac{Costs_t}{Benefits_t}$ With $T = 10$ is the number of time periods (the considered time horizon is from 2023 to 2032).

Cost Benefit Ratio is the ratio of costs to benefits (either on a present value basis or on an annual basis). The smaller the ratio, the more cost-effective the project (or the smart grid solution) is.

Table 19: KPIs for the Smart Grid branch for the Italian demo.

Smart Grid branch		
Smart Grid KPI	**ID**	**Formula**
Forecast Reliability – Customer profile	KPI-IT-02	$\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\frac{\lvert RL\_profile_{i,t} - FC\_profile_{i,t}\rvert}{\lvert RL\_profile_{i,t}\rvert} \cdot 100$
Forecast Reliability – Grid Profile	KPI-IT-03	$\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N_t}\sum_{i=1}^{N_t}\frac{\lvert RL\_Power\_Flow_{i,t} - FC\_Power\_Flow_{i,t}\rvert}{\lvert RL\_Power\_Flow_{i,t}\rvert} \cdot 100$
Flexibility Effectiveness	KPI-PR-04	$\frac{1}{T}\sum_{t=1}^{T}\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert Quantity\_provided_{i,t}\rvert}{\lvert Setpoint_{i,t}\rvert} \cdot 100$

KPI-IT-02 – Forecast Reliability – Customer profile: evaluates the reliability of the tool performing forecasting of power flow exchanged by each resource with the grid. This KPI is calculated for a given forecasted time range (the next 24 hours or the next 4 hours). In particular,

- $RL\_profile_{i,t}$ is the real profile (kW or kVAr) of the i-th customer in the period t;
- $FC\_profile_{i,t}$ is the forecasted profile (kW or kVAr) of the i-th customer in the period t;
- N_t is the number of customers in the period t
- T is the examined period.

KPI-IT-03 – Forecast Reliability – Grid Profile: evaluates the reliability of the tool performing forecasting of power flow in significant assets of the grid. This KPI is calculated for a given forecasted time range (the next 24 hours or the next 4 hours). In particular,

- $RL\_Power\_Flow_{i,t}$ is the real power flow (kW or kVAr) of the i-th asset in the period t;
- $FC\_Power\_Flow_{i,t}$ is the power flow forecasted (kW or kVAr) of the i-th asset in the period t;
- N_t is the number of assets of the same category (e.g., primary substation nodes, secondary substation nodes, etc.) in the period t
- T is the examined period.

KPI-PR-04 – Flexibility Effectiveness: measures the effectiveness of flexibility provision, i.e., the sum of successfully provided flexibility in relation to the requested demand for flexibility. In particular,

- $Quantity\_provided_{i,t}$ is the amount of quantity (kW, KVar, etc.) exchanged with the grid by the i-th flexible resource in the period t;
- $Setpoint_{i,t}$ is the amount of quantity (kW, KVar, etc.) of the i-th request of flexibility in the period t;
- N is the set of flexible resources;
- T is the examined period.

5.1.2 Main findings

The peak loads are achieved for a low number of hours in a specific period of the year, especially during the summer season due to the air conditioning systems and in the winter for the space heating. Moreover, the high energy consumptions are concentrated in a continuous and limited slot of the day, so it is possible to involve the Distribution Energy Resources (DERs) located in the area of the congestion to solve the congestions. Only in the case of significant congestions (e.g., longer the 1000 hours), the grid reinforcement envisaged by the "Fully Reinforcement" scenario is the most desirable solution.

Regarding the "*Only Flexibility*" scenario and "*Fully Reinforcement*" scenario, the latter has proven to be the least cost-effective, although the result is strictly connected to the flexibility cost employed in the work. In particular, this value comes from the experience of an Italian project, promoted by the National Regulatory Agency to involve the DERs into global ancillary market. Next years, several initiatives to test the local flexibility market will be implemented, and the outcomes will be updated allowing for a more refined analysis.

The experimental area represents a significant portion of a metropolitan urban grid of Rome, however the number of involved customers is a small set. Therefore, to be able to better identify the contribution that the distributed resources could offer in the resolution of network critical issues, it is necessary to expand the group of users divided by size and flexibility asset adopted.

The replicability of the solution in a rural environment with high presence of distributed generation is believed to ensure consistent results with what has been identified in the Italian trial.

5.1.3 Conclusions and recommendations

The main findings of the Italian trial are summarised below:

- The Italian demo experience shows that the common DSO-TSO market for ancillary services is suitable for liquid markets with high participation of distributed resources. Such solution facilitates the coordination between system operators and optimises data handling. Furthermore, in order to avoid violations of distribution network constraints, the implementation of a dynamic traffic light following the economic selection of offers is essential;
- The dynamism of distribution networks, subject to constant reconfiguration, and the specificity of local flexibility requirements favour a granularity per PoD (Point of Delivery) of the offers;

- The opening up the market to small users requires standardisation and simplification of the necessary equipment, avoiding possible lock-in phenomena. In this respect, the Light Node enables client involvement in the market by tracking activations and movements. It also increases transparency and trust in the market by using blockchain technology for the certification of measurements;
- The sharing and centralisation of flexibility data is a prerequisite for implementing flexibility processes and ensuring unambiguous information.

5.2 Greek demo

5.2.1 MC-CBA-oriented demo overview

The MC-CBA was implemented for the *UC-GR-3: Distribution network limit violation mitigation of the Greek demo*. The main scope was to assess the total financial and non-financial benefits of the deployed DER algorithm, which allows a dynamic network charging scheme (variable Distribution Use of System (DUoS) charges) and is communicated in a day-ahead context. The state of the network is known with a good degree of certainty based on the state vector that the State Estimation tool produces starting from the available measurements and the topology data from the AMR, GIS, SCADA and PMUs. The DER algorithm runs for three different alternatives and the MC-CBA is used to rank their efficiency, regarding the financial benefit which is achieved through mitigation of network limit violation actions, such as demand and generation curtailment.

The conditions and assumptions of the *UC-GR-3* are the following:

- Customers' consent is required for participation in the flexibility mechanism, so it is assumed that the customers are rational and part of the load is flexible. Moreover, it is assumed that there is a good degree of certainty in the estimation of the network state.
- For the implementation of the Use Case, the technical conditions that need to be fulfilled are the installation of smart metering, the existence of smart appliances for load shifting and the normal operation of DSO systems (e.g., AMR, GIS, SCADA) during the preparation and demonstration period.
- On the regulatory aspect of this Use Case, it is required that a dynamic network charging scheme is allowed.

5.2.2 MC-CBA application

Three different alternatives (or scenarios) are considered in the CBA of the Greek demo:

Table 20: Set of scenarios considered for the CBA of the Greek demo.

Alternative ID	Alternative name	Alternative description
A1	Flat Network Tariff	DUoS charges are fixed for every hour of the day and every network node.
A2	Hourly Network Tariff	DUoS charges can vary by hour but are fixed for every node in the network.
A3	Hourly-Loc Network Tariff	This constitutes the case with the highest spatial-temporal granularity. In this case, the tariffs can vary by both hour and network node.

The branch tree of the decision-making problem of the Greek demo is reported in Figure 41. The economic branch is composed of only one terminal criterion (Internal Rate of Return, IRR). The smart grid branch contains three independent terminal criteria. An externality branch is present, which includes only one terminal criterion (CO_2 emission reduction).

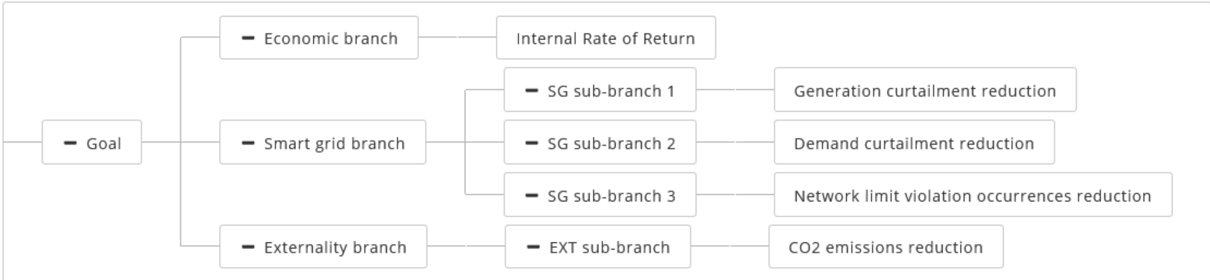

Figure 41: Branch tree of the decision-making problem of Greek demo.

The formulas and definitions of the terminal criteria of the branch tree of Figure 41 are reported in Table 21, Table 22 and Table 23.

Table 21: KPI for the economic branch

Economic branch	
Economic KPI	**Formula**
IRR	$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0$

Internal Rate of Return is the discount rate at which a stream of costs and benefits has a zero value for the Net Present Value (NPV), where:

- C_t is the net cash inflow during the period t; (15 years for the Greek demo case)
- C_0 are the total initial investment costs;
- IRR is the internal rate of return;
- t is the number of time periods.

Table 22: KPIs for the smart grid branch.

Smart Grid branch		
Smart Grid KPI	**ID**	**Formula**
Generation curtailment reduction	KPI_GR_07	$\Delta C_{RES} = \frac{\sum_{t\in T}\sum_{i\in I} E^{BaU}_{g_{i,t}} - \sum_{t\in T}\sum_{i\in I} E^{R\&I}_{g_{i,t}}}{\sum_{t\in T}\sum_{i\in I} E^{BaU}_{g_{i,t}}} \cdot 100$
Demand curtailment reduction	KPI_GR_08	$\Delta C_{DEMAND} = \frac{\sum_{t\in T}\sum_{i\in I} E^{BaU}_{d_{i,t}} - \sum_{t\in T}\sum_{i\in I} E^{R\&I}_{d_{i,t}}}{\sum_{t\in T}\sum_{i\in I} E^{BaU}_{d_{i,t}}} \cdot 100$
Network limit violation occurrences reduction	KPI_GR_11	$NV = \frac{N^{BaU}_{total\ violations} - N^{R\&I}_{total\ violations}}{N^{BaU}_{total\ violations}} \cdot 100$

KPI_GR_07 - Generation curtailment reduction: compares the amount of energy from Renewable Energy Sources (RES) that is not injected to the grid (even though it is available) due to operational limits of the grid, among the Variable Network Tariff scenarios (R&I) and the BaU scenario. In particular,

- $E_{g_{i,t}}^{BaU}$ (kWh) is the energy curtailment of the i-th RES facility at period t in the BaU (i.e., Flat Network Tariff) scenario;
- $E_{g_{i,t}}^{R\&I}$ (kWh) is the energy curtailment of the i-th RES facility at period t in the Variable Network tariff scenarios, i.e., Hourly and Hourly-Loc Network Tariff scenarios;
- I is the set of RES facilities under consideration;
- T is the set of time intervals of the period under consideration (excluding periods of scheduled maintenance and outages).

KPI_GR_08 - Demand curtailment reduction: compares the amount of energy consumption that needs to be curtailed due to operational limits of the grid, among the Variable Network Tariff scenarios (R&I) and the BaU scenario. In particular,

- $E_{d_{i,t}}^{BaU}$ (kWh) is the demand curtailment of the i-th flexible customer facility at period t in the BaU (i.e., Flat Network Tariff) scenario;
- $E_{d_{i,t}}^{R\&I}$ (kWh) is the demand curtailment of the i-th flexible customer facility at period t in the Variable Network tariff scenarios, i.e., Hourly and Hourly-Loc Network Tariff scenarios;
- I is the set of flexible customers under consideration;
- T is the set of time intervals of the period under consideration.

KPI_GR_11 - Network limit violation occurrences reduction: evaluates the difference between the number of network limit violation occurrences under a 24-hour time frame in the Variable Network Tariff scenarios (R&I) and the equivalent one in the BaU scenario. In particular,

- $N_{total\ violations}^{BaU} = N_{RES}^{BaU} \cup N_{DEMAND}^{BaU}$ is the total number of network limit violation occurrences in the BaU scenario;
- $N_{total\ violations}^{R\&I} = N_{RES}^{R\&I} \cup N_{DEMAND}^{R\&I}$ is the total number of network limit violation occurrences in the variable network tariff scenarios.
- N_{RES} is the number of occurrences of RES generation curtailment;
- N_{DEMAND} is the number of occurrences of demand curtailment.

Table 23: KPI for the externality branch.

Externality branch	
Externality KPI	**Formula**
CO_2 emissions reduction (tons)	$(\Delta C_{RES} + \Delta C_{DEMAND} \cdot p^{CO_2-DEM}) \cdot M^{CO_2}$

where:

- p^{CO_2-DEM} is the percentage of demand not postponed due to curtailment (%)
- M^{CO_2} (tons) is the monetization parameter of CO_2, which defines how much CO_2 is emitted per MWh of energy on average by an electric system (in this case Greece). This parameter allows to calculate how much CO_2 emissions are reduced due to the reduction in RES curtailment achieved in the UC-GR-3.

5.2.3 Main findings

The MC-CBA assessment for the Greek demo demonstrated that the alternative achieving the highest overall score is the "*Hourly-Loc Network tariff*" scenario. Therefore, this scenario represents the preferred option according to the MC-CBA assessment made offering the highest reduction of network limit violations to the DSO.

The "*Hourly Network tariff*" scenario ranked second because the DUoS employed in this scenario take into account only temporal granularity in the network, whereas the "*Hourly-Loc Network tariff*" scenario combines temporal as well as spatial granularity. As expected, even with no spatial granularity of the DUoS charges, the network limit violation actions such as demand and generation curtailment, are still reduced, but to a lesser extent compared to the "*Hourly-Loc Network tariff*" scenario.

The lowest-ranked alternative is the "*Flat Network Tariff*" scenario, which represents the Business-as-Usual (BaU) scenario, where the DUoS charge does not vary at all throughout the day or between nodes, hence there is no trigger for flexibility provision to the grid. In this scenario, the DSO effectively does not have opportunities to handle congestions via flexibility, hence network violations occurrences as well as generation and demand curtailment are not reduced at all.

It is worth mentioning that the alternative employing an Hourly-Loc Network tariff policy achieved an IRR of 14%. This percentage is very attractive for the Greek DSO (HEDNO), because it represents a great value regarding the economic returns of the investment plan.

5.2.4 Conclusions and recommendations

The MC-CBA was employed for the Greek demo based on *UC-GR-3: Network limit violation mitigation* and showcased the financial and non-financial benefits that the two advanced tools (namely the State Estimation tool and the algorithm for optimised DER control) provided for the representative network of the Greek demo in the suburban area of Mesogeia, such as the significant increase in network observability and the considerable reduction in network violations' occurrences.

However, the solution that the Greek demonstrator illustrated with the deployment of the two advanced tools could be tested in a completely different network. In particular, the MC-CBA assessment could be replicated intra-nationally by examining the efficiency of the two advanced tools with different technical boundary conditions and features, such as a grid topology with bigger number of nodes with higher penetration of RES. Also, the outcomes of the MC-CBA assessment would be of great interest if the solution was validated in other type of settings (rural and urban areas) or other regions in Greece (e.g. islands), or even outside the national territory of Greece, where regulation schemes and incentives, as well as other financial strategies might differ.

5.3 German demo

5.3.1 MC-CBA-oriented demo overview

The objective of the German Demo is to develop, implement and test a complete energy management system supporting system operators to implement a balancing scheme in lower voltage levels of the distribution grid.

The German demo has executed four main UCs in a field test trial that host a low voltage (LV) community. The objective of the German demonstrator is:

- to demonstrate a local balancing mechanism implemented in coordination with centralized grid operation and DSO-owned flexibility mechanism;
- to develop allocation strategies for flexibility in local networks for maximum benefit to DSO and customers;
- to demonstrate the effective informational and temporary uncoupling of low and medium voltage networks by handling energy supply and export in bulk packages rather than a real time exchange;
- to maintain the safe operation of the distribution network by utilizing the flexibility of Distributed Energy Resources (DERs) to alleviate line limit violations in a cost optimal and practical manner.

The achievement of the afore-mentioned objectives has been addressed in the following UCs.

UC-DE-01 – "Virtual Islanding"

UC 1 aims to enable citizens located in a LV grid section to practice collective self-consumption by using available flexibility from battery storages. The collective self-consumption requires the synchronization of generation from local PV with available battery charging by the ALF-C. The trial is implemented in a local LV grid section located in a rural region that is representative for future citizen energy communities and renewable energy communities, consisting of private agricultural buildings, customer households with privately owned flexible loads, storages, and PV generators. UC1 targets the investigation of different approaches of a local balancing scheme to synchronize generation and consumption and simulate the behaviour of energy communities that practice collective self-consumption. Specifically, the net power and energy exchange at the grid connection point (MV-feeder) shall be examined and minimized during the UC1 application.

UC-DE-02 – "Coordination of Flexibility Activation"

Avacon aims at implementing a balancing scheme that enables local LV grids or energy communities to provide a constant set value of power at the MV/LV grid connection point upon an accepted request from a DSO, a TSO, or a market participant. The balancing schemes apply algorithms, developed by the project partner RWTH Aachen University, that use the battery storages in the grid and try to compensate power fluctuations of the community. Moreover, UC 2 includes a coordination scheme of central and decentral organized flexibilities, based on a prioritization mechanism for relevant market participants, e.g., TSO, DSO, aggregator and other. The prioritization mechanism respects the ranking of requesting market participant, requested power value, requested duration and time of submission.

UC-DE-03 – "Supplying Energy to the LV grid in bulk in advance"

The target of UC 3 is to uncouple the load and energy demand of the LV community from its feeding MV-line by employing a package-based approach for energy supply. The UC shall be applied in a demand driven scenario in a LV community, in which the residual energy demand in a given period of time is higher than the local generation. The residual demand of a LV community (considering the total local generation and consumption of the community) shall be forecasted and supplied to the community (imported from the MV grid) in advance of high times of power demand by charging local storages. The community later can withdraw energy from the storage as requested without creating additional peak loads on the MV feeder.

UC-DE-04 – "Energy Export from the LV grid in bulk ex-post"

The opposite principle described in UC 3 applies to UC 4. UC 4 shall be applied to a LV community, in a generation driven scenario, in which the residual surplus of generation in a given period of time, e.g., 24 hours, exceeds the local demand. In this scenario the generated surplus shall be stored in battery located in the LV community, to be delivered to the MV-feeder at non-critical times. The concept on a larger scale foresees a reduction of peak load and avoidance of critical situations in the MV level caused by high demand in LV levels.

5.3.2 MC-CBA application

Two different scenarios (or alternatives) are considered in the CBA of the German demo for two different distribution grids, Twistringen and Abbenhausen.

Table 24: Set of scenarios considered for the CBA of the German demo.

Alternative name	Alternative description
Fully reinforcement	This scenario considers conventional grid reinforcement as only solution to provide required transmission capacity for the expected increase of generation or load capacities. Fully reinforcement includes grid expansion, building new line and transformers or reinforcement, as replacing lines with larger cable cross sections or laying of two-core cable.
Only flexibility	In this scenario the grid will not be reinforced. Possible grid congestion or bottlenecks will be avoided by flexibility utilization (control of batteries). The implementation requires a grid monitoring and incident detection system to determine the required demand for flexibility control.

Each of the two scenarios are investigated under the CBA perspective for the Twistringen and Abbenhausen distribution networks.

The Abbenhausen distribution network is a LV grid operated with 230/400V voltage. It reflects technical characteristics of regional, renewable generation driven LV networks that in majority host single-family houses with rooftop photovoltaic system and with agricultural buildings, almost no industry or multi-family houses. The network model consists of one point of common coupling (PCC), which is the connection point between medium voltage (MV) and LV. The network hosts about 65 houses with 85 households, 445 kWp of installed generation capacity from rooftop PV system and about 900 kWh of storage capacity.

The Twistringen distribution network is a MV grid operated with a voltage of 20 kV. It is located in a renewable-driven, rural area with a small village (Twistringen) and several small villages, which is a part of the municipality of Twistringen. The MV grid hosts about 140 secondary substations (MV/LV grid connection points), 90.9 MW installed renewable generation capacity from PV and Wind.

The branch tree of the decision-making problem of the German demo is reported in Figure 42. The economic branch is composed of only one terminal criterion (Cost Benefit Ratio, CBR). The smart grid branch contains two independent terminal criteria. No externality branch is present.

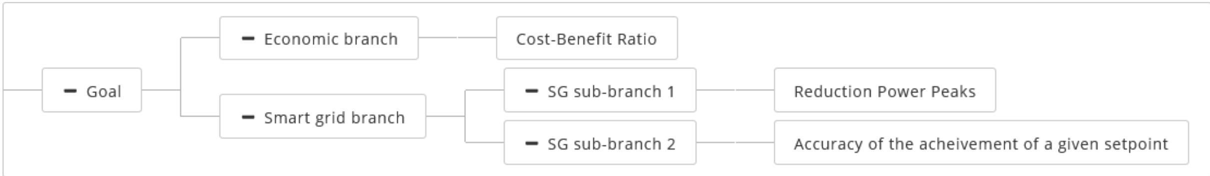

Figure 42: Branch tree of the decision-making problem of German demo.

The formulas and definitions of the terminal criteria of the branch tree of Figure 42 are reported in Table 25 and Table 26**.**

Table 25: KPI for the economic branch for the DE demo

Economic branch	
Economic KPI	**Formula**
CBR	$\sum_{t=1}^{T} \frac{Costs_t}{Benefits_t}$ With $T = 10$ is the number of time periods (the considered time horizon is from 2023 to 2032).

Cost Benefit Ratio is the ratio of costs to benefits (either on a present value basis or on an annual basis). The smaller the ratio, the more cost-effective the project (or the smart grid solution).

Table 26: KPIs for the Smart Grid branch for the German demo.

Smart Grid branch		
Smart Grid KPI	**ID**	**Formula**
Reduction of power recuperation peaks	KPI_DE_2	$\frac{\lvert P\rvert_{C,PCC}(T) - \lvert P\rvert_{M,PCC}(T)}{\lvert P\rvert_{C,PCC}(dt)} \cdot 100$

Accuracy of the achievement of a given set-point	KPI_DE_6	$\left\|\bar{P}_{M,PCC} - P'_{PCC}\right\|$

KPI_DE_2 - Reduction of power recuperation peaks: evaluates the ability to reduce power peaks of the power exchanged between an LV energy community and the MV network at the PCC within a defined period of time dt. In particular, during the application of UC-DE-1 the reduction of power exchange peaks at PCC the MV/LV grid connection point is targeted. A coordinated control of a local BESS household energy storages and flexible loads enables the avoidance of power peak at the PCC.

- $|P|_{M,PCC}$: Active Power Measured at the PCC. The data is measured in kilowatt (kW) on the LV busbar of the MV/LV feeder. The value indicates the net load demand of the LV community (Abbenhausen) considering its total local generation and consumption. Positive values indicate a load flow from the MV grid into the LV grid (to meet the LV grid local consumption) and negative values indicate export power flows.
- $|P|_{C,PCC}$**:** Computed Active Power Exchange at the PCC. It is the computed data in kilowatt (kW) indicating the net load demand of the LV community (Abbenhausen) considering its total local generation and consumption, that would have been measured, if no UC control would have been applied (baseline).

KPI_DE_6 - Accuracy of the achievement of a given setpoint: evaluates the accuracy of the ALF-C to balance consumption with generation to achieve a requested active power exchange at the PCC. In particular, during the application of a use case, this KPI evaluates the relation between the measured active power exchange ($\bar{P}_{M,PCC}$) and a requested power exchange (P'_{PCC}) at the PCC.

5.3.3 Main findings

The MC-CBA assessment for the German demo demonstrated that the alternative achieving the highest overall score is the "*Only flexibility*" scenario in both distribution grids. This scenario is the best option according to the MC-CBA assessment made considering the performance values of each of the two alternatives considering the economic and smart grid branches.

The "*Fully reinforcement*" scenario, although less cost-effective in the analysis, showcase a non-negligible level of importance when compared to the "*Only flexibility*" scenario. However, when interpreting the results, it must be taken into account that grid capacities gained by conventional grid expansion are permanently and reliably available. In the case of flexibility control, the results from the demonstration reports of the German demo have shown that peak generation cannot be ensured at all time by controlling flexibilities in LV grids with volatile PV feed-in, as controllability depends on the availability of the flexibility. In addition, poor forecasting and volatile feed-in can lead to an increase in power peaks, increasing the likelihood of damage to the grid or jeopardizing safe and reliable supply.

5.3.4 Conclusions and recommendations

The MC-CBA was employed for the German demo based on *UC-DE-1: Virtual Islanding, UC-DE-02: Coordination of Flexibility Activation, UC-DE-3: Supplying Energy to the LV grid in bulk in* and *UC-DE-4: Energy Export from the LV grid in Bulk ex-post.*

MC-CBA analysis displayed the financial and non-financial benefits that the energy management system (ALF-C) provided for the representative network of the German demo in the rural area of Twistringen (Abbenhausen), such as the reduction of power peaks and energy exchange with the medium voltage level along the grid connecting MV/LV transformer.

The solution that the German demonstrator has demonstrated with the deployment of the ALF-C could be tested in a completely different network. In particular, the MC-CBA assessment could be replicated in Germany at other DSOs or location of the distribution grid by examining the efficiency of the system with different technical boundary conditions and features, such as a grid topology with increased number of PV systems, flexible loads for control and increased number of nodes. Also, the outcomes of the MC-CBA assessment would be of great interest if the solution was validated even outside the national territory of Germany, where regulation schemes and incentives, as well as other financial strategies might differ.

Due to the benefits identified in the course of the project, the untapped technical potentials of flexibility control to integrate renewable energies into the distribution grid as well as open issues identified during the UC applications are potential areas of further research. In view of this, Avacon has committed to continue with the implemented demonstrator in Twistringen (Abbenhausen), and managed to successfully apply for national-funded follow-up project named “ENSURE” to continue the development of the ALF-C and put it into larger scale with additional actors and system.

6 Business models

In innovative project development, the journey from conceptualization to market implementation is a multifaceted process that demands careful consideration at each juncture. As projects like Platone navigated this path, it became evident that certain preparatory steps are crucial to ensuring the effectiveness and viability of subsequent phases. In particular, the importance of SRA, coupled with a comprehensive MCA-CBA, emerged as a pivotal foundation for the successful testing and refinement of business models.

The process of translating project outcomes, in particular the Key Exploitable Results (KERs), into tangible economic opportunities necessitates a deep understanding of how solutions can be effectively scaled and replicated across diverse contexts. Scalability analysis serves as a proactive examination of the potential to expand project results to larger scales, identifying potential challenges and opportunities. Similarly, replicability analysis delves into the feasibility of reproducing project successes in different geographical, regulatory, and market settings (in D7.5 [47] an analysis of the Platone UCs in the Canadian context has been provided). Both these analyses collectively provide valuable insights into the adaptability and applicability of project outcomes, acting as a crucial prerequisite for robust business model development.

Moreover, the integration of a comprehensive MC-CBA further enhances the foundation for effective business model testing. By quantifying the potential gains and losses associated with different implementation scenarios, this empirical approach offers a systematic framework for evaluating the economic viability of proposed solutions. Such an analysis allows project teams to make informed decisions, prioritizing initiatives with the greatest potential for positive impact and profitability.

The Platone project explored business model development and testing through an organized workshop at the sixth General Assembly on Brussels in October 2022. During this workshop, the consortium identified and selected the four most promising project solutions which were scrutinized using the business model canvas approach (for the outcomes, please refer to Annex A). This strategic activity aimed to investigate the finer details of business model development, ensuring alignment with market dynamics and requirements as well as testing the practical applicability. By employing the business model canvas framework, the project gained insights into crucial aspects such as value proposition, customer segments, revenue streams, and key partnerships. Additionally, the workshop shed light on the fact that some solutions required refinement and further development to facilitate a robust business model approach. This realization meant that not all details for all tested solutions could be finalized, and certain assumptions were necessary during the analysis. Consequently, the need for further investigation of KERs became evident, establishing a necessary precursor for the subsequent development of comprehensive business models.

The development of effective business models necessitates a comprehensive exploration of an exploitation strategy for the project's outcomes. This critical step ensures that the potential benefits and value derived from the project are strategically harnessed and translated into tangible economic opportunities. By thoroughly investigating an exploitation strategy, organizations can identify the most suitable pathways for integrating their innovations into the market or industry.

An exploitation strategy and story delve into how the project's KERs can be practically applied, commercialized, and scaled within a real-world context. This involves a thorough analysis of potential markets, target audiences, competitive landscapes, and regulatory considerations. By looking into these aspects, organizations can tailor their business models to align with market needs and trends, ensuring relevance and viability. Moreover, an in-depth exploration of exploitation strategies enables organizations to make informed decisions about intellectual property protection, partnerships, licensing, distribution channels, open-source methods, and community approaches. This strategic approach helped maximize the long-term value of the project's outcomes, fostering sustainable growth and innovation within the market. Details of this work can be seen in D8.10 [26]. In essence, the process of investigating an exploitation story and strategy, coupled with the practical insights gained through the business model canvas workshop, served as a pivotal bridge between innovation and market success. It transforms conceptual ideas and research findings into concrete avenues for generating revenue, gaining market share, and driving societal impact. As a result, a thorough exploitation strategy not only enhances the prospects of successful business models but also ensures that the transformative potential of a project's outcomes is fully realized in the broader economy and society.

7 Conclusion

Conducting SRA, alongside MC-CBA, prior to testing business models, ensures a holistic understanding of the project's real-world feasibility and market readiness. This knowledge arms project teams with invaluable insights, enabling them to fine-tune and optimize their business models for maximum effectiveness and sustainability. As such, these preparatory analyses act as a strategic compass, guiding the trajectory of project development and laying the groundwork for successful market integration.

Regarding SRA, both classes of SRA-UCs (i.e., the “desired power exchange” and “zero power exchange”) can be implemented in most of the considered scenarios for scalability in density and replicability intra- and inter-national. In the case of urban networks, the amount of local flexibility sources are sufficient to compensate most of the congestions caused by the application of both classes of UCs. In the case of rural networks, the significant growth of DG and flexible loads lead to higher over-voltages and consequently leads to important congestions: in fact, rural grids have longer lines, lower degree of undergrounding, and higher degree of ramifications. For the mitigation of these situations, local sources of flexibility might be complemented with the installation of devices able to compensate local lack of reactive power. Moreover, in cases where it is observed power export to the main grid in some hours of the day and power import in others, both the “negative” and “positive” flexibility of the installed distributed generators are activated, especially in urban networks: this triggers the need for investment in solutions able to offer both types of flexibility services.

The regulatory barriers that might hinder the large-scale deployments of the two SRA-UCs significantly vary among the three countries hosting the Platone demos. In Italy, one of the main regulatory gaps is connected to the lack of a complete and shared definition of the roles and responsibilities of DSOs, aggregators, and other market players. In Greece, the main barrier is the lack of regulation in terms of blockchain technology in the energy sector, as well as the lack of a clear definition of the role of an aggregator. In Germany, a more defined regulatory structure concerning flexibility mechanisms is needed (especially in cases involving devices like remote controllers for control methodologies), and enhancements are necessary in the regulatory framework governing DSOs' use of batteries.

The project's rigorous MC-CBA has been actualized within the context of its demos, yielding significant findings and insights. The Italian demo underscored the importance of a common DSO-TSO market for ancillary services, facilitated by liquid markets with high participation of distributed resources. Additionally, the dynamism of distribution networks favoured granularity per Point of Delivery (PoD) and emphasized the need for data sharing and centralization for successful flexibility processes. The Greek demo demonstrated substantial benefits through advanced tools like State Estimation and optimized DER control, highlighting their potential in diverse network settings. Similarly, the German demo showcased the positive impact of the energy management system (ALF-C) in reducing power peaks and energy exchange. These insightful outcomes reinforced the significance of a thorough analysis and preparation, showcasing the necessity of proper scalability, replicability, and multi-criteria cost-benefit assessments.

Overall, the obtained outcomes demonstrated the significance of performing proper Scalability and Replicability Analysis as well as Multi-Criteria Cost Benefit Analysis.

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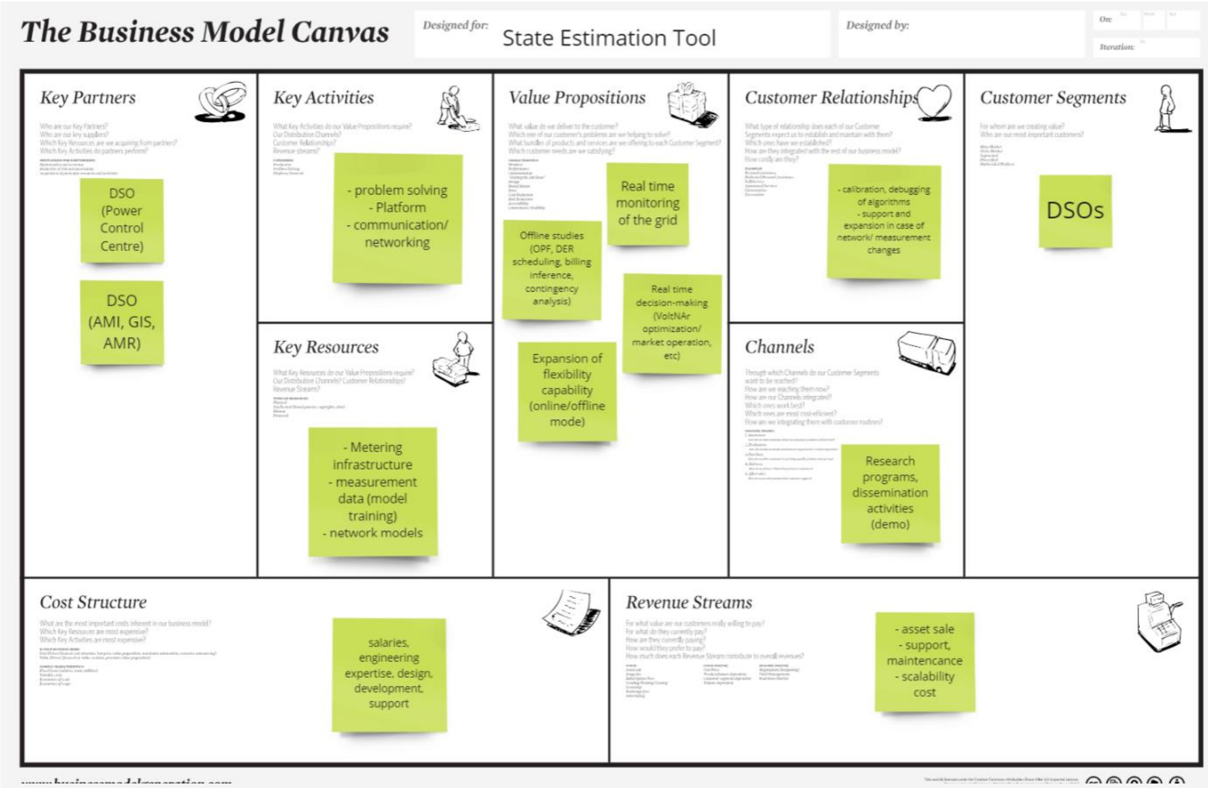
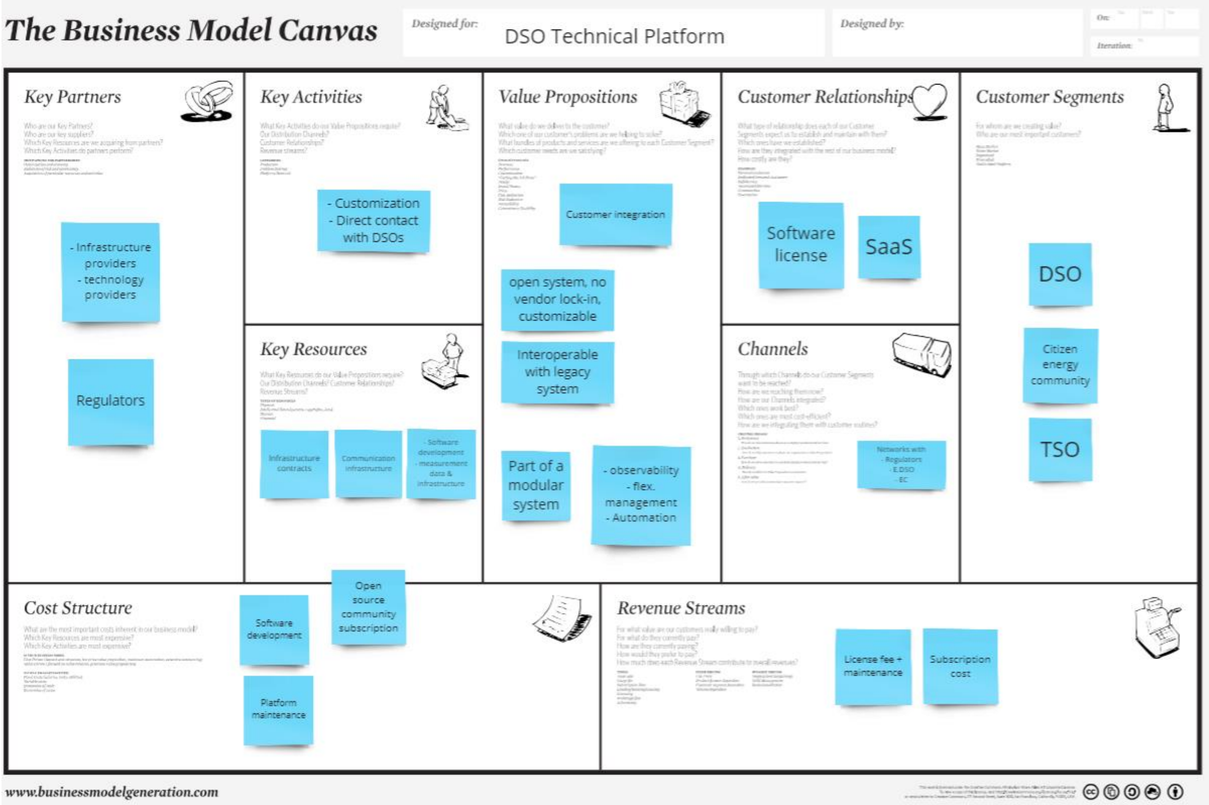
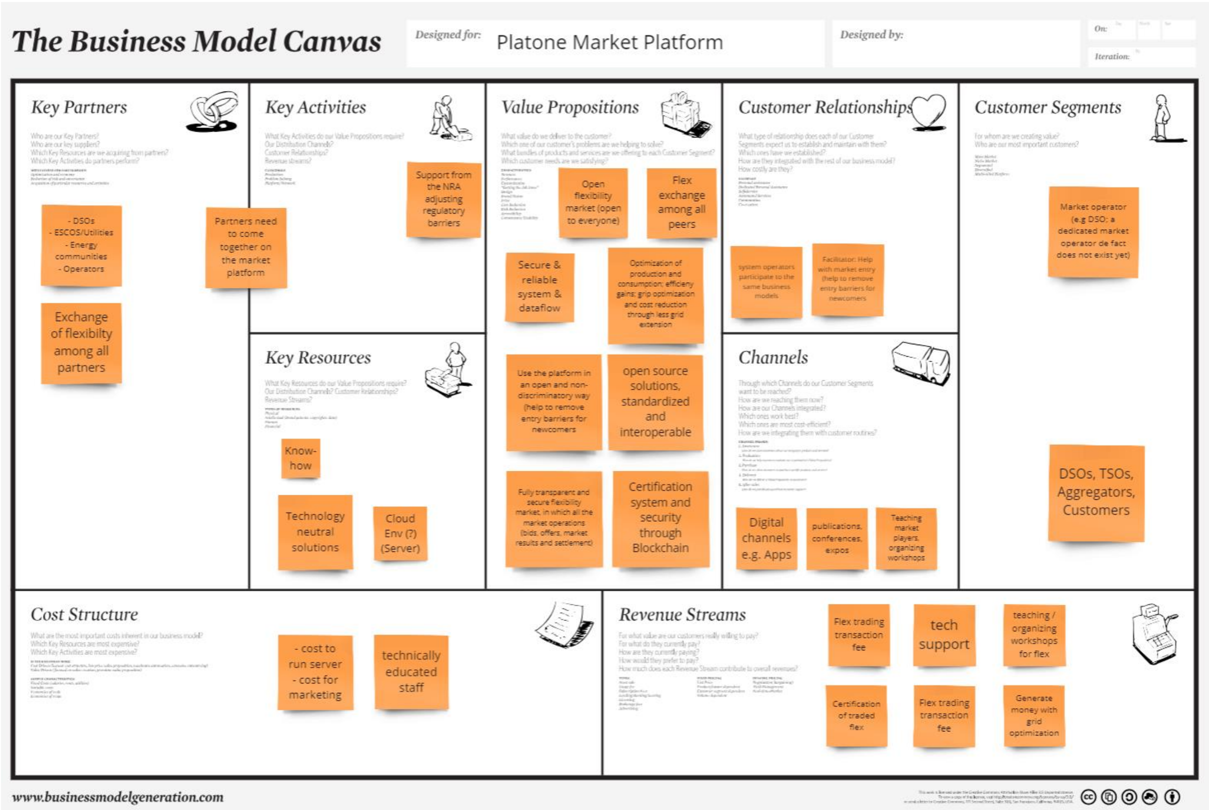
11 List of Abbreviations

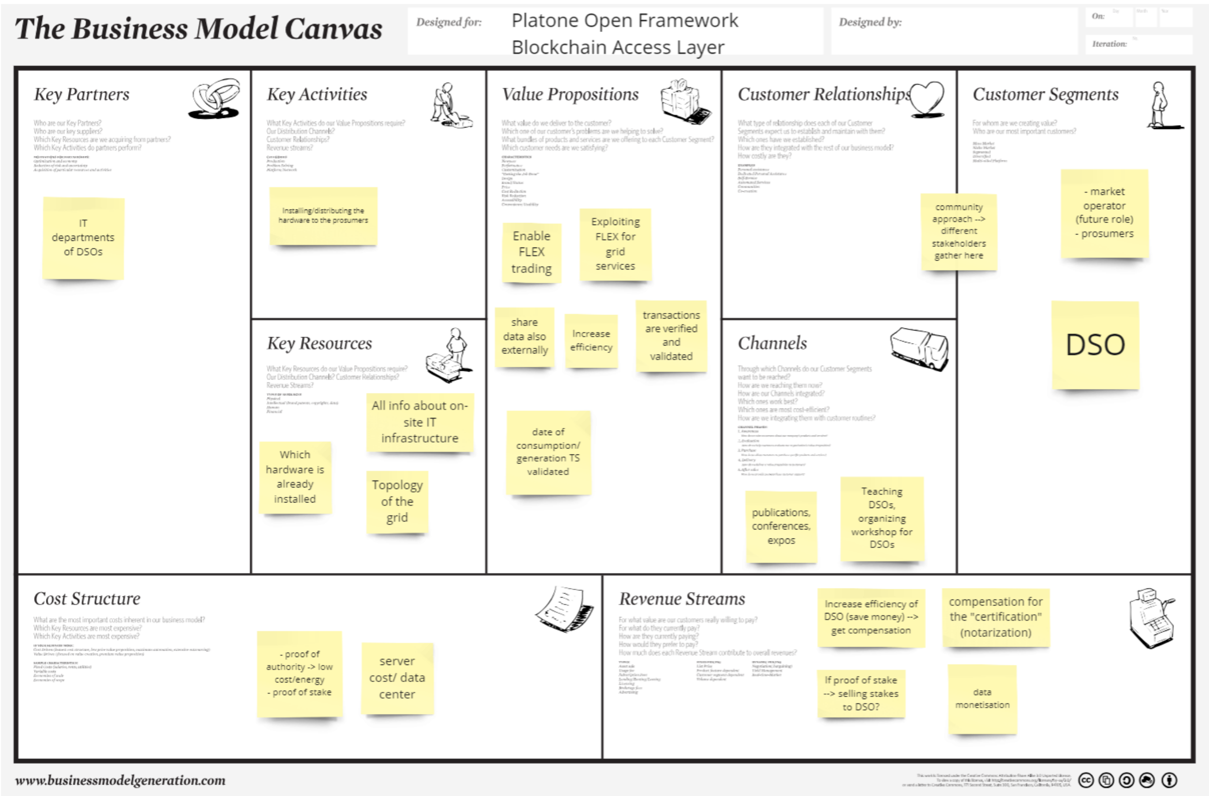
Abbreviation	Term
AHP	Analytical Hierarchical Process
ALF-C	Avacon Local Flexibility Controller
AMR	Automated Meter Reading
BAP	Blockchain Access Platform
BaU	Business as Usual
BESS	Battery Energy Storage System
CBR	Cost Benefit Ratio
DER	Distributed Energy Resources
DSO	Distribution System Operator
DSOTP	DSO-Technical Platform
DUoS	Distribution Use of System
EV	Electric Vehicle
GIS	Geographical Information System
IRR	Internal Rate of Return
ISGAN	International Smart Grid Action Network
JRC	Joint Research Centre
KER	Key Exploitable Result
KPI	Key Performance Indicator
MC-CBA	Multi-Criteria-Cost Benefit Analysis
NPV	Net Present Value
NRA	National Regulatory Agency
PC	Policy Criteria
PCC	Point of Common Coupling
PMU	Phasor Measurement Unit
PoD	Point of Delivery
PV	Photo-Voltaic
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
UC	Use Case

Annex A Business Model Canvas of selected KER






The Business Model Canvas
Designed for:
Platone Market Platform
Designed by:
On:
Iteration:
Key Partners
- DSOs - ESCOS/Utilities - Energy communities - Operators
Exchange of flexibilty among all partners
Partners need to come together on the market platform
Key Activities
Support from the NRA adjusting regulatory barriers
Key Resources
Know-how
Technology neutral solutions
Cloud Env (?) (Server)
Value Propositions
Open flexibility market (open to everyone)
Flex exchange among all peers
Secure & reliable system & dataflow
Optimization of production and consumption; efficieny gains: grid optimization and cost reduction through less grid extension
Use the platform in an open and non-discriminatory way (help to remove entry barriers for newcomers
open source solutions, standardized and interoperable
Fully transparent and secure flexibility market, in which all the market operations (bids, offers, market results and settlement)
Certification system and security through Blockchain
Customer Relationships
system operators participate to the same business models
Facilitator: Help with market entry (help to remove entry barriers for newcomers
Channels
Digital channels e.g. Apps
publications, conferences, expos
Teaching market players, organizing workshops
Customer Segments
Market operator (e.g DSO: a dedicated market operator de fact does not exist yet)
DSOs, TSOs, Aggregators, Customers
Cost Structure
- cost to run server - cost for marketing
technically educated staff
Revenue Streams
Flex trading transaction fee
tech support
teaching / organizing workshops for flex
Certification of traded flex
Flex trading transaction fee
Generate money with grid optimization
www.businessmodelgeneration.com


The Business Model Canvas
Designed for:
Platone Open Framework Blockchain Access Layer
Designed by:
On:
Iteration:
Key Partners
IT departments of DSOs
Key Activities
Installing/distributing the hardware to the prosumers
Key Resources
All info about on-site IT infrastructure
Which hardware is already installed
Topology of the grid
Value Propositions
Enable FLEX trading
Exploiting FLEX for grid services
share data also externally
Increase efficiency
transactions are verified and validated
date of consumption/ generation TS validated
Customer Relationships
community approach --> different stakeholders gather here
Channels
publications, conferences, expos
Teaching DSOs, organizing workshop for DSOs
Customer Segments
- market operator (future role) - prosumers
DSO
Cost Structure
- proof of authority -> low cost/energy - proof of stake
server cost/ data center
Revenue Streams
Increase efficiency of DSO (save money) --> get compensation
compensation for the "certification" (notarization)
If proof of stake --> selling stakes to DSO?
data monetisation
www.businessmodelgeneration.com

-

Annex B Scenario generator

```
import json
import math
import os.path
import os
import random
import logging
import numpy as np
import pandas as pd
from itertools import permutations, islice

# Input parameters
folder_path = "config/German_SRA/German_demo_SRA_NEW_winter"
cfg_path = os.path.join(folder_path,"config.json")
load_as_is_filename = "load_profile_as_is.csv"
gen_as_is_filename = "gen_profile_as_is.csv"

# Main

with open(cfg_path) as f:
    cfg = json.load(f)
logging.debug(cfg)

# input files paths
file_load_as_is_p = os.path.join(folder_path,load_as_is_filename)
file_gen_as_is_p = os.path.join(folder_path, gen_as_is_filename)

logging.debug(file_load_as_is_p)

# output files paths
file_load_p = os.path.join(folder_path, "Target_active_load_nodes_profiles_permutation.csv")
file_load_q = os.path.join(folder_path, "Target_reactive_load_nodes_profiles_permutation.csv")
file_gen_p = os.path.join(folder_path, "Target_active_gen_nodes_profiles_permutation.csv")
file_gen_q = os.path.join(folder_path, "Target_reactive_gen_nodes_profiles_permutation.csv")

# Extract parameters from json config file
n_nodes = cfg["n_nodes"]
nodes_cfg_id = cfg.get("nodes_ids", None)
```

```
slack_node = cfg["slack_node"]

if nodes_cfg_id:
    if len(nodes_cfg_id) != n_nodes:
        logging.error("Nodes_ids size is different from n_nodes!")
    if slack_node not in nodes_cfg_id:
        logging.error("Slack node id is not in nodes id")

logging.info(n_nodes)

# percentage of nodes with generation
perc_nodes_gen = cfg["perc_nodes_gen"]
n_nodes_gen = math.ceil(n_nodes * perc_nodes_gen)

cosfi = cfg["cosfi"]

gen_file = (pd.read_csv(file_gen_as_is_p))

profile_gen_tot_as_is = list(gen_file["active_power"])
time_slices_gen = list(gen_file["time_slice"])

load_file = (pd.read_csv(file_load_as_is_p))
profile_load_tot_as_is = list(load_file["active_power"])
time_slices_load = list(gen_file["time_slice"])

perc_increase_load = cfg["perc_increase_load"]
perc_increase_gen = cfg["perc_increase_gen"]

uncertain_load = cfg["uncertain_load"]
uncertain_gen = cfg["uncertain_gen"]

gen_types = list(cfg["gen_types"].keys())
gen_percs = [cfg["gen_types"][x]["perc"] for x in gen_types]

load_types = list(cfg["load_types"].keys())
load_percs = [cfg["load_types"][x]["perc"] for x in load_types]


perc_min = cfg["perc_min"]
```

```
perc_med = cfg["perc_med"]
perc_max = cfg["perc_max"]
min_contracted_power = cfg["min_contracted_power"]
med_contracted_power = cfg["med_contracted_power"]
max_contracted_power = cfg["max_contracted_power"]
contracted_power_type = [min_contracted_power, med_contracted_power, max_contracted_power]
contracted_power_perc = [perc_min, perc_med, perc_max]

# nodes ids
node_ids = create_nodes_id(n_nodes) if not nodes_cfg_id else nodes_cfg_id

# subset of nodes_ids that will have generation (slack node is mandatory)
node_ids_no_slack = node_ids.copy()
node_ids_no_slack.remove(slack_node)
node_ids_gen = random.sample(node_ids_no_slack, n_nodes_gen - 1) + [slack_node]

# ***************************** LOAD PROFILE *****************************************

# compute nodes weight
contracted_power = create_contracted_power(n_nodes, contracted_power_type, contracted_power_perc)
total_contracted_power = contracted_power.sum()
node_weight = contracted_power/total_contracted_power

# create scenario
nodes_profiles_active_load_target, nodes_profiles_reactive_load_target = create_scenario(n_nodes, cosfi,
                                                                  profile_load_tot_as_is,
                                                                  perc_increase_load,
                                                                  uncertain_load, node_weight)
# export load profiles (active/reactive)
header = ["time_slice_{}".format(n) for n in range(len(profile_load_tot_as_is))]
node_type = create_types(n_nodes, load_types, load_percs)

df_target_active_load_p = pd.DataFrame(nodes_profiles_active_load_target, columns=header)
df_target_active_load_p["node_id"] = node_ids
df_target_active_load_p["node_type"] = node_type
# add p max
p_max_dict = {key: cfg["load_types"][key]["p_max"] for key in load_types}
```

```
df_target_active_load_p["p_max"] = node_type.map(p_max_dict)
# add p min
p_min_dict = {key: cfg["load_types"][key]["p_min"] for key in load_types}
df_target_active_load_p["p_min"] = node_type.map(p_min_dict)
# add flex
p_max_dict = {key: cfg["load_types"][key]["flex_up_cost"] for key in load_types}
df_target_active_load_p["flex_up_cost"] = node_type.map(p_max_dict)
# add contrcted power
df_target_active_load_p["contracted_power"] = contracted_power
# df_target_active_load_p = create_permutation(df_target_active_load_p, n_nodes, node_ids)
df_target_active_load_p = create_shuffle(df_target_active_load_p, n_nodes, node_ids)
df_target_active_load_p.to_csv(file_load_p, index=False)

df_target_reactive_load_q = pd.DataFrame(nodes_profiles_reactive_load_target, columns=header)
df_target_reactive_load_q["node_id"] = node_ids
df_target_reactive_load_q["node_type"] = node_type
q_max_dict = {key: cfg["load_types"][key]["q_max"] for key in load_types}
df_target_reactive_load_q["q_max"] = node_type.map(q_max_dict)
q_min_dict = {key: cfg["load_types"][key]["q_min"] for key in load_types}
df_target_reactive_load_q["q_min"] = node_type.map(q_min_dict)
# add flex
p_max_dict = {key: cfg["load_types"][key]["flex_up_cost"] for key in load_types}
df_target_reactive_load_q["flex_up_cost"] = node_type.map(p_max_dict)

df_target_reactive_load_q["contracted_power"] = contracted_power
# df_target_reactive_load_p = create_permutation(df_target_reactive_load_q, n_nodes, node_ids)
df_target_reactive_load_p = create_shuffle(df_target_reactive_load_q, n_nodes, node_ids)
df_target_reactive_load_p.to_csv(file_load_q, index=False)

# ****************************** GENERATION PROFILE ******************************************

# compute generation profiles
nodes_profiles_active_gen_target, nodes_profiles_reactive_gen_target = create_scenario(n_nodes_gen, cosfi,
        profile_gen_tot_as_is,
        perc_increase_gen, uncertain_gen, pd.Series())

header = ["time_slice_{}".format(n) for n in range(len(profile_gen_tot_as_is))]
node_type = create_types(n_nodes_gen, gen_types, gen_percs)
```

```
# export gen profiles (active/reactive)
df_target_active_gen_p = pd.DataFrame(nodes_profiles_active_gen_target, columns=header)
df_target_active_gen_p["node_id"] = node_ids_gen
df_target_active_gen_p["node_type"] = node_type
p_max_dict = {key: cfg["gen_types"][key]["p_max"] for key in gen_types}
df_target_active_gen_p["p_max"] = node_type.map(p_max_dict)
p_min_dict = {key: cfg["gen_types"][key]["p_min"] for key in gen_types}
df_target_active_gen_p["p_min"] = node_type.map(p_min_dict)
# add flex
p_max_dict = {key: cfg["gen_types"][key]["flex_up_cost"] for key in gen_types}
df_target_active_gen_p["flex_up_cost"] = node_type.map(p_max_dict)
# df_target_active_gen_p = create_permutation(df_target_active_gen_p, n_nodes_gen, node_ids_gen)
df_target_active_gen_p = create_shuffle(df_target_active_gen_p, n_nodes_gen, node_ids_gen)
df_target_active_gen_p.to_csv(file_gen_p, index=False)


df_target_reactive_gen_p = pd.DataFrame(nodes_profiles_reactive_gen_target, columns=header)
df_target_reactive_gen_p["node_id"] = node_ids_gen
df_target_reactive_gen_p["node_type"] = node_type
q_max_dict = {key: cfg["gen_types"][key]["q_max"] for key in gen_types}
df_target_reactive_gen_p["q_max"] = node_type.map(q_max_dict)
q_min_dict = {key: cfg["gen_types"][key]["q_min"] for key in gen_types}
df_target_reactive_gen_p["q_min"] = node_type.map(q_min_dict)
# add flex
p_max_dict = {key: cfg["gen_types"][key]["flex_up_cost"] for key in gen_types}
df_target_reactive_gen_p["flex_up_cost"] = node_type.map(p_max_dict)
# df_target_reactive_gen_p = create_permutation(df_target_reactive_gen_p, n_nodes_gen,
node_ids_gen)
df_target_reactive_gen_p = create_shuffle(df_target_reactive_gen_p, n_nodes_gen, node_ids_gen)
df_target_reactive_gen_p.to_csv(file_gen_q, index=False)


logging.debug("executed")
```