Cluster Demo results evaluation and success metrics analysis

Western Demo

D9.8

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About OneNet

The project OneNet (One Network for Europe) will provide a seamless integration of all the actors in the electricity network across Europe to create the conditions for a synergistic operation that optimizes the overall energy system while creating an open and fair market structure.

OneNet is funded through the EU's eighth Framework Programme Horizon 2020, "TSO – DSO Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation" and responds to the call "Building a low-carbon, climate resilient future (LC)".

As the electrical grid moves from being a fully centralized to a highly decentralized system, grid operators have to adapt to this changing environment and adjust their current business model to accommodate faster reactions and adaptive flexibility. This is an unprecedented challenge requiring an unprecedented solution. The project brings together a consortium of over 70 partners, including key IT players, leading research institutions and the two most relevant associations for grid operators.

The key elements of the project are:

1. Definition of a common market design for Europe: this means standardized products and key parameters for grid services which aim at the coordination of all actors, from grid operators to customers;
2. Definition of a Common IT Architecture and Common IT Interfaces: this means not trying to create a single IT platform for all the products but enabling an open architecture of interactions among several platforms so that anybody can join any market across Europe; and
3. Large-scale demonstrators to implement and showcase the scalable solutions developed throughout the project. These demonstrators are organized in four clusters coming to include countries in every region of Europe and testing innovative use cases never validated before.

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List of Abbreviations and Acronyms

Acronym	Meaning
API	Application Programming Interface
ASM	Application-Specific Module or Assembly
BUC	Business Use Case
CBA	Cost-Benefit Analysis
CEPA	Cambridge Economic Policy Associates Ltd
CM	Congestion Management
CORDIS	Community Research and Development Information Service (EU)
CRUD	Create, Read, Update, Delete
DEMO	Demonstration
DER	Distributed Energy Resources
DSO	Distribution System Operator
ES	Spain
EU	European Union
EV	Electric Vehicle
EVC	Electric Vehicle Charger
FR	France
GET	HTTP GET method
GPS	Global Positioning System
HERA	Hydrogen and Electricity Research Agency
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
IAM	IAM: Identity and Access Management
ICT	Information and Communication Technology
IEEE	IEEE: Institute of Electrical and Electronics Engineers
INEA	Innovation and Networks Executive Agency (EU)
IT	Information Technology
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LC	Life Cycle
LFM	Local Flexibility Market
LOT	Level of Trust
LV	Low Voltage
MV	Medium Voltage
MVA	Mega Volt Ampere
MW	Megawatt

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NRT	Near Real-Time
NS	Network Service
N/A	Not Available
OA	Open Access
OK	Okay
OLTC	On-Load Tap Changer
OT	Operational Technology
POST	HTTP POST method
PT	Portugal
PUT	HTTP PUT method
PV	Photovoltaic
RES	Renewable Energy Sources
REST	REpresentational State Transfer - HTTP REST method
RNM	Reference Network Model
RUC	Regional Use Case
SMA	Success Metric Analysis
SO	System Operator
SP	Service Provider
SRA	Scalability and replicability analysis
TBD	To Be Determined
TLS	Transport Layer Security
TSO	Transmission System Operator
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
WP	Work Package
XML	eXtensible Markup Language

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Executive Summary

This report provides an in-depth assessment of the Western Cluster demonstrators of the OneNet project, covering Portugal, Spain, and France. The primary objectives include a thorough evaluation of demonstrator setups and results, understanding their effectiveness, analysing motivations for evaluation, and formulating strategic recommendations and best practices.

The assessment integrates two main workstreams: the Success Metric Analysis (SMA) and the Scalability and Replicability Analysis (SRA). SMA focuses on evaluating demonstrator experiences, aligning with OneNet objectives, and assessing Key Performance Indicators (KPIs). The methodology involves quantitative and qualitative analyses of national demonstrators, comparing KPI values and experiences to measure the project's success. The SRA examines potential expansion and replication, considering ICT aspects and non-technical constraints like regulatory and business model challenges.

The SMA highlights the project's success in achieving significant objectives such as consumer engagement, technical coordination, market environment compatibility, active system management (ASM) compliance, and platform evaluation. Key achievements include successful prequalification with a 100% execution rate, effective technical coordination leading to accurate load and generation forecasting, and notable flexibility market evaluations, especially in the Spanish demonstrator. The Spanish demo excelled in customer engagement and local market coordination, while the Portuguese and French demonstrators focused on TSO-DSO coordination and innovative platform introduction, respectively.

SRA's ICT aspect underscores the quality of REST APIs implemented in Portuguese and French demos and the favourable adoption of the AMQP protocol in Spain. Non-ICT findings reveal barriers in flexibility markets due to technical, regulatory, behavioural, and legal challenges. Technical barriers include inadequate ICT deployment, while regulatory and economic barriers hamper market development and customer participation.

The quantitative SRA focused on the Spanish demonstrator studies through a simulation-based technical approach the techno-economic viability of local market solutions for congestion management. Central to the analysis are two case studies – Alcalá de Henares and Murcia – which utilize synthetic networks derived from the Reference Network Model (RNM) exploring scenarios with increased Electric Vehicle (EV) charging loads. The simulation outcomes reveal critical insights: in Murcia, the available active power capacity effectively addresses congestion issues throughout the year. In contrast, Alcalá de Henares faces challenges, indicating a need for more flexibility service providers (SPs) for comprehensive congestion management. The study underscores the importance of strategically located SPs in ensuring market solutions effectively resolve technical constraints on the network.

The report identifies overcoming regulatory barriers and enhancing customer engagement as critical for replicability. Addressing technical and economic challenges is vital for scaling up solutions. Standardizing data

exchange interfaces and refining flexibility pricing schemes are recommended. The OneNet Western Cluster's experience offers valuable insights for future energy system transformations, emphasizing the need for harmonized regulations and addressing behavioural barriers for a resilient and adaptive energy ecosystem in Europe. The demonstrator's achievements serve as a model for innovation in Europe's energy ecosystem, providing a roadmap for integrating and scaling energy solutions across the continent.

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1 Introduction

1.1 Task 9.5 and Task 9.6

The OneNet Western Cluster, represented by Work Package 9 (WP9), comprising demos across three countries—Portugal, Spain, and France—aims to implement a diverse array of flexibility mechanisms to address the needs of both Distribution System Operators (DSOs) and Transmission System Operators (TSOs). This includes the coordination between market mechanisms and the planning and real-time operation of the grids. The cluster explores various approaches to study the feasibility of addressing distinct system operation requirements in a coordinated environment, encouraging the active participation of network customers. Test cases include balancing, congestion management at different voltage levels, and voltage control, which will be assessed and replicated in different locations. Additionally, the OneNet Western Cluster focuses on enhancing planning, forecasting, observability, signalling to potential flexibility providers, and control with different time horizons.

Within Work Package 9 (WP9), Task 9.5 "Western demo evaluation" and Task 9.6 "Western Demo – Lessons Learned, CBA and SRA" lead to this document, Deliverable 9.8 (D9.8), that provides an analysis of the Key Performance Indicators (KPIs) derived from the demos in the Western cluster . The examination delves into aspects such as costs, benefits, scalability, and the potential for replicability. D9.8 mainly collects the outputs from three subtasks from tasks 9.5 "Western demo evaluation" and 9.6 "Lesson learned, CBA[1] and SRA[2]". Moreover, since the main goal of D9.8 is to provide an evaluation of the Cluster demo results, all the related activities are addressed in close collaboration with demonstrators'' partners and based on all the relevant outputs from tasks 9.1 "Western demo set-up and overall alignment" , 9.2 "Western demo implementation – Portugal" [2], 9.3 "Western demo implementation – Spain" [3], 9.4 "Western demo implementation – France" [4], and OneNet Deliverable D9.7 - Demo results assessment & data report collection – France [5]. Furthermore, aspects from WP11, and in particular from tasks 11.1 "Evaluation of OneNet demonstrators results" [6], 11.2 "Techno-economic assessment of proposed market schemes for standardized products" [7], 11.4 "Scalability and Replicability Analysis for market schemes and platforms" [8], 11.5 "Business model analysis of OneNet solutions" [9], and 11.6 "Customer engagement strategies recommendations" [10], have been considered in terms of complementary information for demonstration assessment and elements forming the assessment framework adopted in D9.8.

This report aims to provide a comprehensive assessment of the demonstrators' setup and results within the context of Western Cluster of the OneNet project. As the project unfolds, understanding the effectiveness and

[1] CBA: Cost Benefit Analysis
[2] SRA: Scalability and Replicability Analysis

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impact of the demonstrators becomes paramount. This assessment delves into the motivations behind the evaluation, shedding light on the intricacies of the setup, and elucidates the discernible results. By scrutinizing these aspects, we aim to gain valuable insights that can formalise recommendations and define best practices for future strategies, optimize processes, and contribute to the overarching success of the initiatives related to the ongoing power system decentralisation, decarbonisation, and digitalisation.

The assessment described in D9.8 is essentially based on two main workstreams, the Success Metric Analysis (SMA) and the Scalability and Replicability Analysis (SRA). The SMA follows-up on the use cases to assess and identify the status of the defined KPIs. The SMA gathers the data from the three different demos and aggregate their expected results coming from the Western demo. Moreover, the SMA delivers the cluster demo economic results evaluation within the success metrics analysis report. It is worth noting that no CBA framework to be used in project is expected, hence the definition of the data format coming from different partners of the Western demo associated to technical and non-technical information is considered directly in the SMA rather than providing it as an input for the CBA of the OneNet project.

The SRA evaluates the scalability and replicability potential of the solutions showcased in the Western Demo. It aims to gauge the anticipated outcomes should these proposed solutions be implemented in different locations or on a larger scale.

The proposed SRA approach consists of two main steps:

- A quantitative SRA simulation-based technical analysis;
- A qualitative SRA of the non-technical boundary conditions can affect the potential for replication.

These boundary conditions may include regulatory issues, business models' constraints, ICT aspects, and the perspectives of key stakeholders.

1.2 Objectives of the Work Reported in this Deliverable

The objectives of the work reported this deliverable include:

- Comprehensive Assessment: Provide a thorough evaluation of the demonstrators' setup and results within the Western Cluster of the OneNet project.
- Understanding Effectiveness and Impact: Gain insights into the effectiveness and impact of the demonstrated solutions.
- Motivations for Evaluation: Examine the motivations behind the evaluation, elucidating the complexities of the setup and highlighting discernible results.
- Recommendations and Best Practices: Formulate recommendations and define best practices based on the assessment findings to guide future strategies.

Overall, the objectives aim to provide a comprehensive understanding of the Western Cluster's OneNet project, from its performances to the potential for scalability and replication of the demonstrated solutions.

1.3 Outline of the Deliverable

This report is organised as follows:

In section 2, the methodological framework for the assessment addressed in this deliverable are provided. The methodology adopted for the SMA, and the quantitative and qualitative SRA are described.

Section 3 focuses on the SMA analysis presenting the application of the methodology described in section 2 to the Western Cluster demonstrators.

Section 4 presents the qualitative SRA covering aspects such as regulatory issues, business models' constraints, ICT aspects, and the perspectives of key stakeholders.

Section 5 deals with the quantitative SRA addressed to understand the potential of the market-based solutions for acquiring congestion management products deployed by the Spanish demonstrator.

Section 6 closes this document by disclosing the main findings and formalising recommendations and lesson learnt based on the analyses addressed.

1.4 How to Read this Document

As shown in Figure 1.1, D9.8 has strong links with tasks in WP9 and WP11.

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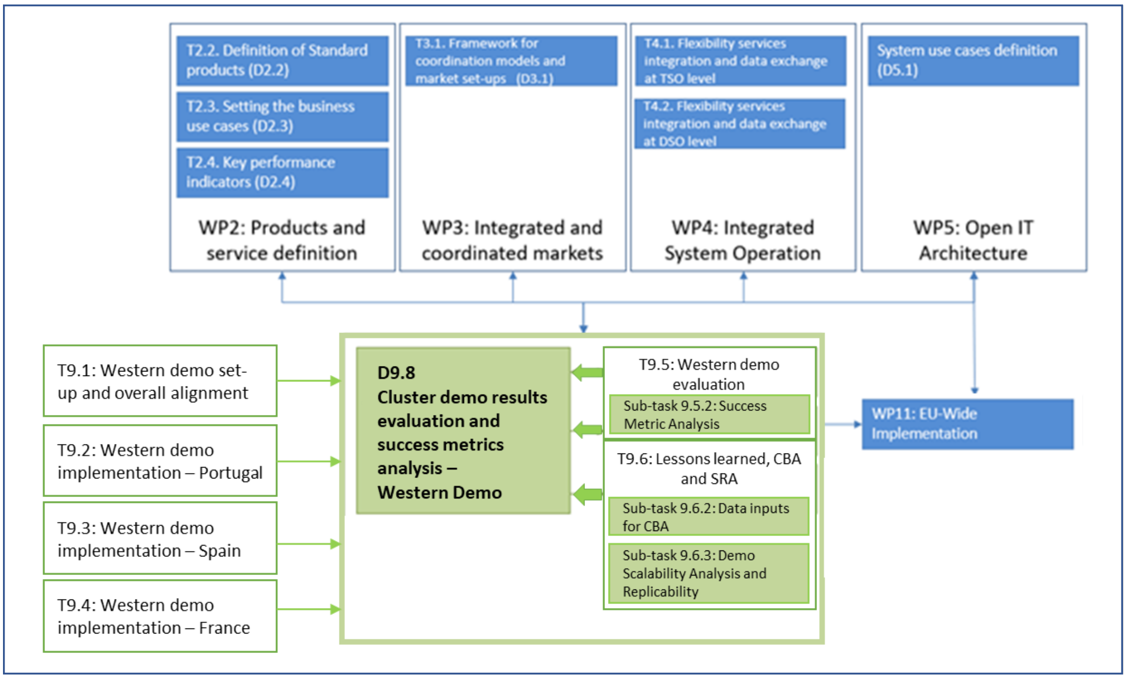

Figure 1.1: Interconnection between the OneNet Deliverable D9.8 with other tasks and work packages in the OneNet project

Moreover, the relevant documents that provide the background for the activities presented in this report are mentioned in Table 1.1.

Table 1.1: Relevant OneNet deliverables that provide the background for the activities presented in this D9.8

Deliverable	Reference
D9.1 Specifications and guidelines for Western Demo	[1]
D9.2 Validation and results of concept test – Portugal	[2]
D9.3 Validation and results of concept test – Spain	[3]
D9.4 Validation and results of concept test – France	[4]
D9.5 Demo results assessment and data collection report – Portugal	[11]
D9.6 Demo results assessment and data collection report – Spain	[12]
D9.7 Demo results assessment and data collection report – France	[5]
D11.1 Evaluation of OneNet demonstrators	[6]
D11.2 Techno-economic assessment of proposed market schemes for standardized products	[7]
D11.4 Scalability and Replicability Analysis for market schemes and platforms	[8]
D11.5 Customer engagement strategies recommendations	[10]
D11.6 Business model analysis of OneNet solutions	[9]

D9.8 and D9.9 are complementary in providing the assessment of the OneNet Western Cluster demonstrators; Table 1.2 illustrates how their complementarity is formalised.

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Table 1.2: Schematic representation of the complementarity between D9.8 and D9.9

Deliverable D9.8	Deliverable D9.9
D9.8: Cluster Demo Results Evaluation and Success Metrics Analysis – Western Demo This deliverable will present the KPIs obtained for the western demo that are further studied in terms of costs, benefits, scalability and replicability potential.	**D9.9: Demonstration Conclusions and Lessons Learned – Western Demo** This deliverable will identify key results and main lessons learned to be compared at the project and European level. It will identify different enablers and barriers, as well as to assess the timing of adoption of the proposed solutions.
Task 9.5: Western demo evaluation	
Sub-Task 9.5.2: Success Metric Analysis	Sub-Task 9.5.1: Result Integration
Task 9.6: Western Demo – Lessons Learned, CBA and SRA	
Sub-task 9.6.2: data inputs for CBA	Sub-task 9.6.1: Lessons learned
Sub-task 9.6.3: Demo scalability analysis and replicability	

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2 Methodological approach to success metric analysis and scalability and replicability analysis

2.1 Success Metric Analysis Methodology

The Success Metrics Analysis (SMA) methodology is presented below. Success metrics are the criteria defined to evaluate the success of the demonstrators. It combines KPI values, quantitative information on demonstration runs and qualitative information to provide a comprehensive overview of the performance achieved by the demonstration activities. This SMA is applied to the experience gained by the demonstrators in the Western Cluster of the OneNet project. The results are presented in Section 3.

Success metrics are to be identified, that allow to measure the success of the undertaken demonstration runs, by evaluating the interpreted results against the relevant objectives set out in the OneNet project. To define success metrics, both qualitative as well as quantitative analysis are undertaken. The quantitative analysis is centred around the mapping and analysing of the KPIs, defined in OneNet Deliverable D11.1 [6], across the different demo sites. The qualitative analysis supplements the quantitative analysis by discussing non-quantitative aspects related to the demonstrator experiences and the relevant objectives. This approach to SMA is illustrated in Figure 2.1.

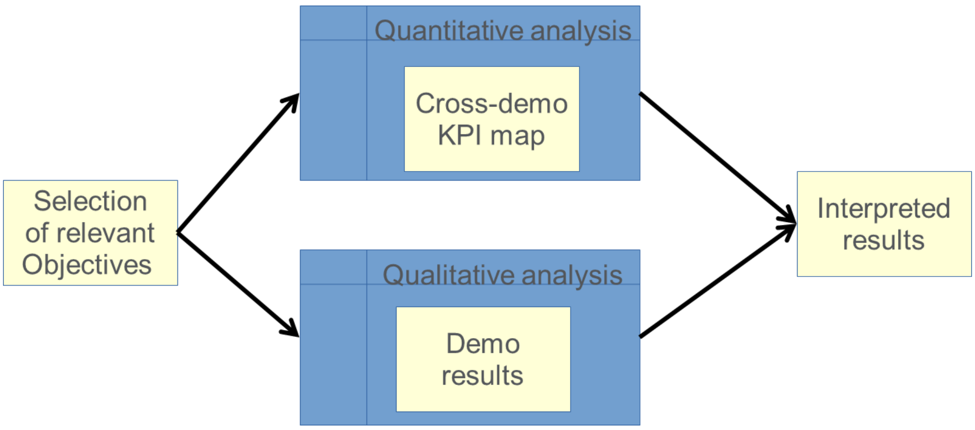

Figure 2.1: Approach to Success Metric Analysis undertaken

As described in section 1, the analysis described in this document is relying on multiple deliverables produced within the OneNet project. Particularly, D9.5 [11], D9.6 [12] and D9.7 [5] as these assess the individual demonstrator results in the Western Cluster (for Portugal, Spain and France). The workflow of the methodology is depicted in Figure 2.2.

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The first step consists of identifying, amongst all OneNet objectives, those objectives that are most relevant for the demonstration phase of the project. This step is mainly based on the information described in the OneNet Grant Agreement [13].

- The second step embodies the quantitative analysis, based on the assessments of the national demonstrators. Here, the KPI values are mapped and analysed across those demonstrators. Obtaining this cross-demo map of KPIs, allows to evaluate and compare the demonstrators' performance in the Western Cluster.
- Following this preparation of the quantitative analysis, the third step comprises the preparation for the qualitative analysis of the same assessment reports. Here, experiences in the demonstrators are identified and mapped.
- In the fourth step, the cross-demo KPI map is analysed quantitatively, measuring the (quantitatively) interpreted results against the objectives identified in the first step, given the quantitative information available.
- The fifth and last step comprises of the qualitative analysis of the results mapped in step three. Here, the (qualitatively) interpreted results are related to the objectives identified in step one of the methodology.

The results of the workflow are then documented in this deliverable in section 3.

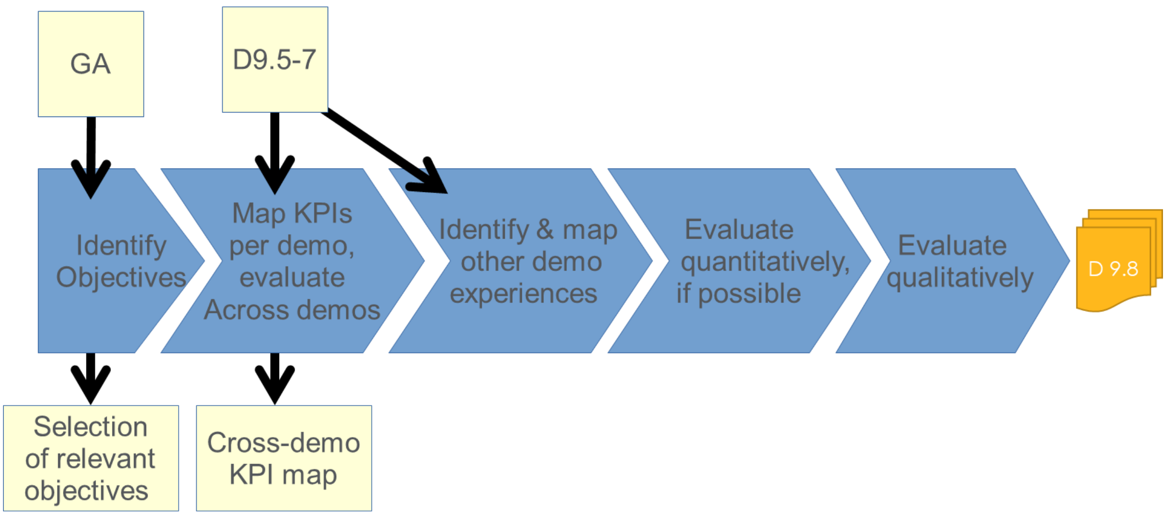

Figure 2.2: Workflow of Success Metric Analysis applied

2.2 Qualitative Scalability and Replicability Analysis

This section explains the methodology for the qualitative SRA of the OneNet solutions demonstrated in the Western Cluster (Portugal, Spain and France). This analysis focuses on technical aspects and non-technical boundary conditions of OneNet solutions. Specifically, it centres on the following aspects:

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- Regulatory issues,
- business model constraints,
- perspectives of key stakeholders,
- ICT aspects.

The methodology followed in the quantitative SRA is depicted in Figure 2.3 and described below.

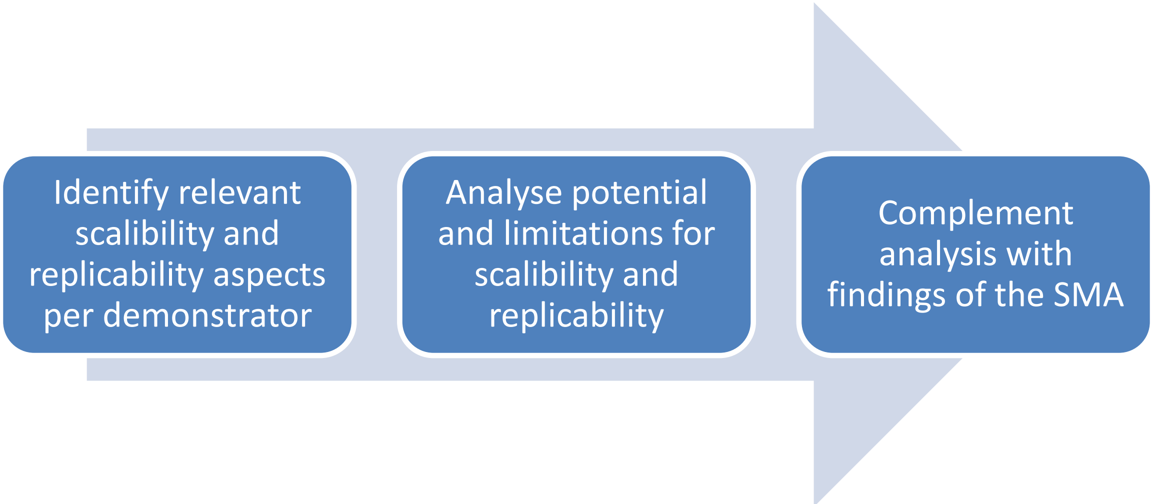

Figure 2.3: Methodology for quantitative scalability and replicability analysis

In the first step, for OneNet Western Cluster demonstrations, all relevant scalability and replicability aspects are identified. In the second step, the potential as well as the limitations for scalability and replicability are analysed and discussed, for each of the aspects identified for each demo in the previous step. For ICT aspects this qualitative analysis to be undertaken for those demonstrators identified in step one, is described in greater detail in Section 2.2.1. Finally, this analysis is complemented with the findings of the SMA that was previously undertaken for each demonstrator.

2.2.1 Qualitative SRA for ICT aspects

In every new solution requiring demonstration, an SRA plays a crucial role in assessing the feasibility of replicating and scaling-up the solution beyond the demo and expanding its scope or involving more stakeholders. When considering Information and Communication Technologies (ICT), two approaches can be distinguished: quantitative (such as simulations or laboratory experiments that assess communication among the devices/systems in a specific use case) and qualitative (focusing on aspects like interoperability, robustness, and reliability).

The quantitative approach for analysing the APIs developed by the demos is inappropriate for two main reasons. First, these communications are carried out over the Internet, and it is difficult to simulate it accurately

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in terms of latencies. Second, the implementation of APIs that adopt Representational State Transfer (REST) architectures already provides a high level of technical scalability.

Despite this, the implementation of an API can be facilitated or hampered by its design. In other words, if developers find it difficult to implement the API or the following versions, the possibility of replicating and deploying the API in new applications is reduced. Thus, the scalability and replicability of an API is linked to its understandability and reusability, achieved by applying best practices in REST API development.

To evaluate the quality of a REST API in these terms, a list of 76 best practices has been developed based on existing guidelines on the topic [14]–[18]. Eight categories have been considered:

- **Uniform Resource Identifier (URI) design:** a compilation of best practices and common rules to enhance the reusability and comprehensibility of URIs for future developers.
- **Request methods:** Fundamental guidelines on how to implement HTTP methods such as PUT, GET, POST, DELETE, or HEAD should be followed to facilitate future developers' use of the API.

Error handling: These practices establish guidelines for using HTTP messages as responses to HTTP request methods [14].

Metadata Design: It includes those practices focused on defining the use of HTTP headers to include metadata in requests [14].

- **Representation design:** This category checks the coherence of the API to represent media formats, schemas, resources, and error responses.
- **Client concerns:** Practices related to API clients.

Versioning: This category collects the best practices for identifying API versions [19]. It has significant relevance to replicability, since a flawed versioning system can hinder API updates in client applications.

- **Security:** This category includes some basic and advanced practices to increase the security level of the API.

This methodology is similar to the one used for the UMEI SRA in the EUniversal project [20]. To verify the compliance of the REST APIs implemented in the demos with this list of best practices, demo partners were asked to fill in the checklist with a 'Yes', 'No', 'not sure', or 'not applicable N / A'.

For each REST API considered, a spider web diagram has been generated to see the scores at a glance. The score for each category is represented by a percentage, which has been calculated by dividing the number of "Yes" (i.e., best practises followed) by the total number of practises that could be applied to the corresponding API.

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2.3 Quantitative Scalability and Replicability Analysis

2.3.1 SRA approach

The Scalability and Replicability Analysis (SRA) of the solutions devised and tested in the Spanish demonstrator aims to assess the potential for scaling-up and replication, i.e., what would be the expected outcome if the proposed solutions were implemented elsewhere or at a larger scale. The proposed SRA approach consists of a simulation-based technical analysis for the techno-economic assessment of the local market for congestion management.

The quantitative SRA concerning the techno-economic assessment of the market functioning is addressed by considering several scenarios modelling different load and generation amounts, distributed resources presence, and flexibility service provider participation. The market model considered in the SRA focuses on the short-term local congestion management markets for the Alcalá de Henares and Murcia demos [2]. The quantitative SRA concerning the techno-economic assessment of the market functioning is addressed by considering several scenarios modelling different load and generation amounts, distributed generation presence, and flexibility service provider participation. Figure 2.4: depicts the schematic procedure for the quantitative SRA analysis adopted for the Spanish demonstrator.

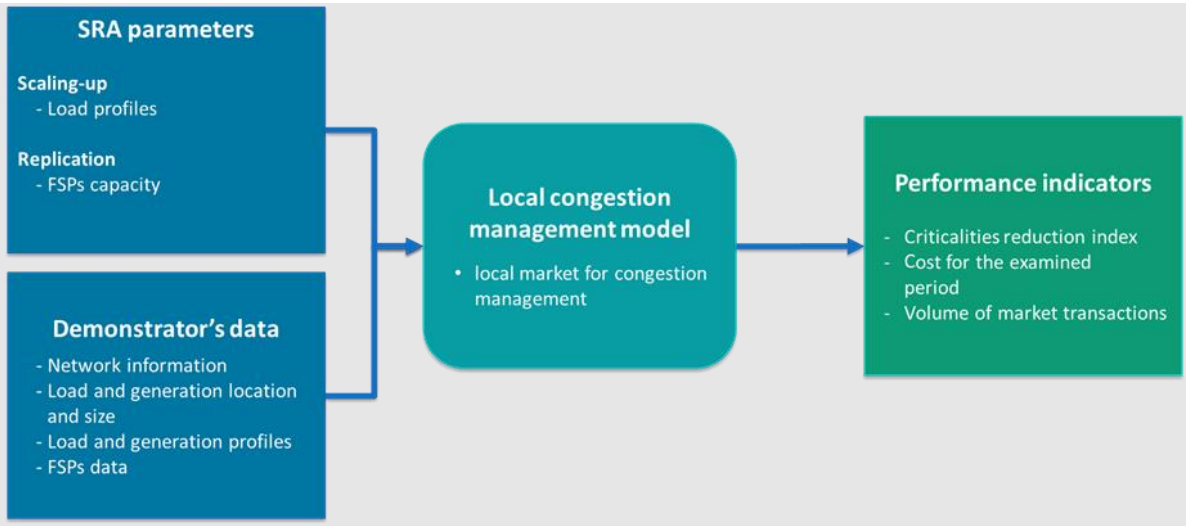

Figure 2.4: Schematic procedure for the quantitative SRA analysis adopted for the Spanish demonstrator

2.3.2 Market model for congestion management

A local flexibility market model for congestion management (CM) using active power is implemented in the current study. This model represents a simplification of the model developed for "Deliverable: D10.4: Scalability and Replicability Analysis of the EUniversal solutions" [20] within the EUniversal Project [23]. The original model incorporated both congestion management and/or voltage control using active and/or reactive power.

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Figure 2.5: illustrates the adjustment of the model within the specific scope of this project. For representing the provision of system service, the generation convention is used, as defined in Table 2.1, as in [20], [24], [25].

Table 2.1: Convention adopted to represent the system service provision from SPs

Action	Generation	Load
Upward	Increase generation $Pgen_{postMarket} > Pgen_{preMarket}$	Decrease load $Pload_{postMarket} < Pload_{preMarket}$
Downward	Decrease generation $Pgen_{postMarket} < Pgen_{preMarket}$	Increase load $Pload_{postMarket} > Pload_{preMarket}$

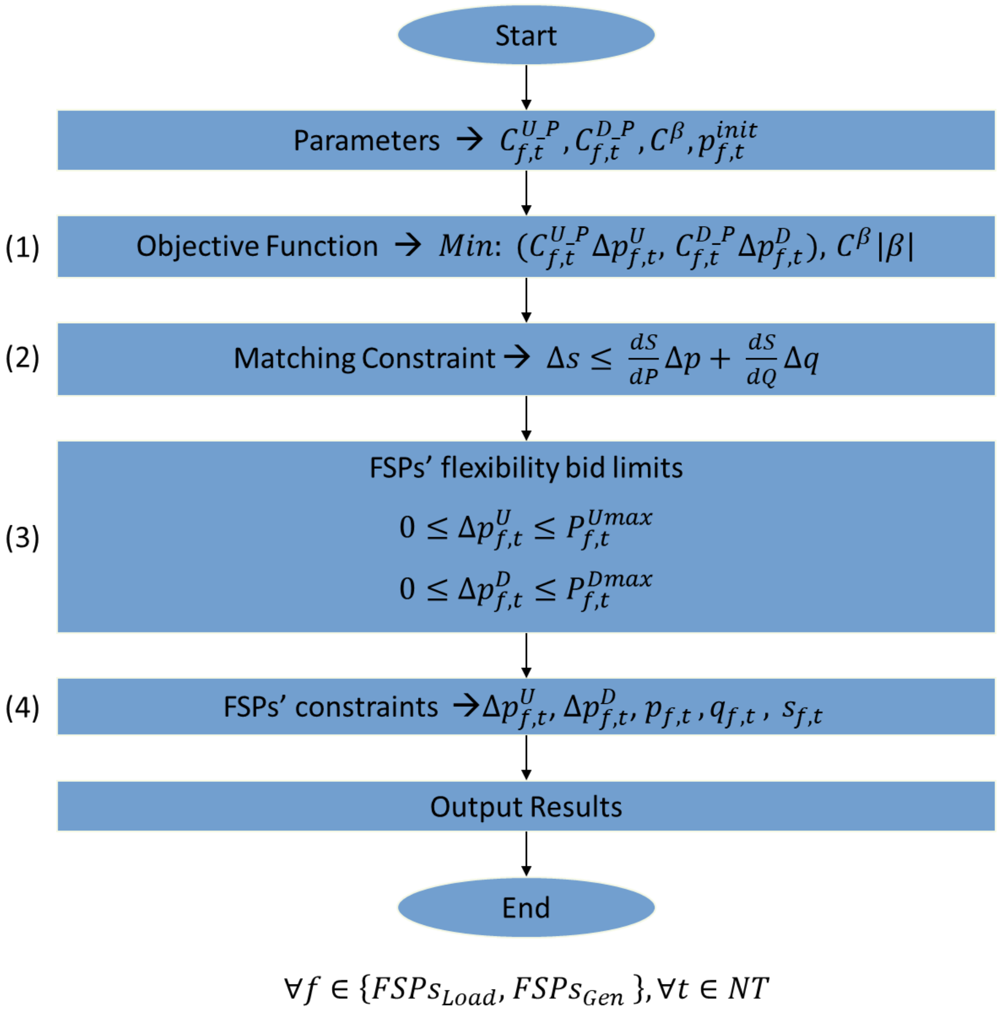

Figure 2.5: Market Model for Congestion Management Methodology

The objective function (1) of the Local Flexibility Market, LFM, is defined mainly by two components: First, the minimization of the flexibility procurement cost, C, considering active power flexibility bids from Services providers (SPs). This includes $C_{f,t}^{U\_P}\Delta p_{f,t}^{U}$, and $C_{f,t}^{D\_P}\Delta p_{f,t}^{D}$, for all f that belong to the set of flexibility providers

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and for all t within the whole timeframe. It considers the provision of both upwards, U, (Increase in generation or reduction in demand) or downwards, D (reduction of generation or increase in demand) active power, p, and their associated costs. Second, the minimization of not supplied flexibility for the congestion management component ($C^{\beta}|\beta|$). This last component corresponds to the potential flexibility that cannot be utilized or remains unexploited due to, among other factors, technical constraints.

Within the established model restrictions, a simplified representation of the flexibility matching constraint for congestion management (2), considers the sensitivity factors. These factors correlate the variation in apparent power with the changes in active or reactive power, respectively. Congestion typically arises from the restricted power capacity of certain lines or transformers. Consequently, it is crucial to examine how the power flow in these components responds to active power injections from SPs.

It also highlights the constraints associated with bid limits (3), along with the specific constraints of SPs (4), depending on whether they are categorized as generation or demand. This last block focuses the mathematical modelling of the SPs' load and generation. Each SP model accounts for capability limits when providing upward and downward flexibility for active power.

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3 Success Metric Analysis

3.1 Overview of demonstrations

The demonstrators in the Western Cluster cover a wide range of business and system use cases, with the aim of gaining valuable practical experience and demonstrating the feasibility and usefulness of the solutions developed in the OneNet project. The main focus areas of the Western Cluster demos are illustrated in Figure 3.1. The three demonstrators in Portugal, Spain, and France are dedicated to showcasing complementary aspects of the OneNet solution. Additionally, the Regional Business Use Case (RUC) involves the data exchange process among the OneNet Western cluster demonstrators through the use of OneNet Connector.

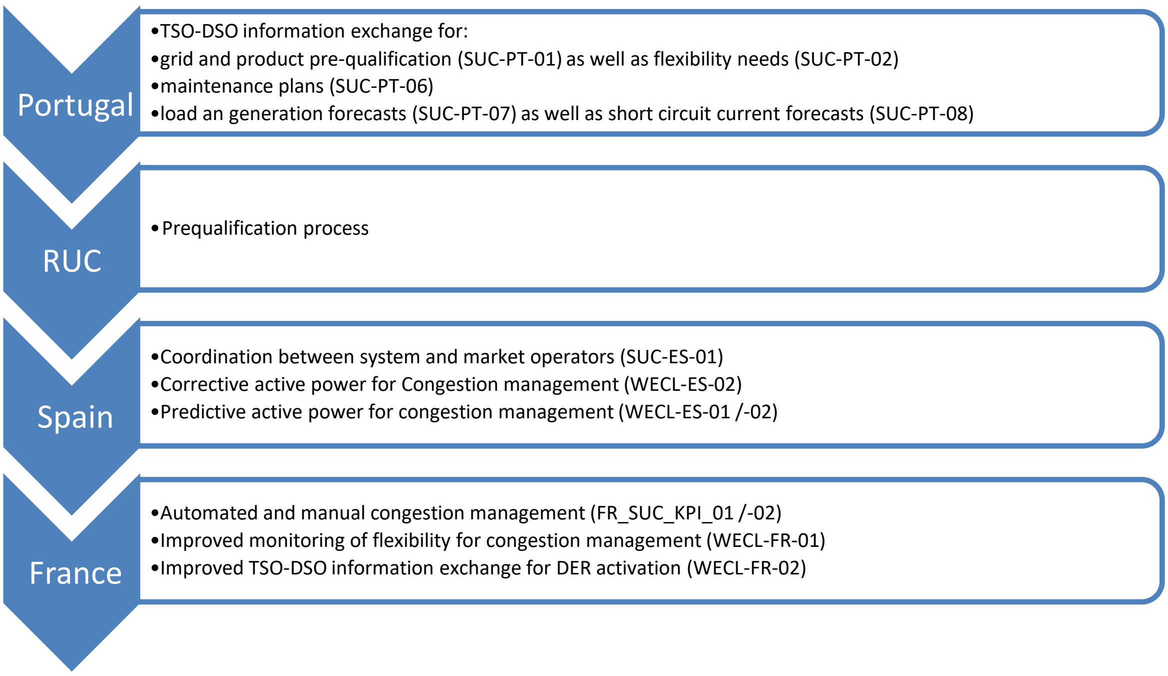

Figure 3.1: Demo focus areas

The order in which the demos are presented in Table 3.1 follows the real operational logic of the participating entities. That is, SPs need to be pre-qualified by the network and the market before they can be considered available to the network and market operators. In order to identify flexibility needs, some network operational considerations must first be taken into account. This means that planned maintenance at TSO and DSO level needs to be reliably and securely communicated between these operators. Making this information available to the respective interconnected network operators provides two main benefits. On the one hand, network reconfigurations have an impact on the short-circuit current potential throughout the network and therefore on its forecasting quality. On the other hand, information on the network configuration is crucial for forecasting flexibility needs and potentials. The latter, in particular, since the network configuration affects the impact of

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individual SPs on congestion or voltage problems at respective locations in the network. In addition to information on the network configuration, load and generation data are crucial for forecasting the operational state of the transmission and distribution networks. TSOs and DSOs therefore exchange their load and generation forecasts securely and reliably, which in turn improves their network operation forecasts or, more generally, their network operation.

Having identified the need for flexibility based on the above considerations, the SO can then turn to the market to obtain cost-optimal flexibility services to manage network congestions. This market-based congestion management can take place either as a corrective measure within the operational planning timeframe or in the short- and long-term network planning timeframe. In the long-term planning horizon, SPs therefore become candidates to replace or delay conventional network investments with high up-front costs and long lifetimes, often 40 years. This long asset lifetime stays in stark contrast to flexibility contracting with much shorter contracting periods, for example between one and five years. The short-term planning timeframe is the timeframe in which, for example, scheduled maintenance work is planned. As the DSO is to be enabled to contract even small SP units, an aggregator role is necessary and useful to increase the efficiency of the market to solve individual congestion problems at scale. Therefore, secure and reliable data exchange between the DSO, the market operator and the aggregator are essential.

It can be expected that market-based procurement of SPs will efficiently resolve congestions in the distribution network, thereby reducing especially the associated investment costs, provided that sufficient SPs are available at a competitive price; in other words, the ability to avoid re-sizing the network (based on robust planning) in many locations and to use flexibility on a selective basis can still reduce overall costs. In all situations where this is not the case, such as in rare but extreme events, TSOs and DSOs need effective measures to ensure continuous and reliable service to all customers. One such last-resort intervention is congestion management through curtailment of renewable energy sources (RES), such as photovoltaic systems. This type of SP activation for congestion management can be initiated at both the TSO and DSO levels and therefore requires efficient coordination between these actors as well as other involved roles such as the SP provider. In general, there are two broader aspects of coordination related to RES curtailment. One is the coordination between the TSO and the DSO to ensure that the curtailment of RES does not lead to unwanted contingencies at either network level. The other is the management of the entire lifecycle of a curtailment intervention, from the formulation of the flexibility offer, through activation and monitoring, to the measurement and settlement phase.

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3.2 Identification of objectives for Success Metric Analysis

In this section, the most relevant objectives to measure the demonstrator success are identified amongst those general objectives of the OneNet project:

1) To develop innovative market structure
2) To upscale, adapt, validate and test the OneNet architecture
3) To remove barriers to the commercial use of the innovative market structure

The selection is made based on the motivation of the project and the demonstrators focus, described in Section 3.1. The objectives identified most relevant when evaluating the success of the OneNet Western Cluster's demonstrator results are the following.

Consumer engagement: Strong Consumer engagement is one of the main objectives to enable sustained SP from decentralised energy resources. Achieving robust consumer engagement in the Western Demo ensures active and diverse consumer participation in demand response mechanisms. In doing so, the project will customize market solutions to suit individual preferences, incorporate input from consumers from different countries, and categorize prosumers in order to create market-driven flexibility services that are not only grid-enhancing, but also respond to the specific needs and choices of end-users. The creation and experimentation of diverse products for every flexibility service highlight the dedication to encouraging significant consumer engagement in the project's mechanisms, with the ultimate measure of success being the level of consumer engagement achieved.

Technical coordination: Reliable and efficient technical coordination is an objective that spans over various aspects of the systems and processes involved, from prequalification, through forward looking grid operation to the leveraging of flexibility markets and congestion management. This technical coordination, comprising information exchange and market coordination, is particularly relevant due to the diverse set of organisations and roles involved, each with their own systems and processes that need to interoperate reliably and efficiently. Some examples are TSO-DSO coordination, flexibility resource procurement and usage across countries borders, the technical coordination between market and grid operation as well as grid planning and SP settling.

Market environments / market assessment: The main objective of the "market environments/market assessment" component in the Western Demo is to incorporate varied flexibility approaches throughout Portugal, Spain, and France. This entails catering to the requirements of Distribution System Operators (DSOs) and Transmission System Operators (TSOs) while promoting coordination between market mechanisms and grid operations. The project intends to display the attainability of managing a variety of system operation requirements in a coordinated setting that involves consumers and prosumers. The demonstrator will evaluate the cost-effectiveness of various market strategies, such as spot markets, auctions, direct agreements, and flexible tariff schemes, with the aim of benefiting customers and supporting regulators in tariff design and

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compensation for regulated activities. The project will also investigate the integration of current regulatory return on investment with incentive mechanisms based on the quality of service delivered.

Compliance with ASM requirements: The goal of aligning with the Active System Management (ASM) requirements is to guarantee that the tested market model combinations meet the specifications and standards set in ASM [26]. To achieve this objective, it is necessary to implement flexible solution toolboxes, adopt unambiguous rules, and open interfaces. The aim is to simplify testing, evaluation, and adoption of best practices in a market setting. By trialling various platforms, regardless of ownership, the aim is to address both local and central needs across different timeframes and scenarios. Incorporating varied realities and findings from each Member State into the Western Demo and the wider OneNet initiative seeks to utilise these differences as valuable resources. This alignment not only enables rapid victories at the TSO-DSO-Consumer level but also stimulates an impartial assessment of technical and market solutions, cultivating a thorough comprehension and implementation of efficient practices.

Evaluate different platforms: The objective of the "Evaluation of different platforms" is to coordinate the Western Demos, ensure their efficient functioning and maximise their aggregated value at EU level. The task intends to lay down standardized definitions and follow-ups for products, services, market arrangements, and use cases within the Western Demo, including conducting preliminary assessments to determine alignment among Portuguese, Spanish, and French demonstrations. Given the diversity of market structures, this task ensures a clear and concise assessment of different market-based solutions and platforms, while considering the coordination schemes put forward in the OneNet project. The objective is to optimise the performance of the Western Demo, ensuring an efficient evaluation and alignment of different platforms across the participating nations.

These objectives will be used to measure the success of the demonstrators of the Western Cluster, based on the demonstrators quantitative (KPIs) and qualitative assessment.

3.3 Demonstrators KPI map

In this section, the KPI results from the individual demonstrators in the Western Cluster are mapped and analysed. Generally, all OneNet KPI are described in deliverable D2.4 [27] as well as in deliverable D11.1 [28], for those KPIs relevant for the demonstrators in the OneNet project. In deliverable D2.4, the KPIs are group in 8 groups, as shown in the first column of Table 3.1 [27]. In this table it is also shown if a demonstrator of the Western Cluster provides KPI results of the respective group defined in OneNet Deliverable D2.4. As can be seen in Table 3.1, the KPI results obtained from the demonstrators of the Western Cluster, do not fully overlap. This is because the demonstrators of the Western Cluster, as described in Section 13, cover various aspects of the flexibility service provision, from prequalification, forward-looking grid operation, through flexibility market operation to congestion management and settlement.

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Table 3.1: KPI groups, as defined in OneNet Deliverable D2.4

OneNet KPI groups	Spain	Portugal	France
GD - General descriptive	X	X	X
E - Economic	X	X	
ES - Environmental and social		X	
MP - Market performance	X	X	X
CM - Congestion management	X	X	X
DP - Data processing	X	X	X
NO - Network operation		X	
PP - Prequalification process	X	X	

In order to measure the success of the demonstrators, the KPIs obtained from deliverable D9.5 [11], D9.6 [12] and D9.7 [5] are mapped against the objectives defined in Section 3.2. That is, the influence of each KPI against each objective is estimated and linked in a mapping. As the KPI grouping provided in Table 3.1, is not helpful to map the various KPI results to these objectives, phases of ASM [26] are introduced, which cover the Western demonstrator system and business use cases well.

These phases of active system management are [26]:

- Prequalification process
- Forward-looking grid operation
- Flexibility markets
- Congestion management

Which are well-aligned with and follow the phases of active system management of the Western demonstrator overview provided in Section 3.1. Mapping these phases of active system management to the objectives described in Section 3.2, the high-level overview depicted in Table 3.2, is obtained.

Table 3.2: Mapping KPI phases of active system management to objectives

		phases of active system management			
		Prequalification process	Forward looking grid operation	Flexibility market	Congestion management
Objectives	Consumer engagement			X	
	Technical coordination	X	X	X	X
	Market environments / market assessment			X	
	Compliance with ASM requirements	X	X	X	X
	Evaluate different platforms	X	X	X	X

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While the overall mapping of demonstrator KPIs of the Western Cluster is provided in Annex A, the following analysis will focus on the KPI review across demonstrators for all KPIs that are member of each of the phases of active system management individually.

3.3.1 KPIs in phases of active system management: Prequalification process

In the following, all KPIs that are members of the phase of active system management "Prequalification process" are evaluated across the respective demonstrators. In this case, KPIs were obtained from the Portuguese demo as well as the Regional BUC (RUC) between Portugal and Spain.

Table 3.3: Western cluster demonstrators KPI results in active system management phase prequalification process

KPIs	***Description***	**KPI: RUC**	**KPI: PT**
KPI_N34	Successful ending of prequalification process		100%
KPI_N46	Nº prequalification process that needs additional information		100%
KPI_N48	SP acceptance	100%	
KPI_N49	Average Processing Time	1 hour	
KPI_N50	Cross SO Prequalification Acceptance	100%	
KPI_N51	Need for additional information for cross SO Prequalification	0%	

The results in the prequalification group shown in Table 3.3, present KPIs for the Portuguese demonstrator as well as the Regional BUC.

With respect to the objective of technical coordination, the demonstration process shows it to be a definite success. Relying on performance of the technical coordination between TSO and DSO for product and grid prequalification, the Portuguese demonstrator showed a 100% rate (KPI_N34 = 100%) of successful process execution. The indication that 100% of the data exchanges needed some additional information (KPI_N46 = 100%), does not result in hindrance of the process, as the "missing" data is only related to optional datapoints. The Regional BUC, which was concerned with the prequalification of SP across system operators from the countries of Spain and Portugal, also showed successful technical coordination, with a SP acceptance rate of 100 % (KPI_N48 = 100%) as well as a 100 % cross SO prequalification acceptance rate (KPI_N50 = 100%). In the case of the Regional BUC demonstration, the need for additional information exchange was 0 % (KPI_N51), indicating a robust data exchange process between the different system operators across countries and therefore regulatory zones. The average processing time of the cross-SO prequalification was 20 minutes (KPI_N49 = 1 hour), which can be interpreted as a successful achievement, considering that the prequalification process is operationally not urgent and robustness of the process should be prioritised over timely performance. It should also be noted that this time is also related to some problems encountered in the use of the OneNet connector. The time is expected to decrease in the deployment, where the use of the connector is a business as usual

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process. A more detailed analysis of the demonstration of the OneNet connector is described in OneNet Deliverable D9.9 [29]. However, it is to be noted that this processing time involves only the technical coordination between the SO, thus, excluding the actual prequalification processes (product and grid). Once implemented in the routine operation of the involved SO, organisational processes could largely extend this processing time. Therefore, it is recommended to ensure that efficient and secure digital processes are extended into the organisational processes, which has not been part of this project. The success of the technical coordination described above clearly demonstrates the successful achievement of the objective of compliance with ASM requirements. That is especially the case since the data exchange between the involved SOs, both in the Portuguese demonstrator as well as in the Regional BUC demonstration, is based on clear and unambiguous rules as well as open interfaces. These systems are used to support the fulfilment of flexibility needs across SO, considering their local as well as central needs. The objective of evaluating different platforms was also reached, particularly due to the successful execution of the Regional BUC that shows alignment between and coordination of the different platforms used in the participating countries.

3.3.2 KPIs in active system management phase: Forward looking grid operation

In the following, all KPIs that are members of the phase of active system management "Forward looking grid operation" are evaluated across the respective demonstrators. In this case, KPIs were obtained from the Spanish and Portuguese demo.

Forward looking grid operation is essential in power systems with high penetration of RES and new active loads. In distribution systems the goal is to coordinate these DER efficiently, relying on granular load and generation forecasts. These forecasts and the related forward-looking operational decision-making promise significant investment and operational savings as well as a higher overall efficiency. The Portuguese as well as Spanish demonstrators were concerned with the testing of forward-looking grid operation. Both successfully demonstrated the necessary technical coordination to allow for forecast-integrated grid and flexibility market operation. The Spanish demonstrator achieved an average load forecasting error of 10 % with a ± 6 % (KPI_H20B = 10 ± 6 %) deviation throughout the test cases. The application of this load forecast in the market-based flexibility procurement demonstrates, not only the successful coordination, but also indicates achieving the objective of compliance with ASM requirements.

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Table 3.4: Western cluster demonstrators KPI results in active system management phase forward looking grid operation

KPIs	***Description***	**KPI: ES**	**KPI: PT**
KPI_H20A (avg)	Error of the RES production forecast calculated T hours in advance, overall		5 ± 1 %
KPI_H20A (solar)	Error of the RES production forecast calculated T hours in advance, solar		3 ± 1 %
KPI_H20A (wind)	Error of the RES production forecast calculated T hours in advance, wind		7 ± 1 %
KPI_H20A (thermal)	Error of the RES production forecast calculated T hours in advance, thermal		4 ± 0 %
KPI_H20B	Error of load forecast calculated T hour in advance	10 ± 6 %	13 ± 8 %
KPI_H21B	Share of false positive congestion contingencies		0 ± 0 %
KPI_N25	Comparison between the Isc max forecasted for the 63kV by the planning and the maximum short circuit value registered for the series under analysis		139 ± 715 A
KPI_N30	Comparison of the rated short circuit current of the circuit breakers for the 63kV and maximum short circuit value registered for the series under analysis		7789 ±4365 A
KPI_N33 (avg)	Improvement of the forecast, overall		41 ± 28 %
KPI_N33 (solar)	Improvement of the forecast, solar		70 ± 4 %
KPI_N33 (thermal)	Improvement of the forecast, thermal		81 ± 0 %
KPI_N33 (wind)	Improvement of the forecast, wind		12 ± 9 %
KPI_N33 (load)	Improvement of the forecast		22 ± 15 %

The latter particularly due to the fact that grid operational needs are fulfilled by a market mechanism that relies on unambiguous rules and open interfaces. Regarding the evaluation of different platforms, it could be a future contribution to provide market-based flexibility between countries and SO, ensuring interoperability and heading for larger and more liquid market potential for SP. In the Portuguese demonstrator, the load forecast error achieved, was on average 13 ± 8 % (KPI_H20B = 13 ± 8 %), where the difference between the different sites was significant. Importantly, the load forecast error has significantly improved by 22 ± 15 % on average (KPI_N33 = 22 ± 15 %), when compared to the initial state without data exchange, demonstrating the achievement of the objective of technical coordination in the category of forward-looking grid operation. Besides load forecasting, the Portuguese demo also made use of generation forecasts, achieving an overall error of 5 ± 1 % (KPI_H20A = 5 ± 1 %) on average. This value is aggregated of the forecast accuracies of 3 ± 1 % for solar (KPI_H20A = 3 ± 1 %), 7 ± 1 % for wind (KPI_H20A = 7 ± 1 %) and 4 % for thermal generation (KPI_H20A = 4 ± 0 %). The objective of technical coordination has again been demonstrated as successful, due to the fact that the data exchange undertaken has not only allowed to improve the load forecast but also the generation forecast, achieving an overall improvement of about 41 ± 28 % (KPI_N33 = 41 ± 28 %). Within this aggregated improvement, the

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thermal generation forecast improved the most with 81 % (KPI_N33 = 81 ± 0 %). The solar forecast improved by 70 ±4 % (KPI_N33 = 70 ±4 %) and the wind forecast achieved an improvement of 12 ± 9 % (KPI_N33 = 12 ± 9 %), due to the additional data exchange. Overall, in the forward-looking grid operation, these forecasts allowed to predict network contingencies very well, with 0 % false positive contingency predictions (KPI_N21B = 0 ± 0%). The resulting 0% is due to the fact that no technical restrictions were identified. In addition to load and generation forecasting, the Portuguese demonstrator also tested the exchange of data between the Portuguese DSO and the TSO for improved operational planning, particularly with regard to short circuit capacity. The results of KPIs N25 (KPI_N25 = 139 ± 715 A) and N30 (KPI_N25 = 7789 ±4365 A) show system security within short circuit limits, but 19.3% of the cases exceed the TSO's 2022 estimate for the 63 kV interface, mainly due to active contributions from the DSO that, in the present time, are not being considered in the TSO development and investment plan. The results demonstrate the effectiveness of the proposed process in improving collaboration for network planning, indicating success in terms of both technical coordination and ASM requirements.

3.3.3 KPIs in active system management phase: Flexibility market

In the following, all KPIs that are members of the phase of active system management "Flexibility market" are evaluated across the respective demonstrators. In this case, KPIs were obtained from the Portuguese, Spanish and French demo.

Customer engagement is one of the major OneNet objectives, that is relevant in the demonstrators of the Western Cluster. The demonstrators of all three countries, Portugal, Spain, and France are aiming at engaging market-based flexibility for enhanced grid operation. Though, only the Spanish demonstrators contains the actual market operation within the demonstration phase. The other two, namely Portugal and France consider market-based or other flexibility procurement processes outside of the scope, and therefore focus rather on other aspects of demonstrating OneNet solutions, such as enablement of SPs and TSO-DSO coordination in the case of Portugal and SP activation and settlement in the case of France. While for the Portuguese demonstrator, customer engagement with a number of 250 SPs (KPI_H01 = 250) was shown to be successful for the demonstrator purposes, while the 7 engaged customers for the Spanish (KPI_H01 = 7) and 2 for the French demonstrator (KPI_H01 = 2) cannot show success in this objective. In the Portuguese (KPI_H02 = 100 %) and French (KPI_H02 = 100 %) demonstrators, all SPs were engaged 100%, while the Spanish demonstrator achieved a rate of 88 % (KPI_H02 = 88 %). The lower rate of SP active participation can be explained with the fact that the Spanish demonstrator actually demonstrated a market.

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Table 3.5: Western cluster demonstrators KPI results in active system management phase flexibility market

KPIs	Description	KPI: ES	KPI: PT	KPI: FR
KPI_H01	Number of SPs	7	250	2
KPI_H02	Active participation	88 %	100 %	100 %
KPI_H03	Cost-effectiveness	75 ± 14 %		
KPI_H04	ICT costs	+10 M€	184.150 €	
KPI_H07	Number of transactions	10		
KPI_H09A	Volume of transactions (Power)	6.63 MW	51.25 ±19.45 kW	
KPI_H09B	Volume of transactions – cleared bids (P or Q Availability)		0 kW	
KPI_H09D	Volume of transactions – cleared bids (P or Q Activation) (Energy)		0 MWh	4.984 MWh
KPI_H11	Number of products per demo	100 %		

The Spanish demonstrator exhibits room for improvement in customer engagement. Enhancements could stem from more attractive economic incentives for SP provision and flexibility products with shorter durations. Educating customers about the flexibility potential of their systems is also crucial. A key achievement of the Spanish demonstrator is the testing of 100% of the targeted products, reflecting success in market assessment and ASM compliance. This success is partly due to the testing of various products in an open market setting, facilitating the understanding of meeting both local and central system requirements. In terms of market environment objectives and flexibility market assessment, the Spanish demonstrator demonstrated effectiveness, particularly noted in the cost-effectiveness of 75 ± 14 % (KPI_H03 = 75 ± 14 %). This was achieved with a total transaction volume of 6.63 MW (KPI_H09A = 6.63 MW) across 10 transactions (KPI_H07 = 10).

In contrast, the Portuguese demo reported a transaction volume of 51.25 ± 19.45 kW (KPI_09A), with no identified flexibility needs leading to an inactive market, hence no cleared bids, resulting in both power (KPI_09B = 0 kW) and energy (KPI_09D =0 MWh) transaction volumes being zero. The French demonstrator also did not operate a market but activated flexibility for approximately 5 MWh (KPI_H09D = 4.984 MWh) in response to 5 identified congestion events.

The Portuguese and French demonstrators successfully demonstrated specific aspects. The French demonstrator effectively activated flexibility, and the Portuguese demonstrator efficiently exchanged data on flexibility needs. These outcomes reflect their success in technical coordination and adherence to ASM requirements. Additionally, the goal of evaluating different platforms was met by testing various systems. This includes the conventional systems in the Portuguese and Spanish demonstrators and a blockchain-based platform in the French demonstrator. The French demonstrator's STAR platform, utilizing existing market or flexibility procurement systems, successfully conducted automatic activations and settlements coordinated between the TSO and DSO. This contribution enriches the OneNet solution toolboxes. The STAR platform's

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approach, characterized by clear rules and open interfaces, facilitates participation in a multi-party trusted environment.

3.3.4 KPIs in active system management phase: Congestion management

In the following, all KPIs that are members of the active system management phase "Congestion management" are evaluated across the respective demonstrators. In this case, KPIs were obtained from the Portuguese, Spanish and French demo.

Table 3.6: Western cluster demonstrators KPI results in active system management phase congestion management

KPIs	*Description*	KPI: ES	KPI: PT	KPI: FR
KPI_H12	Number of avoided technical restrictions (congestions/ voltage violations)	100 %	0 %	
KPI_H13A	Congestion reduction (magnitude)	14 ± 3 %		
KPI_H14A	Available Flexibility	18 ± 7 %	0.15%	36.6%
KPI_H15A	Requested flexibility (Power)		0 kW	
KPI_H23A	Power exchange deviation	16 ± 27 %		
KPI_N26	Tracked flexibility			216
KPI_N26	Tracked flexibility (automatic)			213
KPI_N26	Tracked flexibility (manual)			3
KPI_N27	Total power of avoided congestions through flexibility activation.		0 kW	
KPI_N28	Maximum ratio of false-positive and negative congestion forecasts		0 %	
KPI_N31	Nº of congestions/violations on DSO network		0	
KPI_N32	Nº of congestions/violations on TSO network		0	

In the Spanish demonstrator, the 100 % of the simulated restrictions were avoided using market-based flexibility (KPI_H12 = 100 %). This was achieved by an average rate of congestion reduction of roughly 14 % (KPI_H13A = 14 ± 3 %), based on an average of 18 ± 7 % of power available as flexibility in the respective grid segment (KPI_H14A = 18 ± 7 %). In this demonstrator, the error between the SOs set-point of flexibility and the actual provision varied significantly, with an average of 16 ± 27 % of power exchange variation (KPI_H23A = 16 ± 27%). Therefore, the Spanish demonstrator shows successful technical coordination for grid-enhancing flexibility provision as well as success with respect to the objective of compliance with ASM requirements. As the Portuguese demonstrator did not activate flexibility, as there were no flexibility needs identified during the demonstration period, the number of avoided technical restrictions is naturally 0 %. Therefore, also a number of other KPIs in the Portuguese demonstrator obtain the value of 0 (KPI_H15A = 0 kW, KPI_N27 = 0 kW, KPI_N28 = 0%, KPI_N31 = 0, KPI_N32 = 0), while the available flexibility to resolve any potential congestions was on average 0.15% (KPI_H14A). The fact that the flexibility activation could not be tested was also based on the

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timing of the demonstrator, which coincided with low industrial load situation. The main reason is that the demonstration used real data and the networks are designed to solve at planning stage any possible operational problem (i.e., fit and forget approach) [30], so even if the demonstration took place at a time of high demand and low production, no need would be identified. It is important to note that this is expected to change in the future with increased penetration of DER, increased demand and increased use of flexible connections. The French demonstrator identified a flexibility potential of roughly 37 % (KPI_H14A = 36.6 %) available in the geographic area. One of the main concerns of the French demonstrator is the tracking of automatically and manually activated flexibility and its respective settling. The total number of tracked flexibility activations was 216 (KPI_N26 = 216), which is based on 213 tracked automatically activated flexibility activations (KPI_N26 = 213) and 3 manually activated flexibility activations (KPI_N26 = 3). The French demonstrator therefore showed successful in the objective of technical coordination as well as compliance with ASM requirements, particularly with respect to open interfaces, addressing local and global needs as well as TSO-DSO coordination.

Regarding the objective of the evaluation of different platforms, three different platforms have been used in the Western Cluster, which is an achievement per se. Nevertheless, it could be recommended to repeat the demonstration exercise for the Portuguese demonstrator in future research, in a loading situation where potential restrictions could be avoided using the available flexibility.

3.4 Other demonstrator experiences

Besides the KPI-based success metric analysis, some general findings can be made with respect to the success of the demonstrator experiences in the Western Cluster.

With regard to the objective of customer engagement, the Spanish demonstrator found that improvements could be made, particularly in terms of reducing behavioural, economic and technical barriers. These barriers are rooted in a lack of knowledge and trust in flexibility solutions, combined with a fear of economic penalties for failing to deliver on promised flexibility. This is understandable from a risk management perspective of inexperienced customers facing uncertainty. Reducing this risk to give the customer confidence could be a form of engagement, potentially making more flexibility available. In the Spanish demonstrator, the market environment and valuation objective can also be seen as successfully achieved, as the demonstrator has brought the flexibility market closer to end users developing a market platform for technical co-ordination between network and market operators. This affected both the use of OneNet standard solutions and their interoperability, particularly at the communication level. The testing of these systems by different SOs initially showed difficulties in technical coordination, but the testing of different platforms can be seen as a positive achievement, as the lessons learned will further improve the objective of technical coordination and compliance with ASM requirements.

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In the Portuguese demonstrators, the experience with TSO-DSO coordinated short circuit current forecasting, exchange of maintenance schedules and other learning related to forecasting enhanced by measured data for forward-looking grid operation stand out as successes with respect to the objectives of technical coordination and compliance with ASM requirements.

In the French demonstrator, the STAR platform tested automatic activation and settlement coordinated between TSO and DSO using existing market or general flexibility procurement systems, adding solutions to the OneNet solution toolbox. The STAR platform approach is based on clear rules and open interfaces that allow participation in a trusted multi-party environment. The STAR platform was tested and found to be more difficult to implement due to the non-standardised technology but promised better performance in a multi-party environment. Simplifies back-office management and increases transparency and confidentiality-based trust. The fact that the IT/OT infrastructure tested in the Western Cluster demonstrators represents a successful achievement of the OneNet objective of evaluating different platforms.

3.5 Main findings from the Success Metrics Analysis (SMA)

In conclusion, the SMA of the OneNet Western Cluster demonstrators' results provides a nuanced and comprehensive understanding of the project's achievements and challenges. The identified objectives, including consumer engagement, technical coordination, market environment, ASM compliance and evaluation of different platforms, provided critical benchmarks for measuring success.

Analysis of the KPIs across the demonstrators reveals a tapestry of success. In the prequalification process, technical coordination was a resounding success, with a 100% successful process execution rate and cross-SO prequalification acceptance. Forward-looking network operation showed accurate load forecasting and improved generation forecasting, underlining the success of technical coordination and compliance with ASM requirements.

Flexibility market evaluations showed varying levels of customer engagement, with the Spanish demonstrator leading in market operation. Despite differences, all demonstrators demonstrated technical coordination success and compliance with ASM requirements. Congestion management efforts effectively avoided technical constraints, particularly in the Spanish demonstrator, where market-based flexibility played a key role.

Beyond the KPIs, the experience of each demonstrator provided qualitative insights. The Spanish demonstrator dealt with customer engagement and technical coordination of local market actors, the Portuguese demonstrator addressed TSO-DSO coordination and improved forecasting, while the French demonstrator introduced the innovative STAR platform to improve the coordination between TSO, DSO and SP to address joint management of curtailment flexibilities.

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The journey of the OneNet Western Cluster illustrates the multifaceted nature of energy system transformation. Successes in market-based solutions, coordination mechanisms and platform evaluations underline the impact of the project. Challenges encountered, such as technical coordination difficulties, provide valuable lessons for future endeavours.

In essence, the SMA highlights the resilience, adaptability and collaborative spirit of the OneNet project. The achievements and lessons learned from the Western Cluster demonstrators are helping to shape the future of the OneNet initiative. As Europe moves towards a more sustainable and integrated energy landscape, the OneNet project stands as a pioneering force, driving innovation and transformation towards a resilient and adaptive energy ecosystem.

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4 Qualitative SRA

The aim of the Scalability and Replicability Analysis (SRA) carried out on the solutions developed and tested in the Western Cluster demonstrators is to assess their potential for expansion and replication. In other words, it aims to predict the expected results if these proposed solutions were to be implemented elsewhere or on a larger scale. This section presents the qualitative SRA, focusing in particular on the analysis of non-technical factors that could affect scalability and replication. On the one hand, the qualitative SRA addresses aspects of replicability by examining the structural analysis of standardisation and interoperability in terms of ICT standards, protocols and communication links between stakeholders. On the other hand, the non-technical constraints considered in the scalability analysis include regulatory issues, business model constraints and key stakeholder perspectives. In the first step, the relevant SRA aspects are identified by demonstrator, which in the second step are then evaluated. Due to the specific methodology of the qualitative SRA on ICT aspects, this part of the SRA is treated separately and presented in Section 4.3.

4.1 Discussion of relevant SRA aspects in the Western Cluster demos

In this section, the scalability as well as replicability aspects that are most relevant for the demonstrators of the Western Cluster are identified and discussed.

Generally, barriers for scalability of OneNet solutions that stem from *business model constraints* are considered most relevant and discussed in the following. The most relevant barriers for replicability of OneNet solutions are identified as *regulatory issues* as well as other barriers based on the *perspectives of the stakeholders*.

Based on the analysis presented in OneNet deliverable D11.2, the most relevant barriers for product harmonisation are identified for the demonstrators of the Western Cluster. These are the technical barriers:

- *ICT challenges:* Due to the challenges in Information and Communication Technology (ICT), information exchange is not feasible, making cooperation impossible and eliminating the possibility of harmonizing products.
- *Structure of the grid:* The precise requirements of the grid's structure, topology and installed technology within a particular market area create limitations on certain attributes or product usage, rendering harmonization unnecessary in some cases.
- *SO maturity:* Different levels of maturity of SOs in the procurement of their flexibility can pose another barrier. More specifically, TSOs are typically well accustomed to EU harmonization while DSOs are just beginning to develop markets and products for local services.

And also the economic barrier:

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- *Competition/liquidity:* The market's competition and liquidity may be adversely affected by product harmonization. When a service's requirements are highly specific, often influenced by local factors like grid design and condition, adopting harmonized products could impede the entry of service providers into the market.

Other relevant barriers related to product harmonisation identified in the Western Cluster were the following. The technical barrier of *diverging requirements* for different services for different SOs that make harmonization impossible. The economic barrier of the *economic development stage which varies across different system services and System Operators* (SOs), exemplified by distinctions between balancing products and those catering to local services like congestion management and voltage control. The regulatory barrier of the *national grid code or other regulation imposing certain limitations*, or necessary specifications that are not included (yet). And the barrier of *cultural differences* between countries and stakeholders do not allow for harmonization.

In line with the analysis presented in OneNet deliverable D11.6 [9], three categories of regulatory barriers are identified. These three subcategories are:

- definition of roles and responsibilities,
- economic incentives,
- and lack of additional enabling regulation to establish flexibility markets.

Furthermore, D11.6 found that the non-existence of local flexibility markets is based on the lack of enabling regulation that can be considered a major limitation for business model scalability [9]. This barrier due to lack of regulation is further detailed by the fact that the main roles in flexibility markets are not defined. The missing roles identified as most relevant in the Western Cluster demos are the *independent aggregator* as well as the *independent market operator*. Other key aspects of missing regulation for functioning flexibility markets are measurement of available and provided flexibility (baselining and observability), TSO/DSO coordination (particularly regarding prequalification, registration, product definition, data exchange between markets), constraints regarding metering and submetering and mixed flexibility portfolios (load and generation).

Another barrier for scalability of OneNet business models has been identified in the lack of appropriate remuneration schemes, particularly related to Capex vs. Totex remuneration schemes. That means, as non-conventional grid expansion that is characterised by lower Capex and higher Opex which still has lower Totex than conventional expansion is, is not incentivised, due to a remuneration schema that is centred around Capex remuneration. As well as the lack of appropriate pricing schemes that hinder the mobilization of flexibility and therefore the scaling of OneNet business models. These pricing schemes are related to the appropriate pricing of network investments as well as the coordination between the network pricing and the flexibility market.

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The barriers of customer engagement have been analysed in OneNet deliverable D11.5, where four categories of barriers have been identified, economic, behavioural legal and technical [10]. Those barriers to customer engagement can limit scalability of OneNet solutions. By category, these are:

Economic barriers to customer engagement:

- *Limited value of flexibility:* The economic value of flexibility is currently limited, which hinders consumer participation in flexibility initiatives due to factors such as inappropriate business models for different prosumer categories, high upfront investments, uncertain returns, and challenges in aligning market timing and processes. In addition, tariff structures, existing optimisation strategies, alternative costs and potential negative impacts on other energy cost components all contribute to barriers to consumer participation in flexibility markets.
- *A risky business in an uncertain environment:* The second category of economic barriers to customer engagement in flexibility markets stems from perceived risks in an uncertain environment. Challenges include a lack of clarity in the business case for consumers, limited knowledge of energy use and flexibility potential, difficulty in estimating future financial gains, and unclear allocation of costs and benefits, all of which contribute to uncertainty and reduce the economic benefits for individual suppliers.
- *Current market and product design:* The third category of barriers to flexibility market participation relates to economic challenges arising from current market and product design. High administrative and transaction costs, lack of uniform registration procedures, complex technology requirements, lack of appropriate baseline methodologies for low-voltage customers, and product attribute specifications such as minimum bid size or duration create barriers that make it difficult for customers, especially economically vulnerable groups, to participate in fair and open competition in flexibility markets.

Behavioural barriers to customer engagement are:

- *Lack of awareness:* Energy is seen as a 'derived demand', valued by customers not for its own consumption but for the services it enables through appliances. Despite being a constant aspect of life, energy remains intangible and represents a relatively small proportion of household expenditure, making it difficult for customers to relate their daily habits to energy consumption. Limited awareness and misconceptions about electricity use further inhibit customers' motivation to invest time in understanding their energy consumption, highlighting the potential impact of improved understanding on reducing overall electricity demand.
- *Lack of skills to elaborate on information*: Awareness alone is not enough to engage customers; they need tools to process information and make decisions, especially in the complex and technical realm of energy-related choices. Search activities are perceived as costly, involving mental effort, time and potential monetary expenditure, with limited knowledge and uncertainty acting as barriers to market

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participation, while factors such as the Technology Acceptance Model highlight the importance of perceived ease of use and usefulness in the adoption of new technologies.

- *Status-quo bias:* Status quo bias, characterised by the maintenance of current decisions, can be attributed to transaction costs, uncertainty in decision making, cognitive misperceptions such as loss aversion, and psychological commitment. Loss aversion, associated with reduced investment in efficiency and higher risk premiums, contributes to customer inertia, which can be seen in behaviours such as reluctance to switch suppliers and distrust of market players, especially when dealing with complex tariff structures.

Legal barriers to customer engagement are:

- *Market exclusion:* Regulatory and policy frameworks in the EU can hinder customer participation in demand response programmes and the provision of flexibility, with challenges including a lack of harmonisation for independent aggregators, missing or underdeveloped legal frameworks to enable flexible demand aggregation and define the necessary roles and responsibilities of the actors involved, and barriers to the deployment of new technologies. In addition, the lack of a supportive regulatory environment for active distribution system operators (DSOs) and the need for equal treatment of flexibility service providers are barriers to promoting a competitive flexibility market and ensuring fair participation of customers.
- *Contract issues:* Flexibility contracts often lack customer-friendly termination options, and customers face challenges in understanding their energy contracts due to unclear terms and conditions. In the private rented sector, barriers to customer engagement are exacerbated by the 'split incentive' problem, which prevents tenants from making long-term changes to their property without the cooperation of the landlord.
- *Data privacy and access to information:* The implementation of demand response (DR) programmes relies on sophisticated technologies such as smart meters, but the lack of regulation to ensure customer awareness and consent to shared energy data raises privacy concerns, including the inference of sensitive information, discriminatory customer segmentation, ownership disputes in shared housing, and uncontrolled data aggregation. Legislation such as the General Data Protection Regulation (GDPR) addresses some concerns, but challenges remain, including potential misuse of data over time, vulnerability to cyber-attacks, and the need for clear rules on data collection and use by energy service providers.
- *Lack of standards and interoperability:* The lack of standardisation and guidelines in the area of flexibility hinders its implementation, in particular when scaling up demo projects to be applicable to geographically diverse objects with different distribution system operators (DSOs). The European Commission emphasises the importance of interoperability and plans initiatives, including implementing acts on interoperability requirements for data access and a code of conduct for energy

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smart appliances, but challenges remain, such as the absence of EU minimum requirements for interoperability and rules to prevent vendor lock-in, highlighting the need for continuous adaptation of standards to the evolving technological and regulatory landscape.

The technical barriers to customer engagement are:

- *Lack of infrastructure and harmonised architecture:* Technical barriers to customer engagement in flexibility markets are related to infrastructure constraints and the architecture of existing systems. The choice of appropriate contracts, particularly control-based contracts that require customers to cede control of certain appliances, poses challenges, energy-efficient and programmable appliances are required, and the absence or technical problems with smart meters can hinder engagement. Interactions between service providers (SPs) and complex systems, closed IT environments, limited inclusivity, one-way data flow and the importance of two-way data exchange for innovative models such as peer-to-peer trading highlight the need to overcome technical constraints for effective customer participation in flexibility markets.
- *Data exchange:* Barriers to data exchange and communication protocols for flexibility markets include the lack of consent mechanisms for sharing data with third parties, which prevents service providers (SPs) from accessing customer data. In addition, the lack of standards, different data models, non-uniform interfaces and the increasing volume of data generated by smart devices pose challenges, requiring significant investment in infrastructure and knowledge of big data management for effective interpretation and use by SPs.
- *Interface design and communication:* Barriers in energy flexibility markets related to design and communication challenges include the lack of a single point of contact and coordination between utilities and distribution system operators (DSOs), which leads to customer confusion and hinders effective data exchange. Usability and cost issues with energy management systems, customised web-based models and the need for sustained connectivity across multiple channels pose additional challenges, highlighting the importance of user experience and usability for successful customer engagement with demand response products and services.

4.2 Evaluation of relevant SRA aspects in the Western Cluster demos

In the previous section, the aspects related to the scalability and replicability of OneNet solutions discussed in deliverables D2.4 [27], D11.4 [8], and D11.6 [9] have been summarized. As these often overlap, being discussed from different viewpoints, a concise list of those aspects related to scalability and replicability is presented in Table 4.1. In this table, the relevance of the presented aspects is evaluated qualitatively with respect to their impact on scalability and replicability of OneNet solutions. As can be seen in Table 4.1, aspects that have been discussed in the previous section or more general in deliverables D2.4 [27], D11.4 [8], and D11.6

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[9] that were not considered particularly relevant for scalability and replicability of OneNet solutions, are not presented. Therefore, only aspects that are considered relevant or highly relevant are presented below.

Table 4.1: Summarized imitating aspects to scalability and replicability of OneNet solutions

Regulatory, legal, economic, technical, behavioural and social aspects	**affecting: scalability**	**affecting: replicability**
Technical and regulatory barriers due to lack of or possibility to harmonise architecture and product requirements, including local technological conditions, resulting diverging requirements and impeding national grid codes and regulations.	highly relevant	highly relevant
Behavioural and related legal barriers that hinder flexibility market engagement by customers, due to lack of awareness and understanding as well as a bias to status-quo and data privacy and security concerns.	highly relevant	relevant
Technical barriers related to information and communication technology, including lack of standardised data exchange and communication interfaces and processes	relevant	relevant
Regulatory, legal, economic and social barriers that impede a liquid market with harmonised product design, due to lack of standardisation and interoperability as well as cultural differences that prevent stakeholders from harmonising.	highly relevant	highly relevant
Lack of regulation on measuring and flexibility, allowing for innovative product portfolios, proper baselining, observability and metering.	highly relevant	highly relevant
Regulatory, legal and economic barriers that reduce attractiveness for customers to engage in new flexibility markets, including unattractive contracts and lack of opportunities.	highly relevant	highly relevant
Regulatory and economic barriers that make flexibility unprofitable, due to the lack of appropriate network and flexibility pricing schemes as well as the related remuneration of grid expansion cost.	highly relevant	highly relevant
Regulatory barriers due to a lack of clear definitions[3] for the roles in flexibility markets, such as independent aggregators and independent market operators.	relevant	highly relevant
Technical barriers due to non-readiness of SO engaging in open and innovative environment.	relevant	relevant

4.3 SRA for ICT aspects

[3] It is worth noting that the ACER "Framework Guideline on Demand Response" [31] and the ENTSO-E, EUDSO "Draft Proposal for a Network Code on Demand Response" [32] are currently contributing to improving the regulatory framework on these aspects. However, the process is ongoing and further efforts are needed to achieve stable regulation at national level.

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4.3.1 Results

In this section, the ICT SRA results for the Portuguese, French, and Spanish demo are presented. Two main REST APIs are implemented in the Portuguese demo, Figure 4.1 shows their compliance with the best practices for REST API design based on the information provided by the Portuguese demo partners:

- **DSO Data Exchange Platform API:** This API is used for communications with the DSO Data Exchange Platform (DEP).
- **TSO Data Exchange Platform API:** This API is used for communications with the TSO DEP.

On the other hand, the French demo only implements one REST API, whose results are shown by Figure 4.2:.

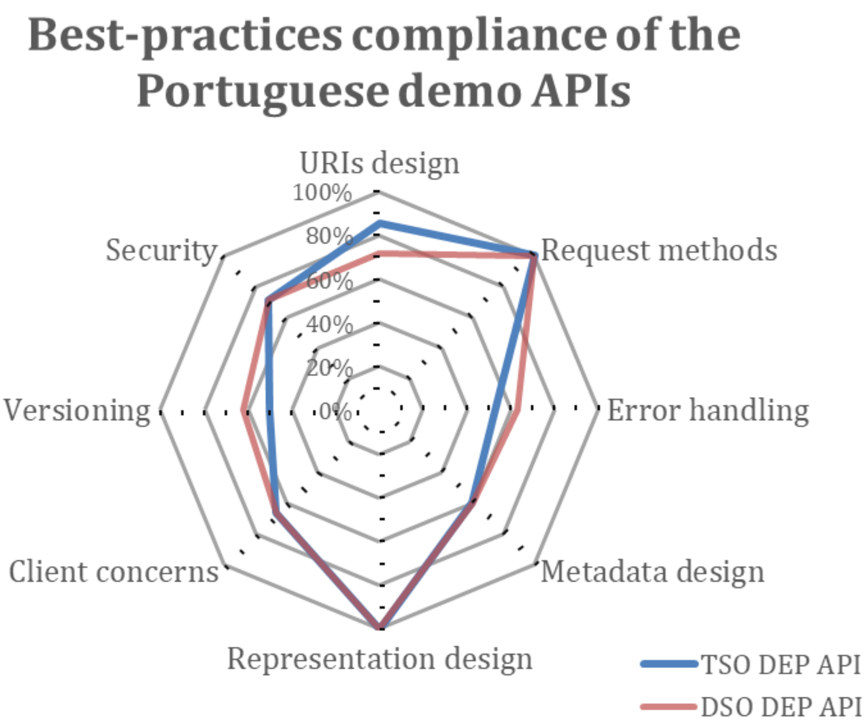

Figure 4.1: Compliance of the TSO and DSO DEP APIs of the Portuguese demo with the best practices for the design of REST APIs that have an impact on its scalability and replicability

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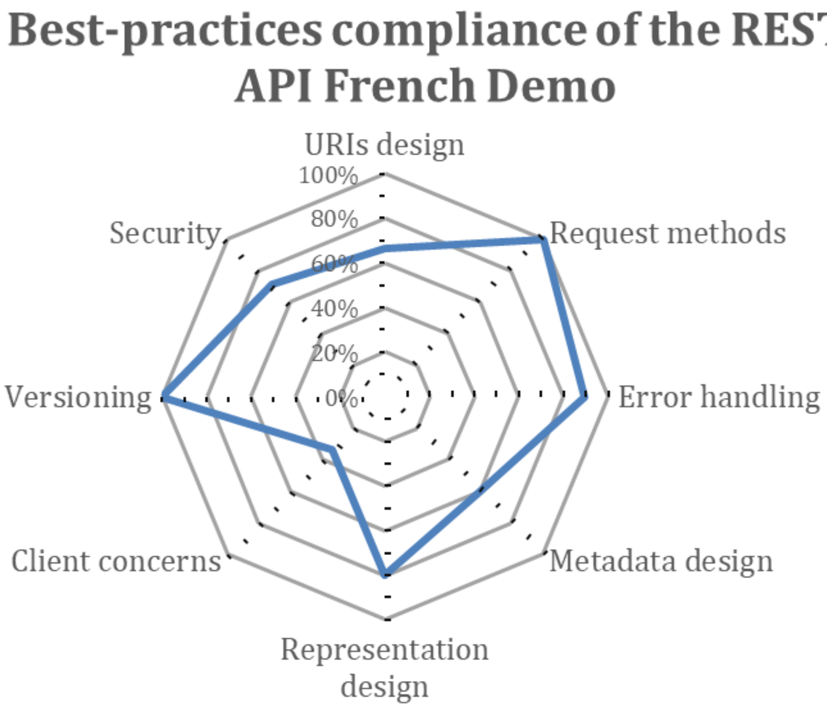

Figure 4.2: Compliance of the French demo API with the best practices for the design of REST APIs that have an impact on its scalability and replicability.

The Portuguese demo DSO DEP API and the TSO DEP API got a score of 71.4% and 85.71% in **URI design**, respectively. On the other hand, the API implemented in the French demo got a score of 67%. The main practices that are not followed by the APIs are (Table 4.2):

- Using plural nouns for store and collection names: This good practice helps to keep consistency throughout the API and makes it more intuitive for developers, as most programming languages and frameworks set plural nouns for arrays or lists. This practice also improves readability and provides intent clarity: a plural noun indicates that multiple items are expected to be returned by the API. The TSO DEP API follows this practice for the collection names, whereas the other two APIs do not.
- Avoid version number in the path: Both the DSO and TSO DEP API will include the version number in the URI path. URIs should focus on the identification of resources and actions. Including the version number in the path can affect the stability of the URIs over time; if new versions of the API are released in the future, the URI paths will change as well, potentially breaking links and dependencies in applications using the API. This may hinder the long-term maintenance of the API and its future replicability.
- Keep API as part of the subdomain: This practice allows to better distinguish the API functionality from other services within the same domain. For scalability, this facilitates the introduction of new services without disrupting existing endpoints.

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Although the French demo API complies with some practices that the Portuguese APIs do not (e.g., keep API as part of the subdomain), it does not use consistent subdomain names, path variables to separate elements of a hierarchy, hyphens, and lowercase letters in URI paths. These practices are mainly oriented at improving the readability and understandability of the API, so future developers may find it more difficult to work with this API.

Table 4.2: Best practices for URIs design in the Portuguese and French demo APIs

Category: URIs Design	Portuguese demo		French demo
	DSO DEP	TSO DEP	
A trailing forward slash (/) should not be included in URIs	Yes	Yes	Yes
File extensions should not be included in URIs	Yes	Yes	Yes
A plural noun should be used for store names	No	No	No
A verb or verb phrase should be used for controller names	Yes	Yes	Yes
The query component of a URI may be used to filter collections or stores	Yes	Yes	Yes
Forward slash separator (/) must be used to indicate a hierarchical relationship	Yes	Yes	Yes
Hyphens (-) should be used to improve the readability of URIs	Yes	Yes	No
Underscores (_) should not be used in URI	N/A	Yes	Yes
Lowercase letters should be preferred in URI paths	Yes	Yes	No
A singular noun should be used for document names	Yes	Yes	Yes
A plural noun should be used for collection names	No	Yes	No
Variable path segments may be substituted with identity-based values	Yes	Yes	Yes
Avoiding version number in the path	No	No	No
Avoiding version number in the query parameters	Yes	Yes	Yes
Avoiding CRUD actions in query parameters	Yes	Yes	Yes
Consistent subdomain names should be used for the API	N/A	Yes	No
CRUD function names should not be used in URIs	Yes	Yes	Yes
Use path variables to separate elements of a hierarchy, or a path through a directed graph	Yes	Yes	No
API as part of the subdomain	No	No	Yes
The query component of a URI should be used to paginate a collection or store results.	Yes	Yes	Yes
Keeping as much information as possible in the URI, and as little as possible in request metadata	Yes	Yes	Yes

Regarding best practices when using HTTP **request methods** and **representation design**, shown by Table 4.3 and Table 4.4, respectively, both APIs in the Portuguese demo got the maximum score of 100%. Since the TSO DEP API is expected to not use the HEAD method, it was not considered when calculating its final score.

For the French API, the maximum score is only achieved for the request method, as the API does not use XML/JSON for resource representation, obtaining a score of 80% in representation design. Nevertheless,

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following this practice is found not to be essential for the scalability and replicability of the API, so no further impact can be expected.

Table 4.3: Best practices for HTTP request methods in the Portuguese and French demo APIs

Category: Request methods	Portuguese demo		French demo
	DSO DEP	TSO DEP	
PUT must be used to both insert and update a stored resource	Yes	Yes	Yes
GET and POST must not be used to tunnel other request methods	Yes	Yes	Yes
GET must be used to retrieve a representation of a resource	Yes	Yes	Yes
POST must be used to create a new resource in a collection	Yes	Yes	Yes
POST must be used to execute controllers	Yes	Yes	Yes
DELETE must be used to remove a resource from its parent	Yes	Yes	Yes
HEAD should be used to retrieve response headers	Yes	N/A	Yes
PUT must be used to update mutable resources	Yes	Yes	Yes

Table 4.4: Best practices for representation design in the Portuguese and French demo APIs

Category: Representation design	Portuguese demo		French demo
	DSO DEP	TSO DEP	
XML / JSON may optionally be used for resource representation	Yes	Yes	No
Minimize the number of advertised "entry point" API URIs	Yes	Yes	Yes
Consistent form to represent media type formats	Yes	Yes	Yes
Consistent form to represent media type schemas	Yes	Yes	Yes
Consistent form to represent error responses	Yes	Yes	Yes

For **handling errors**, the APIs show a significant difference in their final score. Starting with the Portuguese API, the TSO DEP API presents a score of 52.63% while the one for the DSO DEP API is 63.1%. However, it should be considered that demo partners were not sure about three practices in the TSO DEP API, so the score for both APIs could potentially be the same. On the other hand, the French API has an outstanding 89.4%, with only two practices not followed, as shown by Table 4.5. Adopting good error handling practices help developers to understand issues, solve them faster, and develop more stable applications.

Table 4.5: Best practices for error handling in the Portuguese and French demo APIs

Category: Error handling	Portuguese demo		French demo
	DSO DEP	TSO DEP	
200 ("OK") should be used to indicate nonspecific success	Yes	Yes	Yes
200 ("OK") should not be used to communicate errors in the response body	Yes	Yes	Yes
201 ("Created") must be used to indicate successful resource creation	Yes	Yes	Yes

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202 ("Accepted") must be used to indicate successful start of an asynchronous action	Yes	Yes	Yes
204 ("No content") should be used when the response body is intentionally empty	No	No	Yes
301 ("Moved permanently") should be used to relocate resources	Yes	N/A	Yes
302 ("Found") should not be used	Yes	N/A	Yes
304 ("Not modified") should be used to preserve bandwidth	No	N/A	Yes
400 ("Bad request") may be used to indicate nonspecific failure	Yes	Yes	Yes
401 ("Unauthorized") must be used when there is a problem with the client's credentials	Yes	Yes	Yes
403 ("Forbidden") should be used to forbid access regardless of authorization state	Yes	Yes	Yes
404 ("Not found") must be used when a client's URI cannot be mapped to a resource	Yes	Yes	Yes
405 ("Method not allowed") must be used when the HTTP method is not supported	No	No	Yes
406 ("Not acceptable") must be used when the requested media type cannot be served	No	No	Yes
409 ("Conflict") should be used to indicate a violation of resource state	No	No	Yes
412 ("Precondition failed") should be used to support conditional operations	No	No	No
415 ("Unsupported Media Type") must be used when the media type of a request's payload cannot be processed	No	No	No
500 ("Internal Server Error") should be used to indicate API malfunction	Yes	Yes	Yes
Use JSON as error message response	Yes	Yes	Yes

Regarding the **metadata design** of the APIs (Table 4.6), the Portuguese APIs present a 60% best-practices compliance, whereas the French API presents 60% compliance. The use of caching is uncertain by the Portuguese demo partners, so the score for the Portuguese API could potentially increase if finally implemented. Only one practices is clearly not followed by both the DSO DEP and French API: the use of location to specify the URI of a newly created re source. This is a common practice in REST architectures, as it simplifies the integration of client applications and prevents them from creating duplicated resources. It also improves interoperability and facilitates the use of the API by developers in the future (i.e., potential scalability and replicability).

Table 4.6: Best practices for metadata design in the Portuguese and French demo APIs

Category: Metadata Design	Portuguese demo		French demo
	DSO DEP	TSO DEP	
Content-length should be used	Yes	Yes	Yes
Location must be used to specify the URI of a newly created resource	No	N/A	No
Caching should be encouraged	N/A	N/A	No
Content-Type must be used	Yes	Yes	Yes

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Custom HTTP headers must not be used to change the behaviour of HTTP methods	Yes	Yes	Yes

For how the APIs deal with **client concerns** (Table 4.7), the Portuguese and French APIs got a score of 66.7% and 33.3%, respectively. The only practice that was not followed (Portuguese DSO DEP API and French API) or whose compliance was uncertain (TSO DEP API) was related to the use of the query component of a URI to support partial response. Partial responses provide flexibility by allowing clients to request only some specific properties from a resource, minimizing bandwidth usage and processing time, which may relevant when scaling up the system. In addition to this, the French API does not support Cross-Origin Resource Sharing (CORS). CORS simplifies the development process for client-side developers, provides security by specifying which origins can access the API, and ensures compliance with web standards.

Table 4.7: Best practices with respect to client concerns in Portuguese and French demo APIs

Category: Client concerns	Portuguese demo		French demo
	DSO DEP	TSO DEP	
The query component of a URI should be used to support partial response	No	N/A	No
CORS should be supported to provide multi-origin read/write access from JavaScript	Yes	Yes	No
New URIs should be used to introduce new concepts	Yes	Yes	Yes

Regarding **versioning** (Table 4.8), only the French API gets a 100% compliance, while the DSO DEP API presents a score of 62.5% and the TSO DEP API a score of 50%, since the practice of incrementing the major version when incompatible API changes are made remains uncertain for this last one. The three best practices that are not followed by the Portuguese APIs are the same:

- Increment minor version when functionalities are added in a backward compatible way: This practice is related to consistency and predictability. As it is aligned with common versioning best practices, it would make it easier for future developers to work with the API. It also indicates to clients that they can safely upgrade to new versions without modifying their functioning, so it is relevant for the scalability and replicability of the API.
- Increment patch version when backward compatible bug fixes are made: By clearly indicating that the new version includes bug fixes, clients can be aware of the changes and safely update to the new version of the API.
- Increment draft version when changes are made during the review phase that are not related to production releases: although this practice has a reduced effect on scalability and replicability, it would help to continue expanding the APIs in the future.

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In addition to this, none of the APIs change the logic for handling the response from one version to another but put the version in the URL. For this case, the recommended approach is to put the version in the header and not in the URL [19].

Table 4.8: Best practices for versioning in the Portuguese and French demo APIs

Category: Versioning	Portuguese demo		French demo
	DSO DEP	TSO DEP	
Increments major version when incompatible API changes are made	Yes	N/A	Yes
Increment minor version when functionalities are added in a backward compatible way	No	No	Yes
Increment patch version when backward compatible bug fixes are made.	No	No	Yes
Increment draft version when changes are made during the review phase that are not related to production releases	No	No	Yes
API extensions do not take anything away	Yes	Yes	Yes
API extensions de not change processing rules	Yes	Yes	Yes
API extensions do not make optional things required	Yes	Yes	Yes
Anything added in the API extension is optional	Yes	Yes	Yes

Finally, the last category of best practices is related to security, where all the APIs present a score of 71.4%. The French API implements partially the practice of Zero Trust Network access: the communications between members of the network are validated using server and client certificates, but some internal services are not validated this way. As shown in Table 4.9, all the APIs implement HTTPS and OAuth, achieving a great security basis.

However, throttling and quotas are not implemented, which makes it possible for a client or group of clients to monopolise the system resources, which is relevant when scaling up the solution and when suffering denial of service (DoS) attacks. Throttling and quotas allow optimal response times to be maintained and make sure that the API can efficiently handle an increase in demand.

Another practice that is not implemented is endpoint verification, which provides protection against man-in-the-middle attacks. It also allows better control and monitoring the API usage, which could provide information for performance optimization and potential improvements and/or extensions.

In addition to the practices listed in Table 4.9, French demo partners reported that the API implements user authorization with a dedicated identity access manager (IAM), email validation, password minimum strength enforcement, and rate limiting.

Table 4.9: Best practices for security in the Portuguese and French demo APIs

Category: Security	Portuguese demo		French demo
	DSO DEP	TSO DEP	
Does the API use HTTPS?	Yes	Yes	Yes

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Are authentication tokens implemented?	Yes	Yes	Yes
Is OAuth used?	Yes	Yes	Yes
Are throttling and quotas used in the implementation of the API?	No	No	No
Does it implement zero-trust network access?	Yes	Yes	Partially
Does it implement endpoint verification?	No	No	No
Does it implement least-privilege access?	Yes	Yes	Yes

Regarding the Spanish demo, an HTTP REST API was not used. The Spanish Market Operator implements the Advanced Message Queuing Protocol (AMQP) for the integrators to have access to the functionality of the local markets developed. AMQP is an open standard for the application layer that allows process-to-process communications. It provides message orientation, queuing, and routing. There are AMQP libraries for different programming languages, which facilitates its integration within existing systems, and therefore, its replicability. It is known for its reliability and security, implementing Transport Layer Security (TLS).

The scalability of AMQP mainly depends on the broker (i.e., server), as it is in charge of dispatching the messages. Therefore, the capacity of the broker must be considered when including new actors that communicate with the local market platforms. Regarding replicability, the main aspect to consider is the message format and data model used, which must be clearly defined to facilitate the seamless integration of new actors. In general, if these aspects are correctly addressed, there should not be any other potential issue regarding the technical SRA of the AMQP communications in the Spanish demo.

4.3.2 Conclusions

Based on the outcome of a survey carried out by [15] about the importance of these practices (excluding the versioning and security categories), the results obtained are a good indicator of the quality of the REST APIs implemented by the Portuguese and French demos. The categories of URI design, HTTP request methods, error handling, and representation design are considered more important by developers, whereas client concerns and metadata design categories are considered not so impactful.

The Portuguese APIs show a good compliance of the best practices. Both APIs (TSO and DSO DEP API) follow all the guidelines for using HTTP request methods and representation design, two of the most relevant categories. For the other two, URI design and error handling, the scores of the APIs are above 50%, showing an appropriate level of compliance. Regarding versioning, the scores for the Portuguese APIs are between 50-60%. Versioning can be considered a very relevant category for the scalability and replicability of an API, as it is related to the evolution and future implementation of the API. Based on this, the Portuguese APIs should consider following more good practices in this regard, so that developers do not find difficulties in the future if new versions are developed.

Regarding the French API, it shows an outstanding compliance of the practices for HTTP request methods and error handling, and good compliance of URI and representation design practices. In addition to this, the API follows all the guidelines for versioning. The only category with a score lower than usual is client concerns. However, this category is not among the most relevant ones when implementing an API. Considering this, developers should not find many inconveniences when implementing future versions of the API.

Although the Portuguese and French APIs show a good level of security, future implementations of the APIs should consider using throttling and quotas, to improve scalability, and verification of endpoints, which becomes relevant when the number of API clients increase significantly (i.e., scalability), to protect the system against man-in-the-middle attacks.

Since the Spanish demo does not implement an HTTP REST API, it could not be assessed in these terms. The protocol used, AMQP, is a good choice, as it is easy to implement within existing systems and is known for its reliability and security. From the scalability point of view, the only aspect to consider is the correct dimensioning of the AMQP broker. For replicability, the message format and data model must be clearly defined.

One aspect that should be considered by each new implementation is the correct integration of Information Technology (IT) and Operational Technology (OT) systems from the cybersecurity point of view. When using different protocols or technologies to exchange information in different stages of a process, the security level should be the same in all phases (e.g., same level of authentication, encryption, access rights, etc.). In some cases, this is a significant challenge. Some demos in OneNet initially had difficulties in installing the OneNet connector due to how the firewalls were configured, blocking the access to certain network components that were necessary for the correct functioning of the connector. Future deployments can take advantage of this experience to minimize risks during replication.

4.4 Main findings from the quantitative SRA

The ICT SRA, which evaluates REST APIs in Portuguese and French demos, shows strong adherence to best practices in categories such as URI design, HTTP request methods, error handling and representation design. Both Portuguese APIs show good compliance, particularly in the areas of HTTP request methods and presentation design. However, there's room for improvement in versioning practices to improve scalability and replicability. The French API excels in HTTP request methods, error handling and versioning, with slight room for improvement in client concerns. The security levels in both APIs are commendable, but future implementations should consider adding throttling, quotas, and endpoint verification to improve scalability and protection against potential threats. The Spanish demo's use of AMQP is notable for its reliability and security, with an emphasis on proper sizing for scalability and clear definition of the message format and data model for replicability. The integration of Information Technology (IT) and Operational Technology (OT) systems is highlighted for

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maintaining a consistent level of security across different protocols and technologies, learning from past deployment challenges in OneNet demos to minimise risks in future implementations.

The qualitative SRA on non-ICT aspects has highlighted the importance to actively work on the reduction of these several categories of barriers. Challenges related to flexibility markets include technical and regulatory issues arising from the difficulty of harmonising architecture and product requirements, leading to divergent conditions influenced by local technological factors, which make it difficult to comply with national grid codes. In addition, behavioural and legal barriers impede customer engagement due to lack of awareness, resistance to change and concerns about privacy and security. Technical barriers include inadequate information and communication technology, characterised by a lack of standardised data exchange interfaces and processes. Regulatory, legal, economic and social barriers impede the development of a dynamic market with harmonised product design, due to issues such as lack of standardisation, interoperability and cultural differences between stakeholders. The lack of clear rules on measurement of flexibility, such as on baselining, observability and metering, further limits innovation in product portfolios. Customers face reduced attractiveness to participate in new flexibility markets due to regulatory, legal and economic barriers, including unattractive contracts and limited options offered at their specific site. Profitability challenges arise from regulatory and economic barriers, such as inadequate network and flexibility pricing schemes and insufficient compensation for network expansion costs. Regulatory barriers persist in the lack of clearly defined roles for entities such as independent aggregators and market operators, while technical barriers arise from the unpreparedness of system operators for an open and innovative environment. In conclusion, overcoming regulatory barriers and improving customer engagement are critical to the replicability of OneNet solutions. The challenges of harmonising regulations across different regions and overcoming behavioural barriers are critical considerations. At the same time, overcoming technical and economic barriers is essential for successfully scaling OneNet solutions. Establishing standardised data exchange interfaces, improving flexibility pricing schemes and overcoming regulatory and economic challenges are key steps to ensure widespread implementation and scalability of OneNet solutions.

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5 Quantitative SRA

As the modelling and simulation of local congestion management is a crucial component of the methodology outlined in section 2.3, this section provides further details of this process according to the below description:

1. **Collection of data (Step 1):** The initial step of this process focusses on collecting data from each demo to facilitate simulations, including power flows and optimization algorithms needed for the quantitative SRA. This comprehensive approach enables a detailed understanding of each demo's specific conditions and ensures that the simulations adequately represent real-world scenarios, thereby enhancing the reliability and applicability of the SRA results. This data consists mainly of network data, load and generation profiles, and SPs' characteristics alongside the BUC's descriptions.
2. **Definition of the Scenarios (Step 2):** Different scenarios are established for each demonstrator based on their characteristic and BUCs information. This analysis operates on the premise that grid congestions, like overloading lines/transformers can be predicted in terms of location and magnitude. To determine an appropriate SRA scenario, the first step involves conducting a power flow analysis with the initial load and generation profiles (Scenario 0). If this analysis reveals grid congestions, it becomes the chosen scenario for the SRA. Conversely, if no congestions are detected, the profiles are iteratively modified by modifying SRA parameters such as loading and generation conditions, until congestions emerge (so that generating Scenarios 1, 2, etc.), and the resultant modified scenario is then used for the SRA evaluating the techno-economic performances of the local market for congestion management. This ensures that the selected scenario accurately reflects potential grid congestions for detailed study. Furthermore, for each scenario, SRA parameters (e.g., volume of flexibility available, SPs location, bid price) are determined to assess the sensitivities for the scalability and replicability capability of the BUCs.
3. **Local flexibility market model (Step 3):** A local flexibility market for congestion management using active power is implemented, as indicated in Figure 2.5:. Therefore, once gathering the essential information from the electrical network and SPs, and the SRA scenarios are determined, the next step is to assess the implementation potential of the market model. It considers the following stages:

   Estimation of the congestion management needs (step 3.1): The starting point consists in determining the congestion management needs by focusing on overloaded lines and transformers. In PandaPower Tool [33] by executing a power flow, it is possible to obtain the loading percentage of lines and transformers, which are subsequently converted into MVA. The loading percentage that exceeds the element rating represents the congestion management need that must be covered by the SPs through the market-clearing process.

   Calculation of the sensitivity factors (step 3.2). An important step of the modelled local market for congestion management is the calculation of the sensitivity factors. A local flexibility market-clearing can be conducted either with or without incorporating network data. There are various methodologies to integrate network data and flow constraints in market models for distribution systems. These include second-order cone programming formulations [34], quadratically constrained programming [35], and linearization approaches for power flow constraints [36]. Despite the effectiveness of these solutions, they present practical implementation challenges, especially in networks with thousands of nodes. As a result, utilizing sensitivity factors could offer a viable alternative for linear market representations when integrating grid information into the market-clearing process [20], [25].

In the SRA approach described in this document, sensitivity factors are calculated for each SP in relation to the specific flexibility requirement. The resulting values depend on the location of the SP and the impact of the SP on mitigating network constraints violation. In congestion management, the criticalities typically arise from the restricted power capacity in certain branches or transformers. Thus, analysing how the power flow in these specific branches and/or transformers responds to active power injections/reduction from the SPs (in buses) have to be exanimated. The formulation for these sensitivities is given below, and considers that the change in the apparent flow in line ij related to the active power injection at node k and equivalent withdrawal at node m:

$$\Delta S_{ij} = H_{ij,km}^{P} \Delta P_{km} \; + \; H_{ij,km}^{Q} \Delta Q_{km}$$

Where $H_{ij,km}^{P}$ and $H_{ij,km}^{Q}$ represent the congestion management sensitivity factors. These factors are calculated considering the variation in the apparent power flow in the network element *ij* caused by the unitary change in active or reactive power injections in the node *k*, respectively, as described in [20].

a. *SPs bid generation (Step 3.3):* the system proceeds with the generation of bids for the SPs. This step involves creating bids for active power, considering the maximum and minimum capabilities of each SP and tailoring them to the specific technology type of each provider. These bids encompass: i) volumes for increasing or decreasing generation (representing upward and downward flexibility, respectively), as defined in Table 2.1, and ii) volumes for decreasing or increasing demand (i.e., upward and downward flexibility , as defined in Table 2.1) at a distribution node. The bids also include the cost of flexibility activation, as SPs are viewed as active market participants who set their own flexibility prices. It's important to note that these bid calculations are cost-based, which may not align with actual market offerings by SPs, especially under pay-as-bid pricing frameworks. For simplicity, market clearing is conducted using simple bids for each time interval (hourly, in this instance). Nonetheless, the bid generation process does consider certain specific constraints of each SP type (such as synchronous generators, inverter-based generators, storage, demand) when formulating the bids.
b. *Local flexibility market-clearing (Step 3.4):* The local flexibility market-clearing phase allows selecting the most cost-effective flexibility offers from SPs to fulfil the identified congestion

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management needs. This step employs the LFM (Local Flexibility Market) model outlined in Figure 2.5:. The inputs for this market-clearing process include:

- Congestion management needs calculated according to the step 3.1.
- Sensitivity factors computed as indicated in step 3.2.
- SPs Bids obtained according to step 3.3.
- SRA parameters. The LFM market-clearing in executed for each SRA parameter and scenario defined in step 2.

c. *Post-evaluation (Step 3.5):* Beyond the preceding steps, the SRA simulation approach incorporates a post-evaluation to assess whether the market results allow to solve the congestions that led to the definition of the congestion management needs. Hence, the cleared quantities are considered, accordingly the network is simulated considered the novel profile for the cleared SPs.

4. **KPIs calculation (Step 4):** A set of Key Performance Indicators (KPIs) is adopted to evaluate the effectiveness and practicality of the model for addressing congestion management issues, aligning with predefined scenarios. The indicators aim assessing the technical and economic performance of the local market for congestion management. KPIs are defined on case-basis since they have to reflect the specific objectives, a detailed description for the KPIs adopted in this document is provided in section 5.3.

5.1 Synthetic networks models for the demos to study

For each demo site, a synthetic grid is built with similar characteristics of the real one. The Reference Network Model (RNM) served as the foundation for constructing electrical networks at both the Alcala and Murcia demo sites. The RNM is a large-scale planning tool that plans the electrical distribution network using GPS coordinates and power of every customer and Distributed Energy Resources (DERs) [37], [38]. The tool has found diverse applications in various research studies, including DiNeMo, an online platform enabling the creation of distribution network models using the RNM framework [25].

Figure 5.1 exemplifies the RNM greenfield approach. This approach starts by creating a network from a street map as the initial input. The RNM then automatically identifies consumer locations, constructing the synthetic network with general consumer statistical data and a standard library of network components. After creating the synthetic network, structural network indicators are computed and compared with actual network data provided by DSOs.

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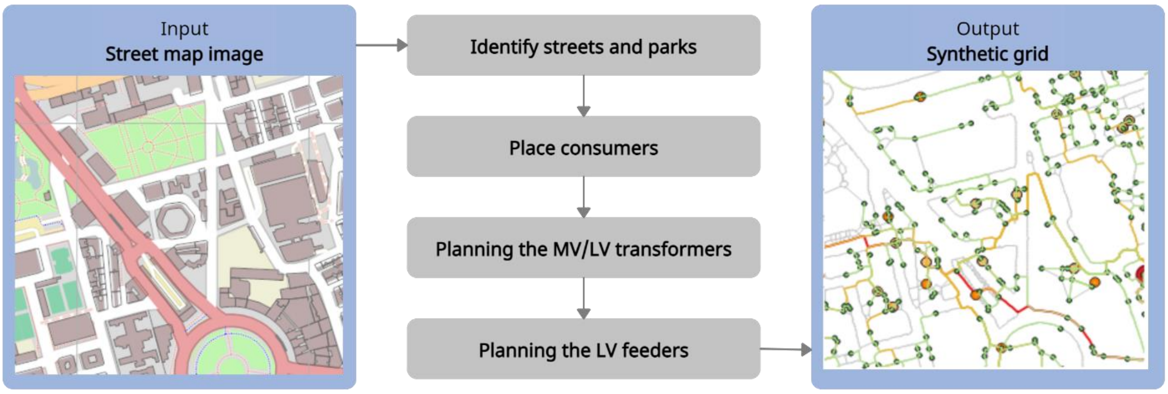

Figure 5.1: RNM approach for designing synthetic distribution grid models [38], [39]

5.2 Load and generation profiles

The methodology for defining the load and generation profile is equal in both case studies presented in this document (i.e. Alcalá de Henares and Murcia demos). The load profiles are presented once in this section for both case studies. Regarding generation profiles, these vary between the cases and therefore the profiles are presented case-specific, all PV generation profiles utilised for the study presented in this document are obtained from Renewables Ninja [40].

5.2.1 Load profiles for the Spanish case studies

The yearly load profiles used in this report are based on the normalised profiles made publicly available by Red Eléctrica España in [41]. To be adopted in the SRA described in this report, these profiles are demoralised in terms of energy and peak power to be adapted to the characteristics of the loads connected to the synthetic networks of the two case studies obtained through RNM. Figure 5.2 depicts the yearly profiles from Red Eléctrica España that are used in the study presented in this document as normalised profiles for the low and medium voltage loads. Figure 5.3: depicts two specific days of those normalized profiles: the day of the maximum value for the peak and the day of the year in which the peak has the lowest value.

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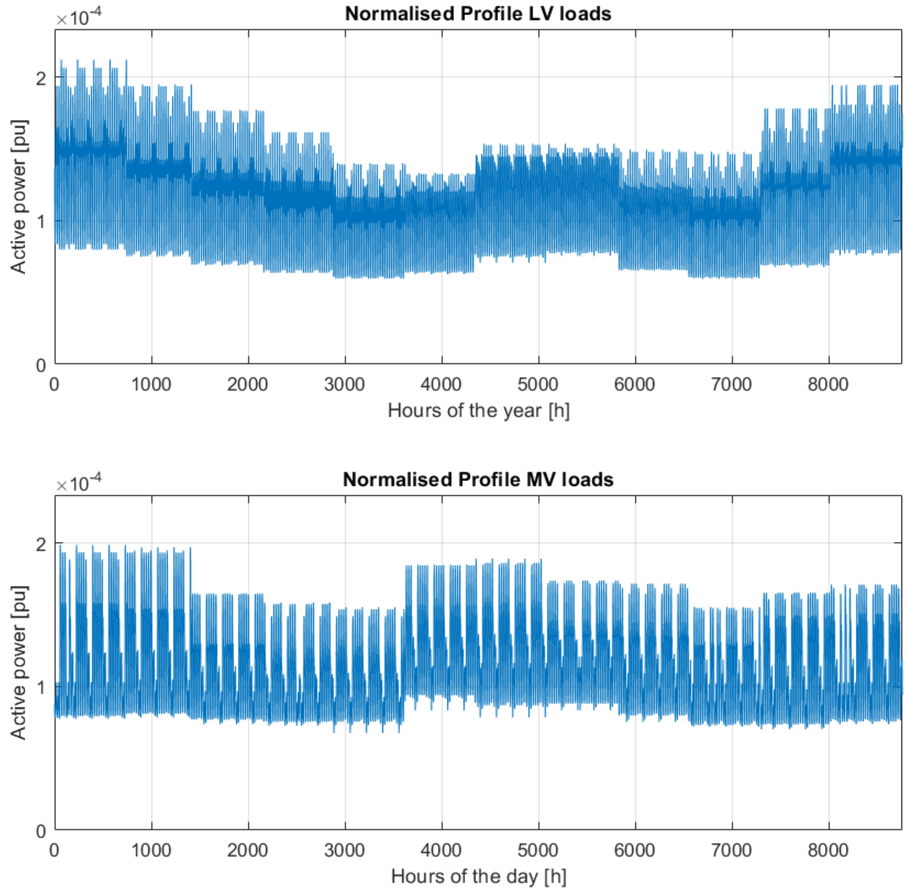

Figure 5.2: Normalised profiles for loads adopted in this study, from [41]

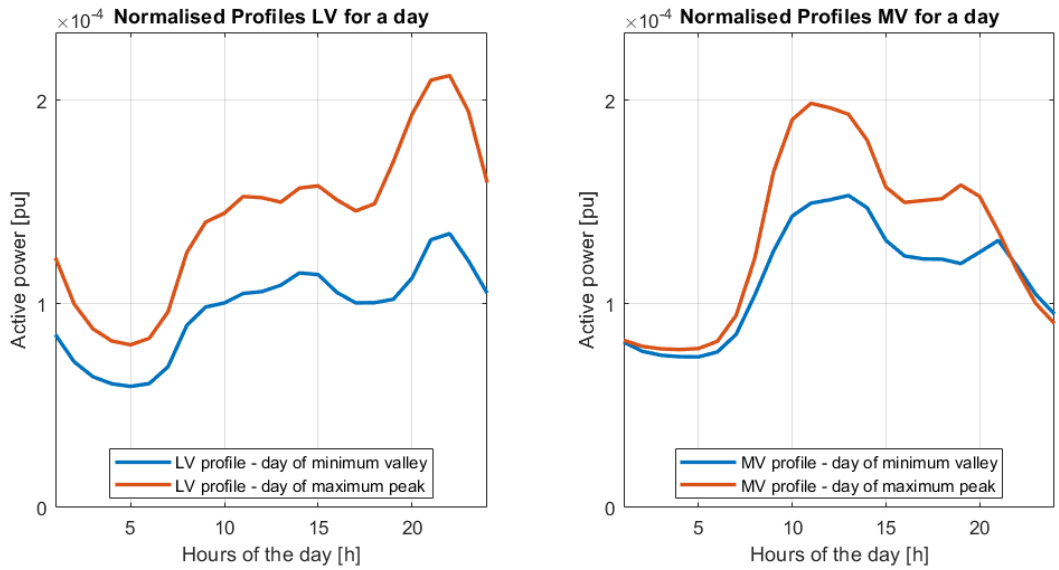

Figure 5.3: Normalised profiles for loads adopted in this study – particular days, from [41]

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In addition to the load profiles from Red Eléctrica España, a typical yearly profile for EV charging stations is adopted in the study described in this document, as shown in Figure 5.4 and Figure 5.5. The source of the EV charging station profile is a repository hosts realistic electric vehicle (EV) demand profiles generated by The University of Melbourne using data from the Electric Nation trial in the UK [42]. The EV profiles specifically represent light-duty EVs and focus on home charging scenarios. They are categorized into four groups based on charging level (level 1/level 2) and the type of day (weekday/weekend). Currently, only diversified profiles are available, including those with and without a Daily Plug-in Factor. The profiles are designed for groups of 100 EVs (suitable for studies involving a distribution transformer with up to 100 home chargers/EVs) and for 1,200 EVs (useful for studies involving primary substations with thousands of home chargers/EVs) [42]. It is worth noting that these EV profiles, and the siting and sizing of the EV charging stations represent a merely theoretical and academic assumption that does not reflect the actual and future status of the Spanish demonstrators' demos.

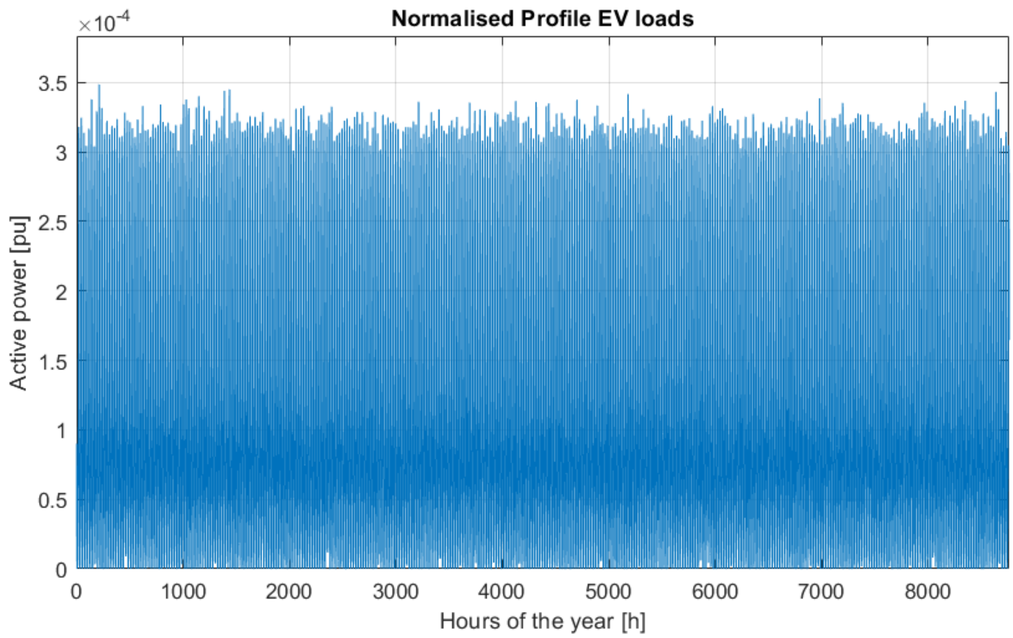

Figure 5.4: Normalised profiles for EV charging stations adopted in this study, from [42]

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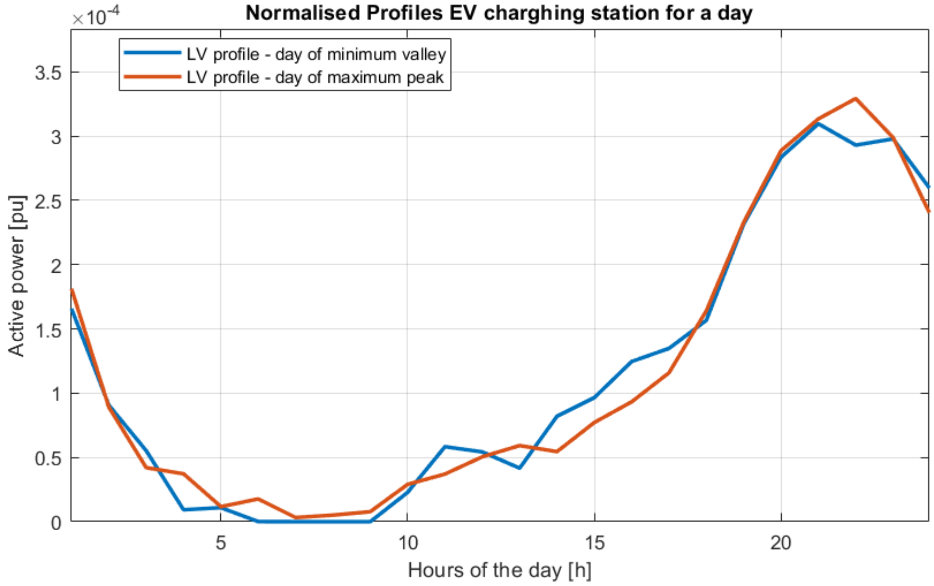

Figure 5.5: Normalised profiles for EV charging stations adopted in this study – particular days, from [42]

5.2.2 Alcala de Henares case study generation profiles

In the Alcala power network, distributed energy generation primarily stems from two sources: solar power through photovoltaic (PV) systems and HERA Biogas Plant. The biogas plant plays a key role, serving additionally as a flexibility service provider. Figure 5.6: and Figure 5.7: depict the daily operational patterns, highlighting the generation profiles of the PV units and the biogas plant, respectively. Figure 5.6: shows the normalised daily profiles of the PV sources for two generic days to illustrate the seasonal changes in power outputs from PV sources, in relation to the availability of sunlight during winter and summer. Additionally, for simplicity, the biogas plant production profile has been considered constant thought the year, as shown in Figure 5.7: [3], [12].

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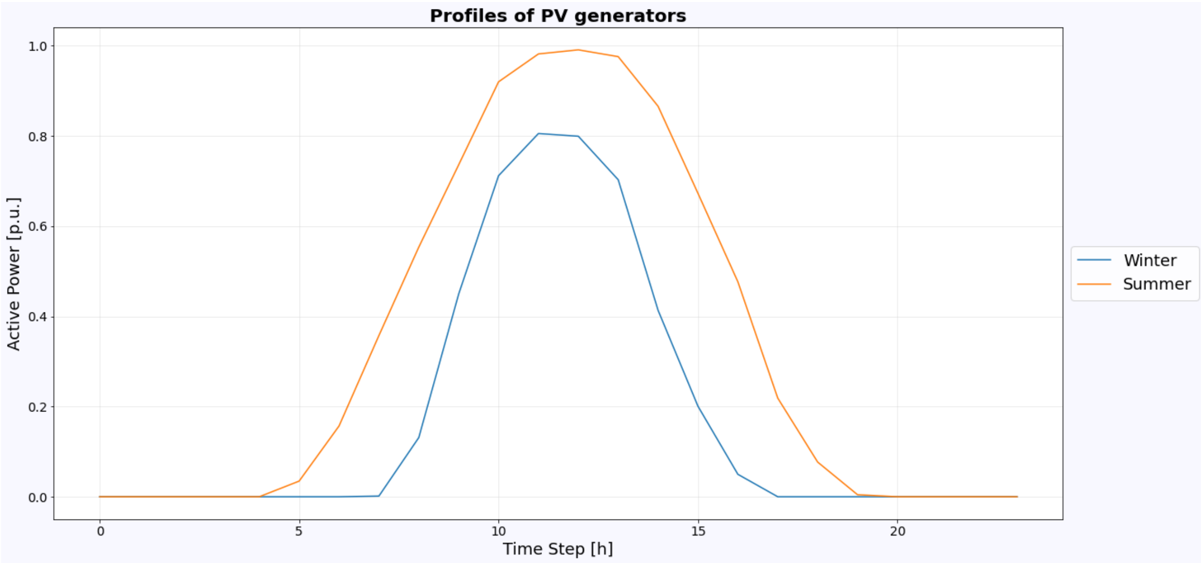

Figure 5.6: Representative days profiles (average) of PV generators for Alcalá

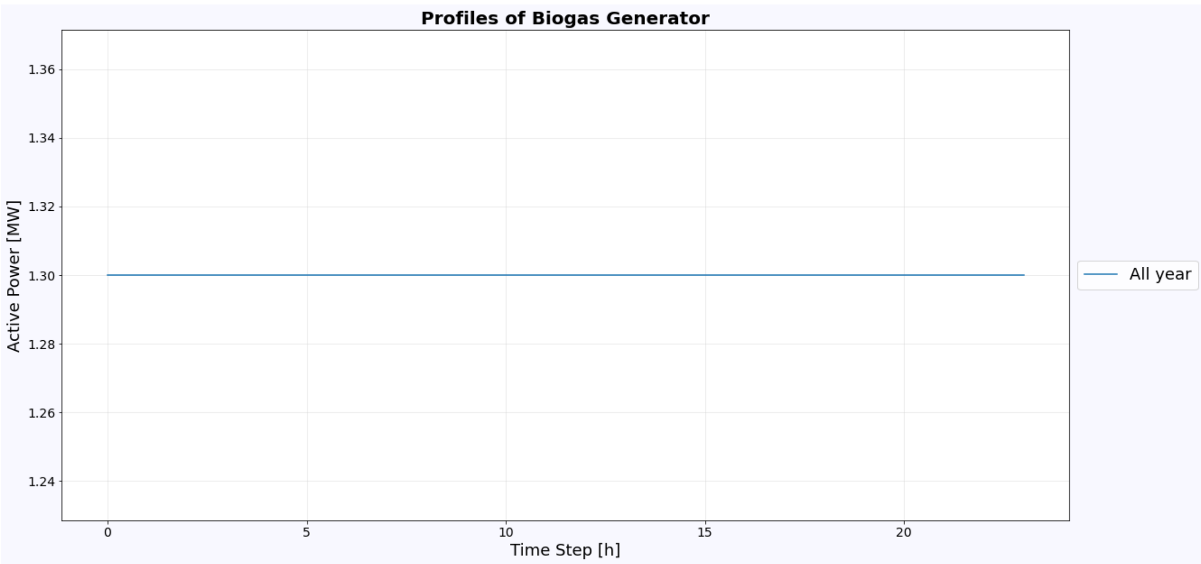

Figure 5.7: Representative day profile of Biogas generator for Alcalá

5.2.3 Murcia case study generation profile

In the Murcia power network, the entire distributed energy generation is sourced from solar power through 21 photovoltaic (PV) systems. With the absence of flexibility providers among these PV generators, the network is characterized by a reliance on flexible loads. The network must adapt to the inherent fluctuations of solar energy, which depend heavily on the availability of sunlight. Figure 5.8: displays the normalized daily profiles of

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the PV sources for two typical days, illustrating the seasonal variations in the power output of the PV sources corresponding to the sunlight availability in winter and summer.

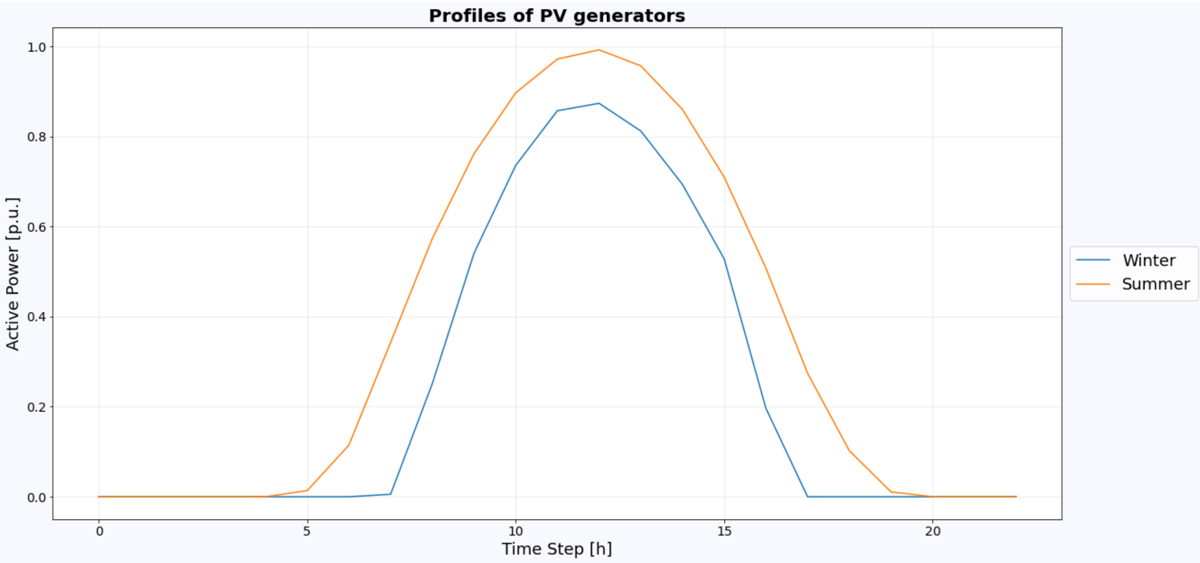

Figure 5.8: Representative day profile (average) of PV generators for Murcia

5.3 Key performance indicators

The KPIs identified for the SRA presented in this document encompass technical and economic dimensions, ensuring a comprehensive evaluation of the proposed solutions. The calculation methodology for each KPI has been established according to Table 5.1:, which also provides an overview and formulations of the indicators considered. The identified KPIs rely on the insights from past experiences and outcomes from other research initiatives:

- EUniversal: Deliverable: D6.2 Definition KPI for DEMOs [43]
- EUniversal: Deliverable: D10.4 Scalability and Replicability analysis of the EUniversal solutions [20]
- CoordiNet Deliverable D1.6 List of KPIs: KPI and process of measures [44]
- OneNet: OneNet priorities for KPIs, Scalability and Replicability in view of harmonised EU electricity markets D2.4 [27].

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Table 5.1: Key Performance Indicators (KPIs) defined for Scalability and Replicability Analysis of OneNet Solutions

Nº	KPI Name	Description	Domain	Formula
1	Avoided Congestions (Lines and Transformers)	This KPI facilitates the assessment for the contribution of the flexibility in grid support. It quantifies the deviation of the congestion problems through the mobilization of flexibility services. It considers congestion problems (delta) regarding overloaded lines and transformers.	Technical	Measurement factor [u]: $\delta = \begin{cases} 1, I > I_{rating} \\ 0, Otherwise \end{cases}$ Number of cumulative restrictions avoided [element x hour]: $n_{element}\ [u] = \sum_{t=1}^{NT} \delta_t$ $element \in \{Lines, Trafo_{2windings}, Trafo_{3windings}\}$ Percentage of cumulative congestions avoided [%]: $Overall\ [\%] = \frac{n_{pre} - n_{post}}{n_{pre}} \times 100\%$ n_{pre} : Number of congestion problems pre-market n_{post}: Number of congestion problems after the market clearing
2	Density plots for Loading Percentage [%] of all lines and transformers	Graphical KPIs that allow to observe how the dynamics within the lines and transformers change due to before and after market execution in the different cases.	Technical	
3	Amount of Total Flexibility activated	It measures the amount of flexibility that the market has mobilized from SPs for solving problems in the network. This flexibility can be provided in terms of active power or in terms of reactive power.	Technical	$TotalActivePower\ [MW] = \sum_s (\Delta W_{Upwards} + \Delta W_{Downwards})$ $TotalReactivePower\ [MVAR] = \sum_s (\Delta R_{Upwards} + \Delta R_{Downwards})$ $\forall s \in \{Generator, Load, Storage\}$
4	Cost of the amount of Total Flexibility activated	It measures the cost of the amount of flexibility that the market has mobilized from SPs for solving problems in the network.	Economical	$TotalActiveCost\ [Eur] = \sum_s (\Delta W_{Upwards} \times \Delta W\_Cost_{Upwards} + \Delta W_{Downwards} \times \Delta W\_Cost_{Downwards})$ $TotalReactiveCost\ [Eur] = \sum_s (\Delta R_{Upwards} \times \Delta R\_Cost_{Upwards} + \Delta R_{Downwards} \times \Delta R\_Cost_{Downwards})$ $\forall s \in \{Generator, Load, Storage\}$
5	Volume of Transactions	It serves as indicator for measuring the volume of transaction depending on the service that is provided. It is used to measure the volume of offered and clear bids for each SP.	Technical	Volume of offered or cleared capacity [MVA]: $\sum_T \sum_S W_{s,t}$ $\forall s \in \{Generator, Load, Storage\}$
6	Cost of the flexibility not supplied	It serves as a benchmark for assessing the market's effectiveness in resolving network problems	Economical	$Total\ Cost\ of\ FNS\ [Eur] = \sum_i Cost_\beta \times \beta_i$

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5.4 Murcian Case study: equivalent Murcian case study synthetic network

As mentioned in section 5.1, the Murcia case study, as described in this document, utilizes a synthetic grid modelled with characteristics akin to the actual grid of Murcia city. To construct this synthetic medium voltage (MV) and Low Voltage (LV) network, the Reference Network Model (RNM) was employed [38]. Figure 5.9: presents the resultant synthetic distribution network for Murcia. This network originates from a 400/132 kV transformer, which connects to two 132/20 kV transformers. The network model has a radial topology and contains 7373 busses, 7084 lines, 303 and transformers that represent the MV and LV networks. In the context of local congestion management for Murcia's case study, only one SP is considered, as specified in [12]. The characteristics of the SP in the Murcia case study are reported in Table 5.2:, based on the information available in [12]. It is worth noting that the characteristics in Table 5.2: are inspired by the actual Murcian demo to define a case study that is indicative of the conditions presented in [12], but Table 5.2: may not fully represent the actual and future SPs and network characteristics.

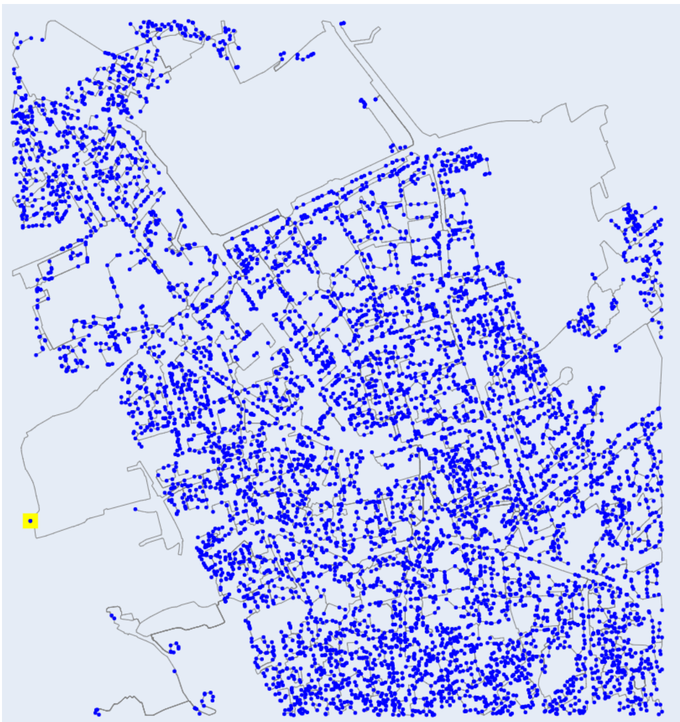

Figure 5.9: Synthetic network representation for Murcia network

Table 5.2: Characteristics of the SP for the synthetic network for the Murcia case study

Id	Name	Type	Maximum power capacity [MVA]
SP01	UMU	load	7.55

Considering the localized nature of the congestion management service, an equivalent network for the Murcia case study is developed to simplify the computational complexity of the problem. This is achieved by

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condensing the original network depicted in Figure 5.9: into a more compact version. This reduced network, shown in Figure 5.10:, encompasses only those feeders which are critical to the electrical proximity of the SPs, thereby maintaining the focus on the area most relevant to the congestion management objectives of the Spanish demonstrator. The equivalent network is characterised by 322 busses, 309 lines, and 12 transformers. In Figure 5.10: the red squared bus represents the SP, in yellow the MV bus that serves as a slack bus for the network model.

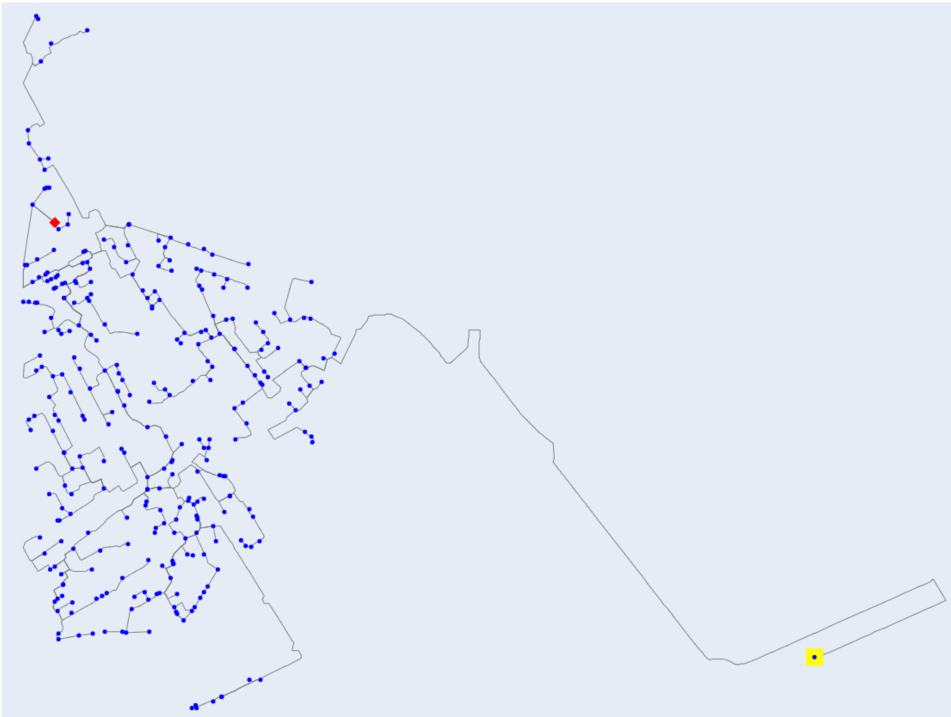

Figure 5.10: Equivalent network for the Murcia case study

The study described in this document considers the base scenario (Scenario 0) as the current state of the network, characterized by loading and distributed generation conditions that do not lead to congestion within the studied timeframe.

Scenario 1 envisions a potential future state in which network load conditions escalate, resulting in network congestions. This scalability scenario particularly focuses on the integration of multiple electric vehicle charging stations. These high-power demands are projected to cause congestions within the studied timeframe. The objective of the SRA in this context is to conduct a techno-economic assessment of a local market designed for congestion management. This market aims to avoid these congestions by leveraging demand response strategies from the participating SPs. The characteristics of the EV charging stations are reported in Table 5.3 while Figure 5.11 provides a graphical representation of the point of connection of these new loads in the equivalent network for the Murcia case study by means of a green star marker. It is worth noting that the EV charging stations' profiles, and the siting and sizing of the EV charging stations represent a merely theoretical

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and academic assumption made for the scope of the SRA that does not reflect the actual and future status of the Spanish demonstrators' demos.

Table 5.3: Characteristics of the additional load for the Scenario 01 – Murcia case study

name	Maximum power capacity [MVA]	Power Factor
scen1_EVC_load1	2.04	0.98
scen1_EVC_load2	2.04	0.98
scen1_EVC_load3	2.04	0.98
scen1_EVC_load4	2.04	0.98

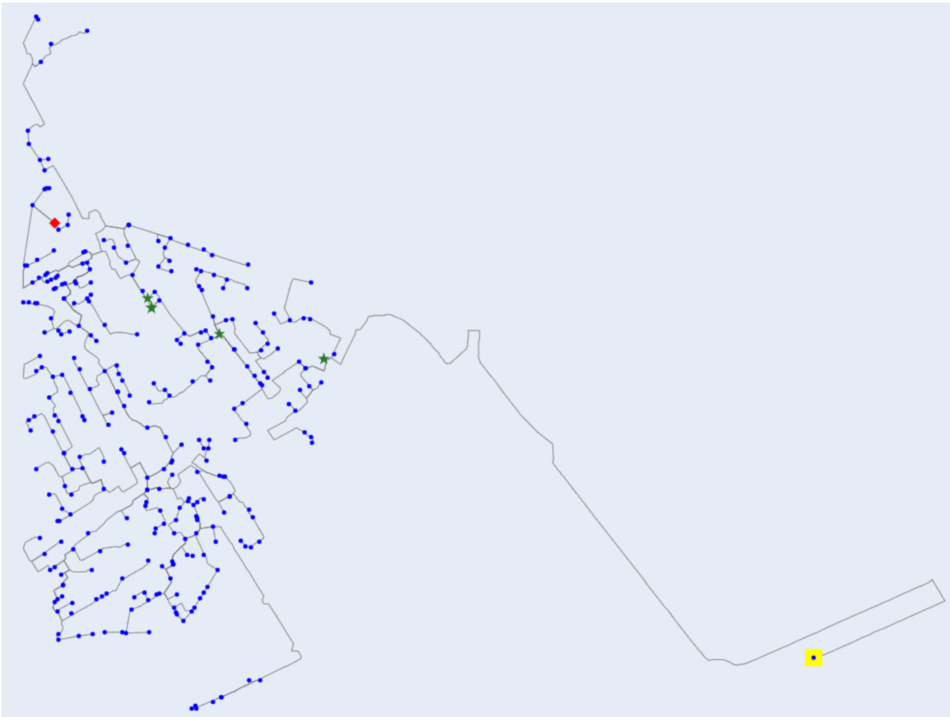

Figure 5.11: Equivalent network for the Murcian case study with EV charging station location (green-star markers) – Scenario 1

The equivalent network for the Murcian case study is studied by means of power flow calculation simulation to detect power network congestion. The analysis focuses on identifying potential issues in the power flows in the network over an entire year, considering the variations in demand and generation patterns. The simulation's goal is to identify the network congestions in lines and transformers. This process is carried out by performing an hourly-based power flow analysis for 8760 hours (market horizon) to identify likely constraints in the grid. This analysis considers network data, and load and generation initial profiles described in section 5.2.

Figure 5.12: and Figure 5.13: display representative loading percentages profiles for the main feeders and all the transformers, respectively. These analyses enable the graphical identification of those lines and

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transformers which are experiencing congestion problems. The yearly loading percentage profiles are displayed for main feeders in medium (TMT) and low (TBT) voltage lines for the Murcian Network. Figure 5.14:, a detailed segment of Figure 5.12:, illustrates a representative day for congestion detection, linking these profiles to earlier discussed patterns of generation and demand.

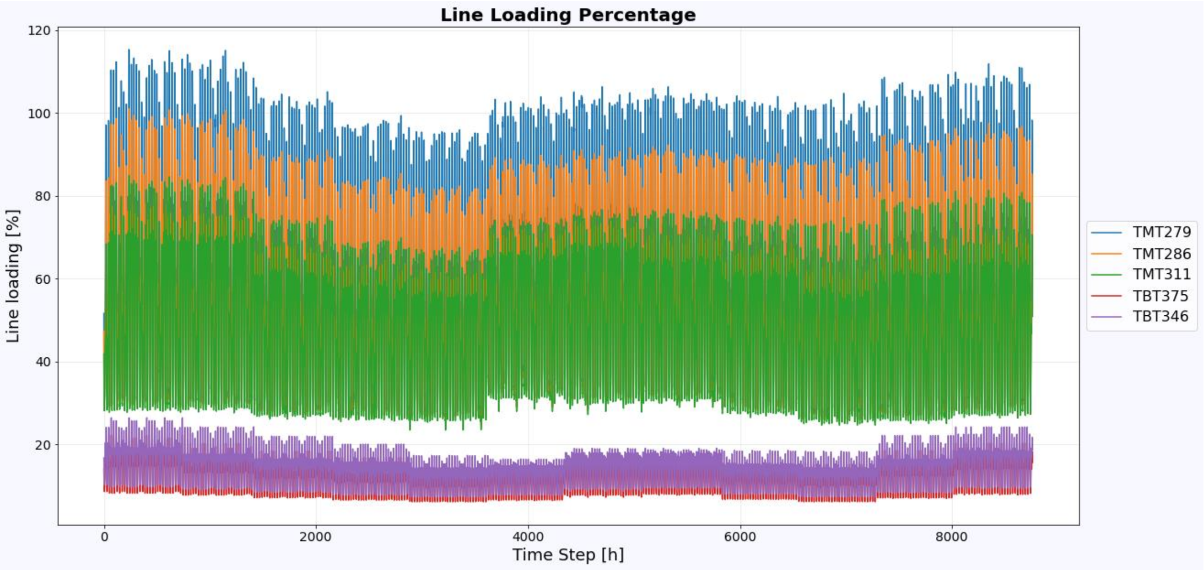

Figure 5.12: Representative yearly line loading profiles for main feeders of Murcian network

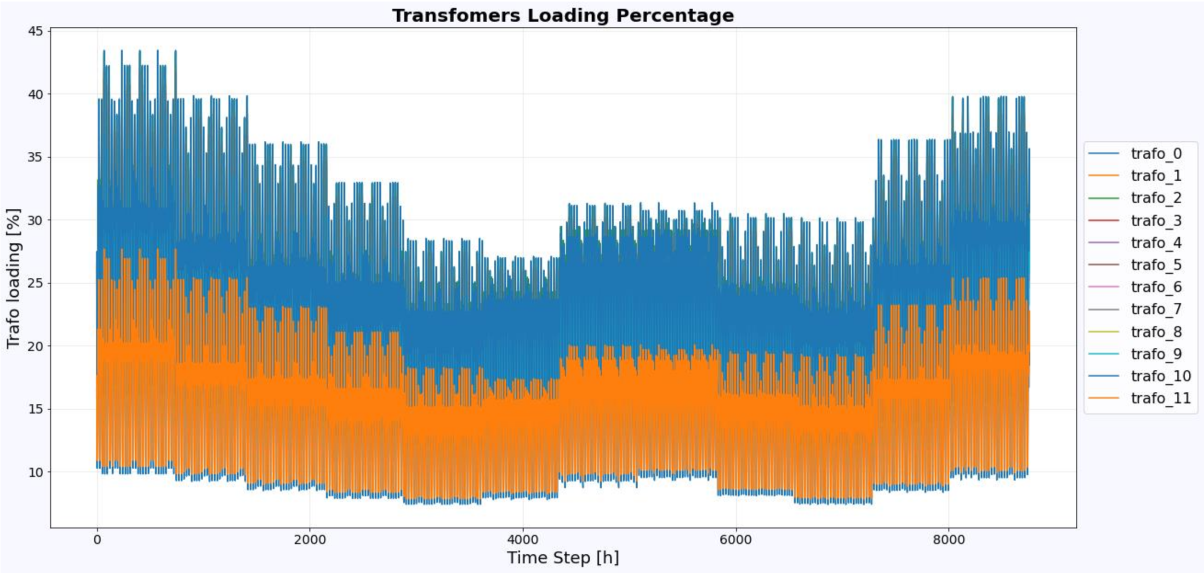

Figure 5.13: Representative yearly transformers loading profiles in Murcia network

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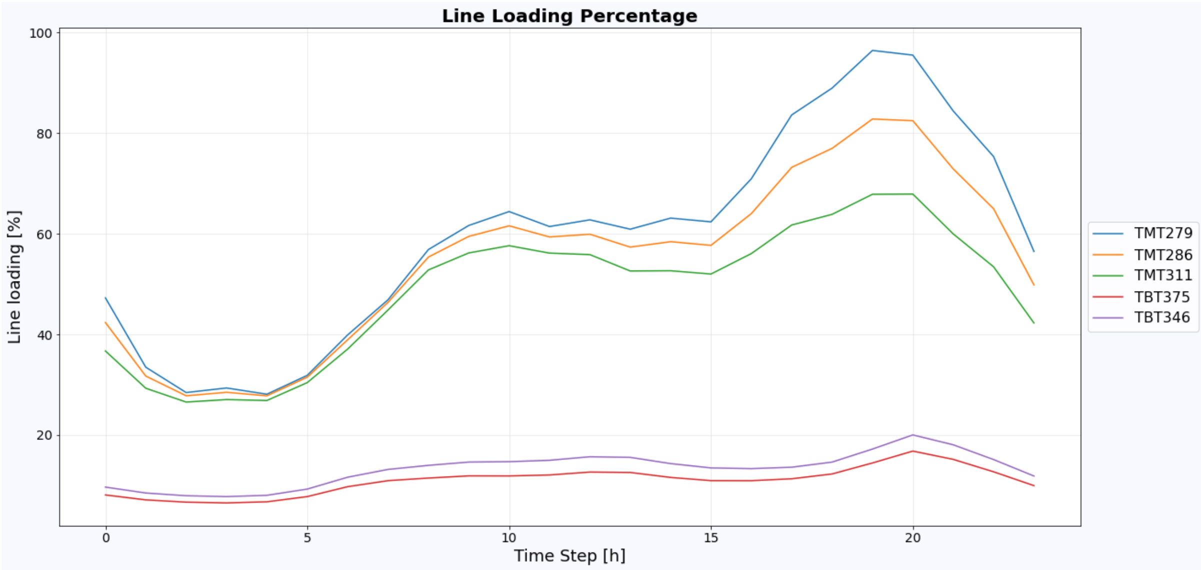

Figure 5.14: Representative day line loading profiles for congestion detection in Murcian network

5.5 Alcalá Case study: equivalent Alcalá de Henares case study synthetic network

The Alcalá de Henares case study, outlined in section 5.1, is portrayed using a simulated grid that mimics the features of the real Alcalá de Henares grid. The synthetic medium voltage (MV) and Low Voltage (LV) network were created using the Reference Network Model (RNM) [38].

Figure 5.15 presents the resultant synthetic distribution network for Alcalá de Henares. This network originates from a 400/132 kV transformer, which connects to two 132/20 kV transformers. The network model has a radial topology and contains 5288 busses, 5020 lines, 304 and transformers that represent the MV and LV networks.

In the context of local congestion management for Alcalá de Henares' case study, five SPs are considered, as specified in [12]. The characteristics of the SPs in the Alcalá de Henares case study are reported in Table 5.4, based on the information available in D9.6 [12]. It is worth noting that the characteristics in Table 5.4 are inspired by the actual Alcalá de Henares demo to define a case study that is indicative of the conditions presented in [12], but Table 5.4 may not fully represent the actual and future SPs and network characteristics. In Figure 5.15, the red squared markers identify the busses to which the SPs are connected. It is worth noting that the EV charging stations' profiles, and the siting and sizing of the EV charging stations represent a merely theoretical and academic assumption made for the scope of the SRA that does not reflect the actual and future status of the Spanish demonstrators' demos.

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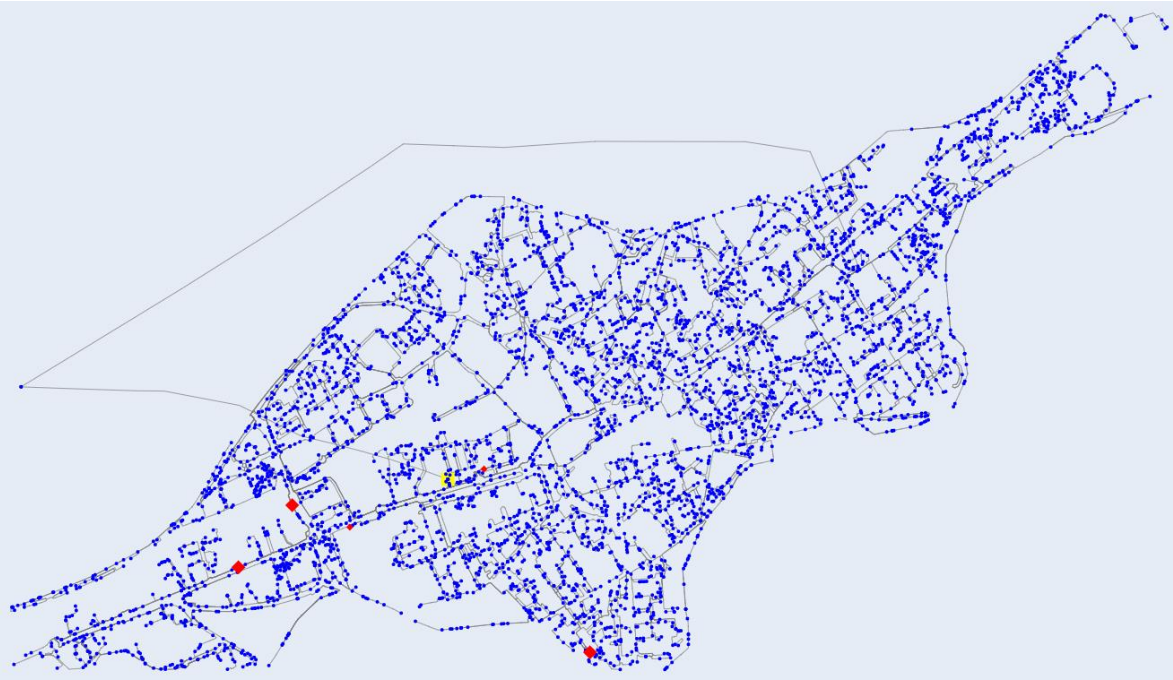

Figure 5.15: Synthetic network representation for Alcalá de Henares network, SPs location identified by the red-squared markers

Table 5.4: Characteristics of the SP for the synthetic network for the Alcalá de Henares case study

Id	Name	Type	Maximum power capacity [MW]
SP1	Concejalia	load	0.11
SP2	Polideportiva El Juncal	load	0.05
SP3	Metallurgica	load	2.4
SP4	Fiesta Colombina	load	1.1
SP5	HERA Biogas Plant	generation	2.3

An equivalent network is also constructed for the Alcalá de Henares SRA case. This network considers the electrical proximity of the SP area. This reduced network, shown in Figure 5.16, maintains the focus on the area most relevant to the congestion management objectives of the Spanish demonstrator by including only those feeders that are critical to the electrical proximity of the SPs.

The equivalent network is characterised by 333 busses, 314 lines, and 19 transformers. In Figure 5.16 the red squared bus represents the SP, in yellow the MV bus that serves as a slack bus for the network model, and in green the MV/LV transformers.

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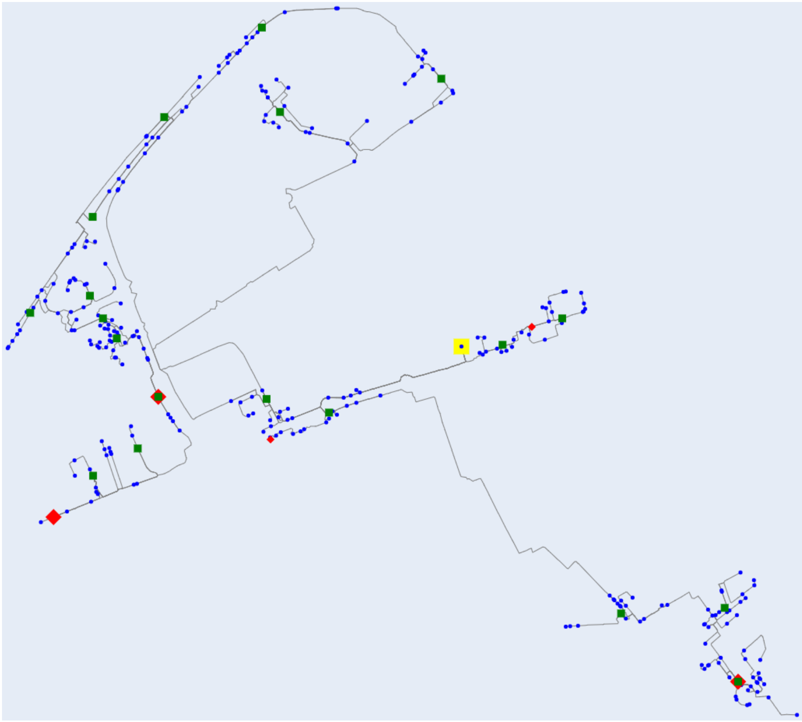

Figure 5.16: Equivalent network for the Alcalá de Henares case study with SPs location (red-squared markers) and MV/LV transformers location (green-squared markers)

Also for the SRA of the congestion management market for the Alcalá de Henares case study, the study described in this document considers the base scenario (scenario 0) as the current state of the network, characterised by load and distributed generation conditions that do not lead to congestion within the timeframe studied.

Scenario 1 considers a potential future state where grid loads escalate, leading to grid congestion. In particular, the integration of multiple electric vehicle charging stations is the focus of this scalability scenario. These high-power demands are expected to cause congestion within the timeframe considered. The techno-economic evaluation of a local congestion management market is conducted through an SRA, which involves defining various scenarios identified by changes in the parameters' values. The aim of this market is to avoid these congestions by making use of demand response strategies of the participating SPs. The characteristics of the EV charging stations are reported in Table 5.5 while Figure 5.17 provides a graphical representation of the point of connection of these new loads in the equivalent network for the Alcalá de Henares case study by means of a green star marker. To ease the identification of the new EV charging stations, in Figure 5.17 the green circles highlight the three areas in with the additional load for scenario 1 are connected.

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Table 5.5: Characteristics of the additional load for the scenario 01 – Alcalá de Henares case study

name	Maximum power capacity [MVA]	Power Factor
scen1_EVC1	1	0.98
scen1_EVC2	1	0.98
scen1_EVC3	1	0.98
scen1_EVC4	1	0.98
scen1_EVC5	4	0.98
scen1_EVC6	4	0.98
scen1_EVC7	4	0.98

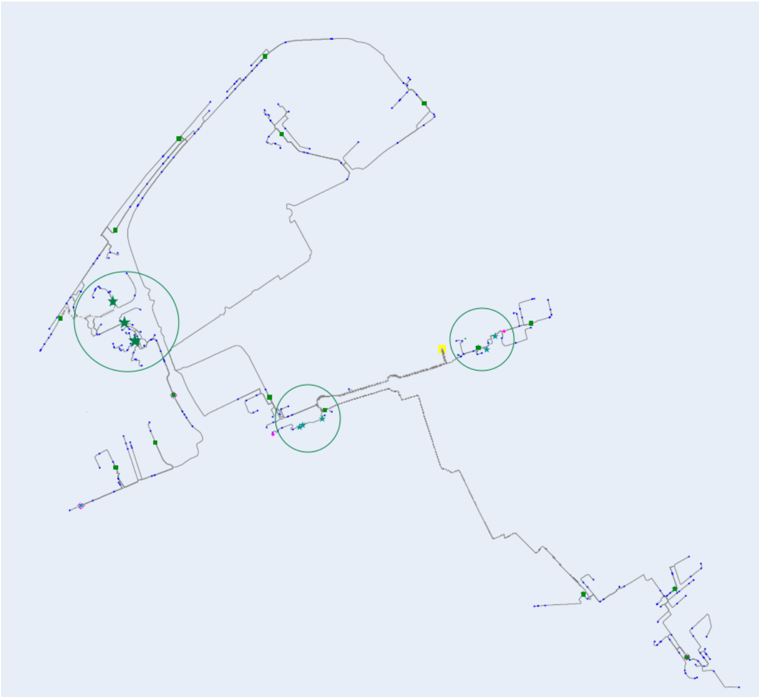

Figure 5.17: Equivalent network for the Alcalá de Henares case study with additional loads location (green-star markers. The green circles highlight the three areas in with the additional load for scenario 1 are connected.

The equivalent network for the Alcalá de Henares case study is studied by means of power flow calculation simulation to detect power network congestion. The analysis focuses on identifying potential issues in the power flows in the network over an entire year, considering the variations in demand and generation patterns. The simulation's goal is to identify the network congestions in lines and transformers. This process is carried out by performing an hourly-based power flow analysis for 8760 hours (market horizon) to identify likely constraints in the grid. This analysis considers network data, and load and generation initial profiles described in section 5.2.

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Figure 5.18 and Figure 5.19 display daily loading percentages profiles for the main feeders and all the transformers, respectively. These analyses enable the graphical identification of those lines and transformers which are experiencing congestion problems. The loading percentage profiles are displayed for main feeders in medium voltage (TMT) lines from the Alcalá Network. Figure 5.20, a detailed segment of Figure 5.18, illustrates a representative day for congestion detection, linking these profiles to earlier discussed patterns of generation and demand.

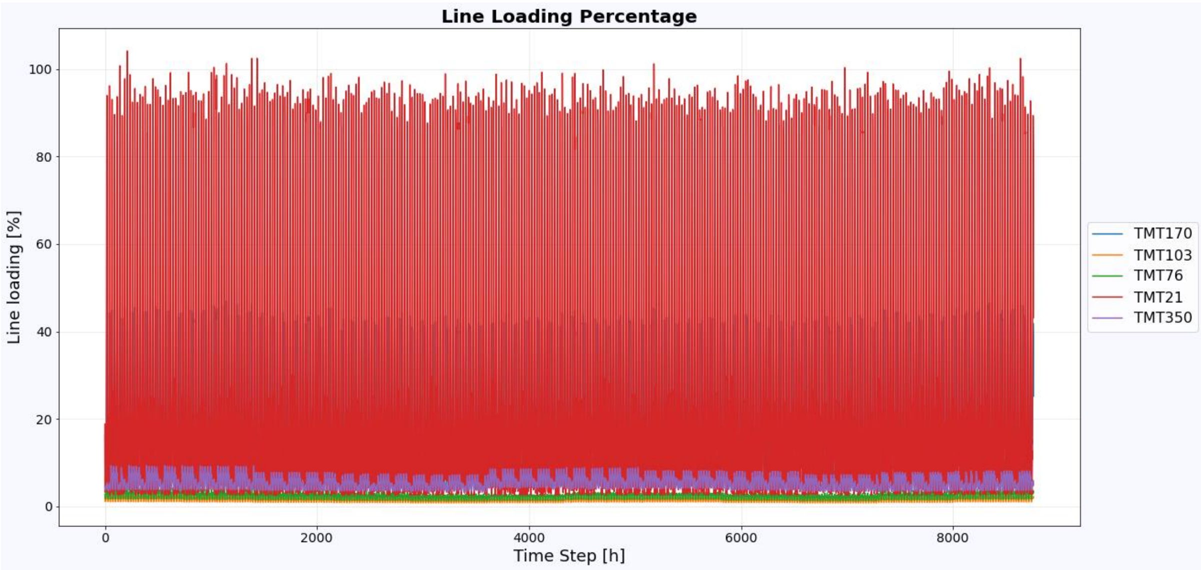

Figure 5.18: Representative yearly line loading profiles for main feeders of Alcalá network

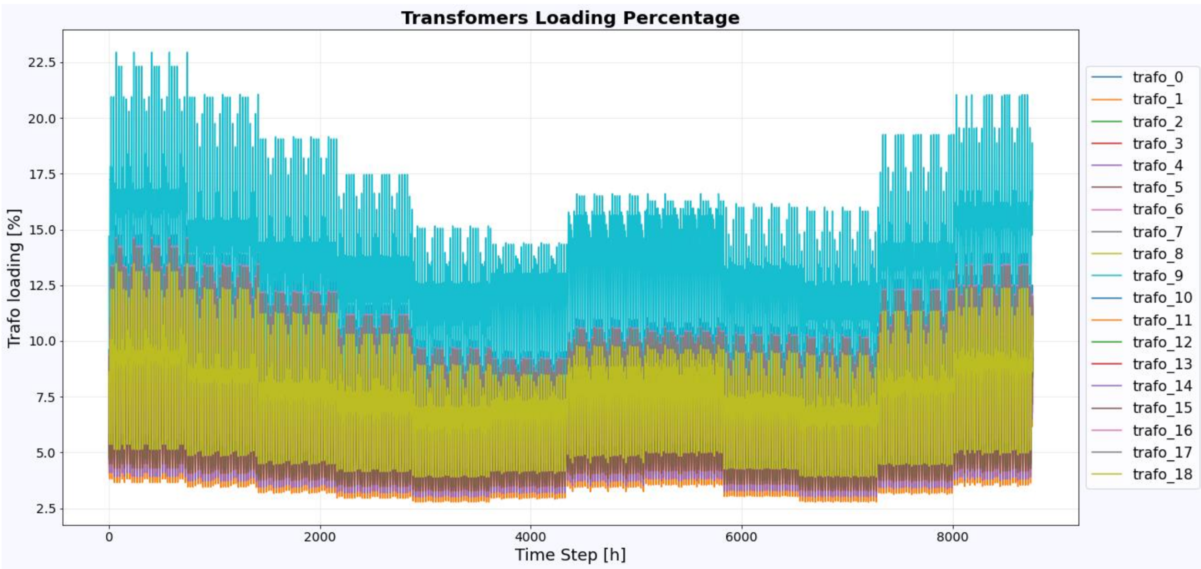

Figure 5.19: Representative yearly transformers loading profiles in Alcalá network

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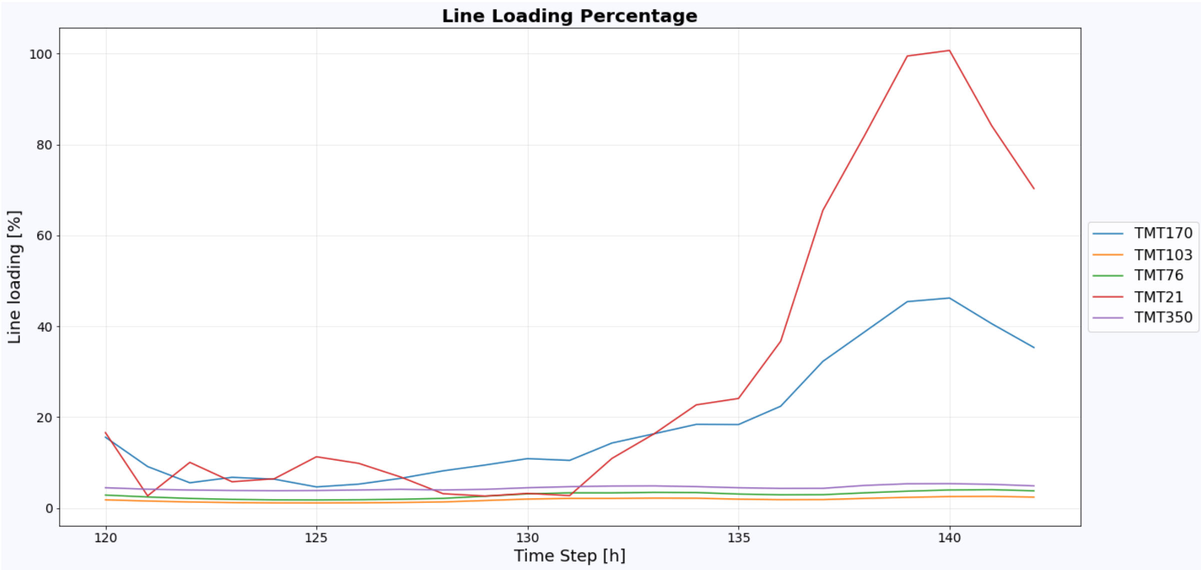

Figure 5.20: Representative day line loading profiles for congestion detection in Alcalá network

5.6 Results of the local market for congestion management simulation

The necessary step after congestion detection consists in determining the congestion management needs for overloaded lines and transformers, as described in the methodology in section 2.3. In this section, the results of the local market for congestion management clearing simulations for the Murcia and Alcalá de Henares case study are presented. These results encompass the steps of congestion management needs quantification, market simulation, ex-post power flow analysis, KPI calculation. Two scenarios are considered for the Murcia case study: scenario 1 in which only one SPs is connected, as in the demonstrator activities, and scenario 2 in which more SPs are connected to the network. A single scenario is studied for the Alcalá de Henares case study.

5.6.1 Modelling assumptions for the SRA of the two case studies

This section summarises the necessary modelling assumptions adopted to address the SRA of the two case studies based on the Spanish demonstration demos of the OneNet project. The two case studies are derived from the setting of the Spanish OneNet demos, but it is important to note that these necessary assumptions are made for the sake of generality and comparability of the cases studied, and are based on academic literature and previous projects. These assumptions do not reflect the actual settings, attributes and attribute values of the demos of the Spanish OneNet demonstrator and therefore do not represent these demos and the implied parties. Therefore, without loss of validity considering the objective of an SRA, the results presented in this section regarding the SRA of the case studies based on the Spanish OneNet demonstrator demos are indicative and based on theoretical analysis but cannot considered representative of the real Spanish demonstrator demos.

Load and generator profiles

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Unlike the real demos, the SRA considers load and generation profiles obtained from public databases and academic literature. Therefore, the load and generation profiles adopted for this SRA and the resulting load conditions are in no way representative of the real conditions that characterise the Spanish demonstration demos. Therefore, the congestion management studies and results (i.e. number of congestions, active power requirements, sensitivity factors) have to be considered as indicative and approximate to the conditions experimented for the demonstration runs. However, the modelling assumptions and simplifications necessary to obtain the synthetic networks and profiles make these models far from being a digital twin of the demo networks.

Moreover, it is worth underlining that the EV charging stations' profiles, and the siting and sizing of the EV charging stations represent a merely theoretical and academic assumption made for the scope of the SRA that does not reflect the actual and future status of the Spanish demonstrators' demos.

Products and volumes offered by the SPs to the market

Differently than in the real demos in which the product volumes are fixed, the SRA assumes that the two case studies are analysed considering as a scalability parameter the volume of active power offered to the market by the SP. In this case, scalability refers to the platform's ability to handle an increased volume of active power offered to the market by the SP without requiring additional development work. It is essential to clarify that the term 'scalability' in this context does not imply a greater number of case studies but rather the platform's capability to seamlessly integrate a higher volume of flexibility into the market. It is of interest to evaluate how the techno-economic performances of the market change by increasing the volume of service offered to the market. Within each analysed scenario, five distinct cases are defined, modelling incremental quantities of active power bids submitted to the market. These cases are structured based on a scaling factor ranging from 1 to 5, directly impacting the baseline percentage of active power associated with the SP. Consequently, in Case 5, the volume of bids submitted by the SPs is fivefold compared to that in Case 1, upholding the essential definition of the scalability parameter. Table 5.6 reports the nomenclature used to identify the five cases.

Table 5.6: Parameters' range considered for generating the SRA cases

Parameter	Parameter description	Sensitivity range
F01 – F05	Coefficient increasing the available flexibility from SPs for the 5 cases	F0x = [1, 2, 3, 4, 5]

The five cases analysed feature a progressively increasing quantity of active power available for market clearing. This increase is due to a higher percentage of flexibility being offered relative to the initial active power value (baseline). Given that the quantity offered in the market as a submitted bid is contingent upon the SP

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baseline power profile, there is not a single number representing in absolute terms the quantity the SPs bid to the market across different hours of the year.

Like in the real demos, the SP loads offer upward service exclusively, hence demand decrease, as defined in Table 2.1. The simulation for congestion management in the local market exclusively considers active power products.

Service cost to be considered for bid prices

Differently than in the real demos, the SRA assumes that information regarding flexibility costs for active power is derived from the data from local markets for congestion management in United Kingdom [45]. This data is obtained through a statistical analysis of clearing prices for analogous products [20]. It should be noted that these values are purely indicative, and any other value could have been used for the SRA described in this document. It is important to emphasise that the market performance must be considered in relative terms, comparing the different scenarios and cases; the absolute values obtained for each individual scenario or case are not representative and should not be considered in drawing any valid conclusions. For reasons of replicability and comparability, values from existing markets with similar products have been preferred for this analysis, rather than those from the demo runs, as the latter may not be representative of real competition. For the motivations described, the absolute values of bid prices are not reported in this report in order to avoid any misleading interpretation of the results presented in this report. For the simulated market runs that form the SRA described in this report, a reference price for upward and downward service is assigned to each SPs. The assigned price is the same for all market runs. The reference price is randomly assigned considering a normal distribution obtained by means of a statistical analysis of the local markets for congestion management in United Kingdom.

Metrics for the techno-economic assessment

The techno-economic assessment of the market functioning simulated in the SRA described in this document concerns the ”total system cost” metric, which serves as an indicator of the overall techno-economic efficiency of the market. This metric is the aggregate of the market's economic (monetary) performance and the monetized technical performance. The market's economic performance is indicated by the total cost incurred in acquiring active power products from SPs, referred to as 'Active power cost'. Whereas, the monetized technical performance is captured by the ”cost of service not provided”, which monetises the impact of network congestions that remain unresolved despite the SPs activations defined by the market clearing solution. Hence, the 'total system cost' metric provides the techno-economic assessment of the market functioning from the social welfare perspective; while the ‘Active power cost’ metric represents the buyer perspective since it is the cost that the buyer has to pay to acquire the active power products from the SPs.

The cost of the “cost of service not provided” represents the monetary value associated to the congestion management needs that remains unsolved after activating the SPs corresponding to the cleared bids in the

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market [24], [39], [46]. However, if the market clearing results in 100% congestion avoidance, the "cost of service not provided" incurs a cost of zero. In all other instances, these values are positive and are integrated into the mathematical model of the market as an auxiliary variable within the linearized power flow equation for congestion management. This auxiliary variable serves a dual purpose: first, it prevents optimization solutions from becoming infeasible in cases where the market cannot resolve all congestions with the available SPs bids; second, it highlights the quantity and associated cost that would have been necessary to acquire to achieve a condition where all congestions are resolved. In the context of this report's study, the "cost of service not provided" is computed by considering the value of lost loads, which, for Spain, is set at 7880 €/MWh [47].

Load and generator models as SPs

Differently than in the real demos, the SRA assumes that that in the model used for solving the two case studies, loads acting as SPs operate at a constant power factor. Consequently, when the cleared amount of active power changes, the reactive power output adjusts proportionally. The contribution to congestion management of the delivered reactive power is always coherent with delivered the active power (i.e., upwards or downwards) hence it also contributes to solve the congestions (i.e. an active power decrease for the load implies a reactive power demand decrease for that load, hence a reduction of the magnitude associate line current component, hence a contribution to reduce the line congestions). To ensure a comprehensive analysis, our simulation model also accounts for the reactive power contribution. For simplicity, in this study, the unitary cost of the reactive power component is assumed to be zero. Nevertheless, the simulated congestion management market considers active power products only. Therefore, in the OneNet demonstration under study, the total system cost of active power is considered for the SRA evaluation described in this document. However, as defined in [46], based on the different possible phenomena associated to reactive power exchange for the different technologies, for generality and without loss of validity, it is assumed also in this report that the opportunity cost of reactive power provision may be equal to the 5% of the corresponding active power bid unitary price. Although this provision has a minor impact on internal losses, it contributes to the overall social cost of congestion resolution through system service acquisition (i.e., "total system cost" metric) [48], [49]. Differently than in the real demos, the SRA considers the contribution to congestion solutions of the reactive power provision due to the constant power factor assumed for the SPs of type loads.

5.6.2 Results for the Murcian case study – Scenario 1

To undertake the SRA of the local market for congestion management for Murcia case study, hourly power flow calculations are executed over the course of one year using the equivalent network model depicted in Figure 5.11. In this specific scenario, the introduction of high-power loads from the EV charging stations, as detailed in Table 5.3, leads to congestion management challenges. These augmented loads result in the exceeding of capacity ratings for some network components at various times during the year. Figure 5.21 visually represents the extent of the congestion issues detected over the year in the studied scenario. The objective of

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the local market for congestion management is to procure enough congestion management active power products from SPs to avoid the congestion issues.

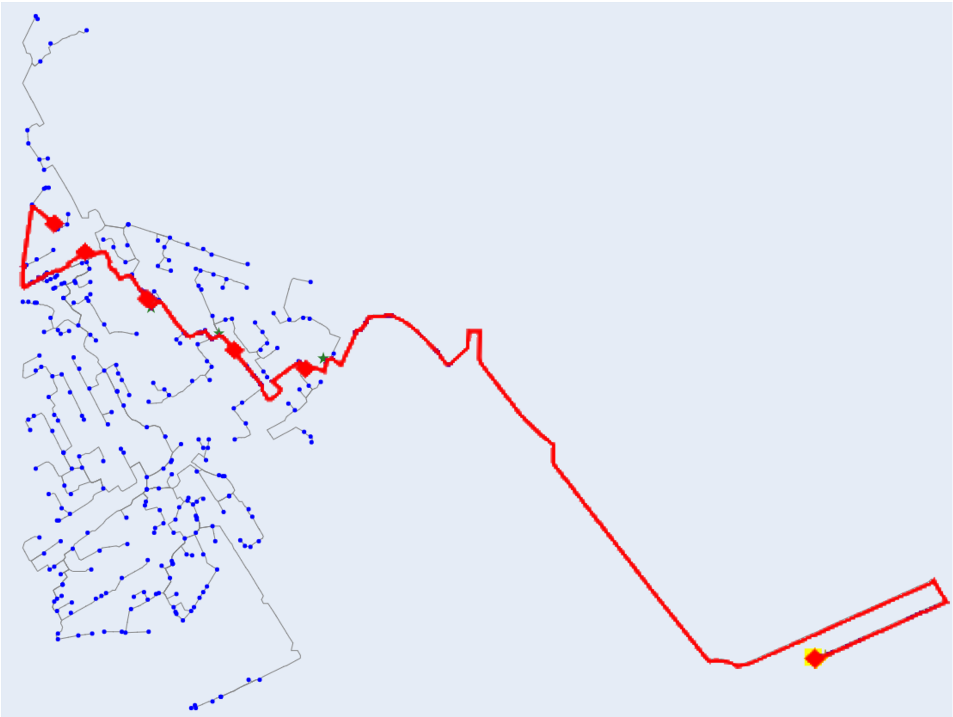

Figure 5.21: Equivalent network for the Murcian case study with EV charging station location (green-star markers) and the congested elements (red line)

In the simulated SRA Murcia case study, the number of hours with congestions and hence, the corresponding nº of occurrences for which the market is called, is equal to 419, that corresponds at 4.8% of the analysed time horizon.

In Case 1, the precise percentages of the baseline active power allocated for congestion management by the SPs is outlined in Table 5.7. The quantity is deliberately chosen to align with the active power bid at maximum capacity in Case 1, aiming to approximate the amount demonstrated in the activities outlined in [3], [12]. Additionally, Table 5.7 presents the prices for the active power upward and downward bids submitted by the SPs. It is assumed that the SP loads are willing to provide upward service only (i.e., decrease demand) while the generator may provide both upward and downward support (i.e., increase or decrease generation), according to the definitions in Table 2.1. Only active power products are considered in the local market for congestion management that is simulated.

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Table 5.7: SPs active power bids for scenario 1 for Murcian case study

Id	Active power upward bid Case F01 [%]	Active power downward bid Case F01 [%]
SP1	10	0

Figure 5.22 presents the overall results of the local market for congestion management for the simulated Murcia case study. In Figure 5.22, the term "number of occurrences [nº]" pertains to the cumulative count of elements (such as lines and transformers on the left-hand side, and congested lines and transformers on the right-hand side), multiplied by the respective number of hours of interest. For instance, on the left-hand side, it represents hours of the year with a specific loading percentage value, while on the right-hand side, it denotes hours of the year with congestion. Furthermore, "_pre" designates the ex-ante case before market execution, representing the initial state of the network. This initial state serves as the basis for calculating the flexibility requirements to be acquired through the local market. Similarly, "_post" signifies the ex-post cases after market execution, wherein the cleared SPs are activated in accordance with the quantities cleared in the market, aligning with their submitted bids.

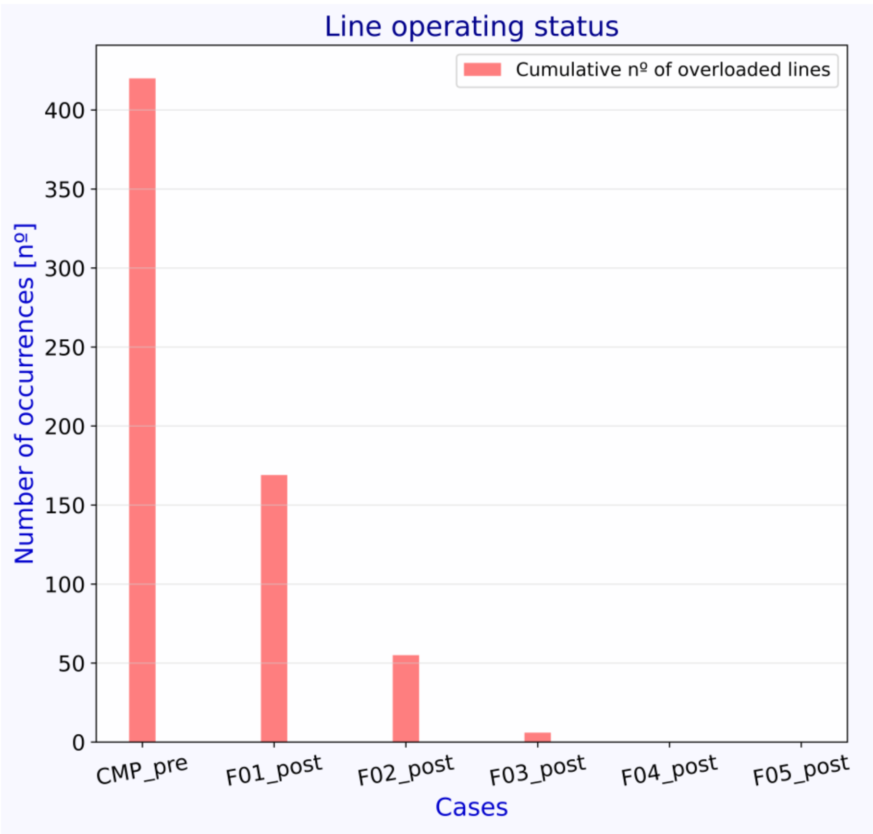

Figure 5.22: Murcia case study: technical effectiveness of the local market – Scenario 1.

On the left-hand side, the loading percentage occurrences for all the lines in the network are shown in the cases before and after the market. On the right-hand side cumulative number of overloaded lines is shown.

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Figure 5.22 illustrates the cumulative count of congestions in the Murcia case study, starting at 420 in the pre-market situation. These congestions are gradually resolved through the activation of the SP cleared by the local market. Case F01 corresponds to the scenario with the lowest volume of upward flexibility offered in the market, while F05 represents the case where the upward flexibility offered by the SP in the market is the highest. Upward and downward services adopt the convention defined in Table 2.1. In Figure 5.22, the right-hand side illustrates a notable difference in the resolution of congestions across various cases. Specifically, the F01 case exhibits already a not negligible resolution of congestions (284). By increasing the flexibility volume available in for congestion management, the F02 case demonstrates a progressive increase in technical effectiveness. In cases F04 and F05, all the congestions are solved through the coherent activation of the SP in the Murcia case study.

Figure 5.23 provides the comparison of the SRA cases for increased volume of flexibility offered in the market for the Murcia case study in terms of avoided congestions. Figure 5.23 shows that the case F01 is able to solve 59.8% of the initial congestions, 86.9% for F02, and F03 98.6%. While F04 and F05 reach the 100% of avoided congestions. Figure 5.23 also highlights that in the studied SRA scenario for Murcia case study, the lines are the elements congested, while there are not congested transformers (Trafo_2windings).

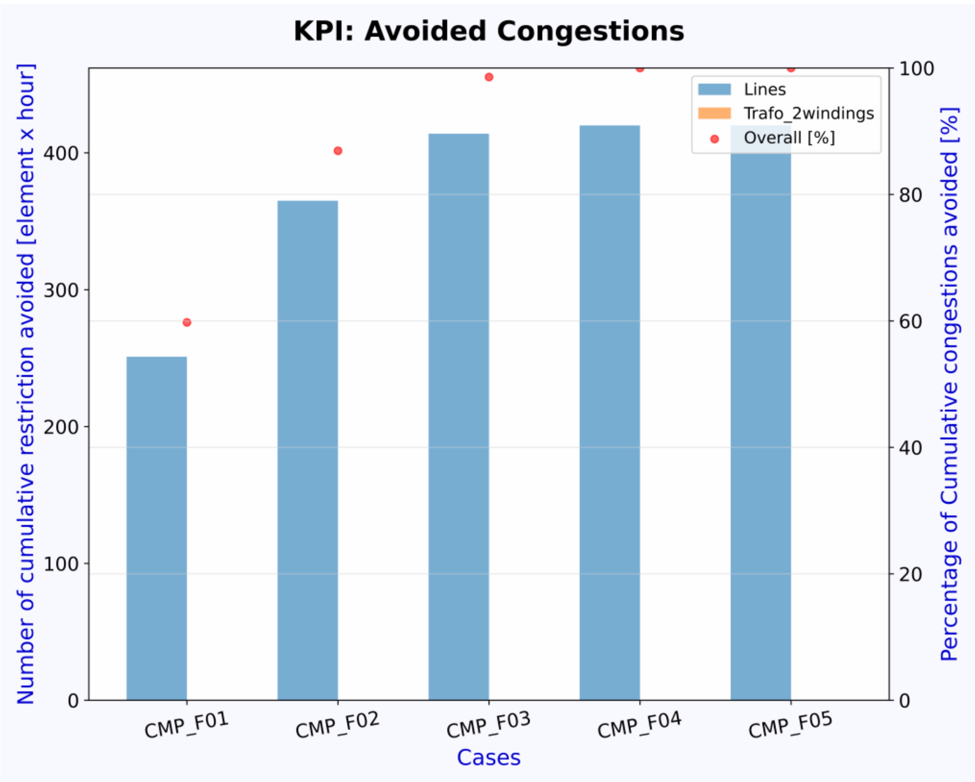

Figure 5.23: Comparison of the SRA cases for increased volume of flexibility offered in the market for the Murcian case study – Scenario 1.

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Table 5.8 summarizes the results obtained after the market clearing for each evaluated case. In Table 5.8, according to the assumptions in 5.6.1, all the values for each metric are presented in relative terms with respect to value obtained in case F01. The cost of the Objective Function equals the sum of the costs of the total active power SP's bids cleared in the market plus the cost of the flexibility service not provided (auxiliary variable in the optimisation model of the market), which implies that the model has been satisfactorily solved.

In Table 5.8, considering the "total system cost" metric, the case F05 shows the best performance since it is characterised by the lowest value, while F01 shows the worst performance since, due to the highest share of non-avoided congestion, the impact of the "cost of service not provided" determines the highest social costs. Although both F04 and F05 achieve 100% congestion avoidance, the total system cost for F05 is lower than for F04. This outcome arises from the tolerances incorporated in the optimization model, which slightly overestimate the technical performance of F04, rounding it up to 100%. However, these two solutions can be considered equivalent.

Table 5.8 indicates that the annual activation of active power products varies reaching in the case F05 the 235.5% of the case F01, allowing to solve all the expected congestions. The associated acquisition costs, "Active power cost" metric, follow the same growth trend. However, not in all cases the residual number of congestions is zero leading to accounting a cost related to the "cost of service not provided" that is non-zero for all cases except for F05. Considering the bid price submitted by the SP, as specified in section 5.6.1, and the amount of service not provided, and considering F01 as a reference for the calculation of percentages, the potential cost to be paid to potential optimally located SPs would be 36.03% for the F02 case, 8.20% for the F03, and 0.64% for case F04, which would augment the total system cost for active power.

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Table 5.8: Summary of the market clearing for congestion management with active power for the Murcian case study – Scenario 1.

	Cases				
	F01	F02	F03	F04	F05
Objective function value [%]	100.0%	36.6%	9.0%	1.5%	0.8%
Total system cost [%]	100.0%	36.6%	9.0%	1.5%	0.8%
Active power cost [%]	100.0%	186.7%	224.4%	234.6%	235.5%
Cost of service not provided [%]	100.0%	36.0%	8.2%	0.6%	0.0%
Total active power acquired [%]	100.0%	186.7%	224.4%	234.6%	235.5%
Service not provided [%]	100.0%	36.0%	8.2%	0.6%	0.0%
Percentage of avoided congestions with respect to the total [%]	59.76	86.91	98.57	100.00	100.00

The five cases analysed are characterised by a progressive increase of the percentage of flexibility being offered relative to the initial active power value (baseline). Given that the quantity offered in the market as a submitted bid is contingent upon the SP baseline power profile, there is not a single number representing the quantity the SP bids to the market across different hours of the year. Table 5.9 contains SPs' market participation data, encompassing the average, standard deviation, maximum, and minimum values of both the baseline and the quantities for submitted bids. For the brevity, only cases F01 and F05 are presented in the table, as they represent the two extremities of the SRA.

Table 5.9: Comparative analysis of cases F01 and F05 considering active power baseline (initial) values, submitted bids, and cleared bids – Murcian case study

	Average	standard deviation	Maximum value	Minimum value
Baseline value [MW]	4.88	0.36	5.62	3.62
F01 submitted bids [MW]	0.49	0.04	0.56	0.36
F05 submitted bids [MW]	2.44	0.18	2.81	1.81

Figure 5.24 shows the offered and cleared bid quantities in cases from F01 to F05 for the Murcian case study (scenario 1).

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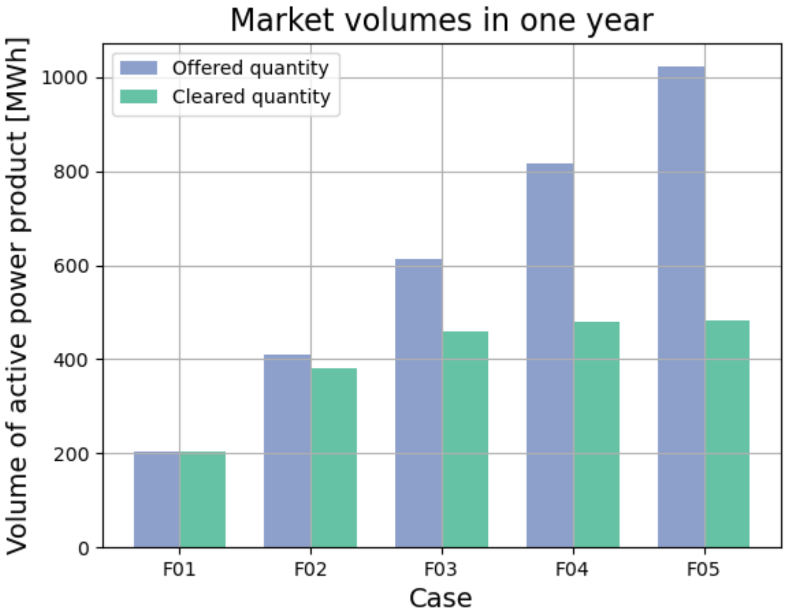

Figure 5.24: Offered and cleared bid quantities in cases from F01 to F05 – Murcian case study (scenario 1)

Figure 5.25 depicts the cumulative distribution analysis of offered and cleared bid quantities in cases from F01 to F05 for the Murcia case study. The plot provides the comparison bid quantities across the five cases studied, showcasing the distribution patterns and differences between them.

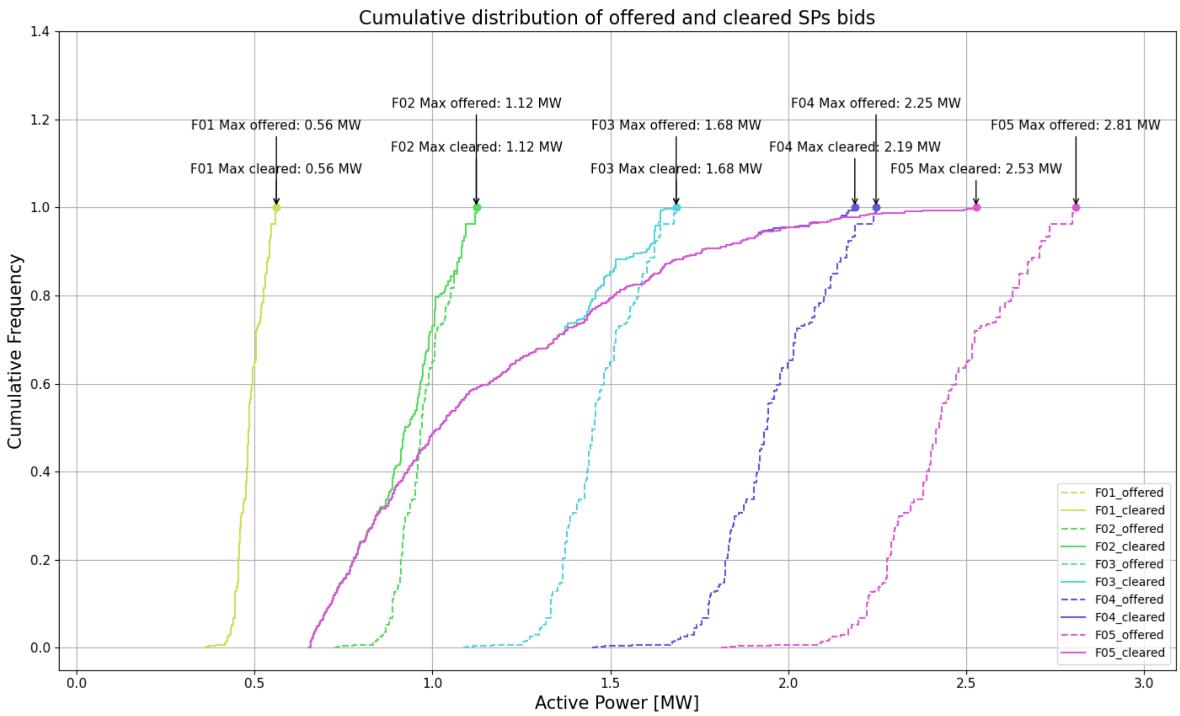

Figure 5.25: Cumulative distribution analysis of offered and cleared bid quantities in cases from F01 to F05 – Murcian case study (scenario 1).

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Figure 5.25 indicates the variability of the cleared quantities (solid lines) considering the quantity offered in the market (dashed lines). Figure 5.25 highlights that in case F01, the offered quantity is entirely cleared; case F02 also shows a relatively small differences between offered and cleared quantities, only for bids lower than about 1 MW the cleared quantity is smaller than the quantity offered. In cases F03, F04, F05, the quantity available in the market is considerably larger than the quantity that is cleared to solve the network congestions, as can be seen by the different path of the lines representing the offered quantities (dashed lines) and the cleared quantities (solid lines).

Moreover, starting from F02, the minimum cleared quantity that the market privileges is about 0.66 MW. For cases F03, F04, F05, the bid size of about 1.7 MW represents the quantity below which the 80% of the cleared bids fall. This value is close to 1.5 MW for F03 1.1 MW for F02 and to 0.5 MW for F01. The steep ascent of the F01 curve within a narrow interval indicates the concentration of cleared bid quantities. This suggests that a significant portion of bids is cleared within a relatively small range, showcasing that the flexibility potential available is entirely cleared along the market runs instances. Moreover, F01 presents a peculiar shape due to the lack of enough potential active power support available that determines the steep curve showcased Figure 5.25. In contrast, the F05 curve's slower ascent over a broader interval on the active power axis suggests a more gradual clearing of bid quantities along the market runs instances. This pattern implies a wider spread of bid values across the different market sessions, indicating greater variability or diversity in bid clearing thanks to the greater range of flexibility offered to the market.

Figure 5.26 provides insights on the relationship existing between cleared and offered quantities in the market, it represents the cumulative distribution plot of the ratio between those quantities, calculated for each hour of the market. Figure 5.26 confirms that in the case F01 the quantity cleared corresponds to the quantity offered (ratio equals to 1 for a cumulative frequency of 1). From F02 to F05, the increased quantity available in the market results in a reduced ratio when considering the cleared quantities. In case F05, no market runs during the year experience a ratio equals to 1 between cleared and offered quantities; while, about the 80% of market runs are characterised by a ratio between cleared and offered quantities equals to about the 60%.

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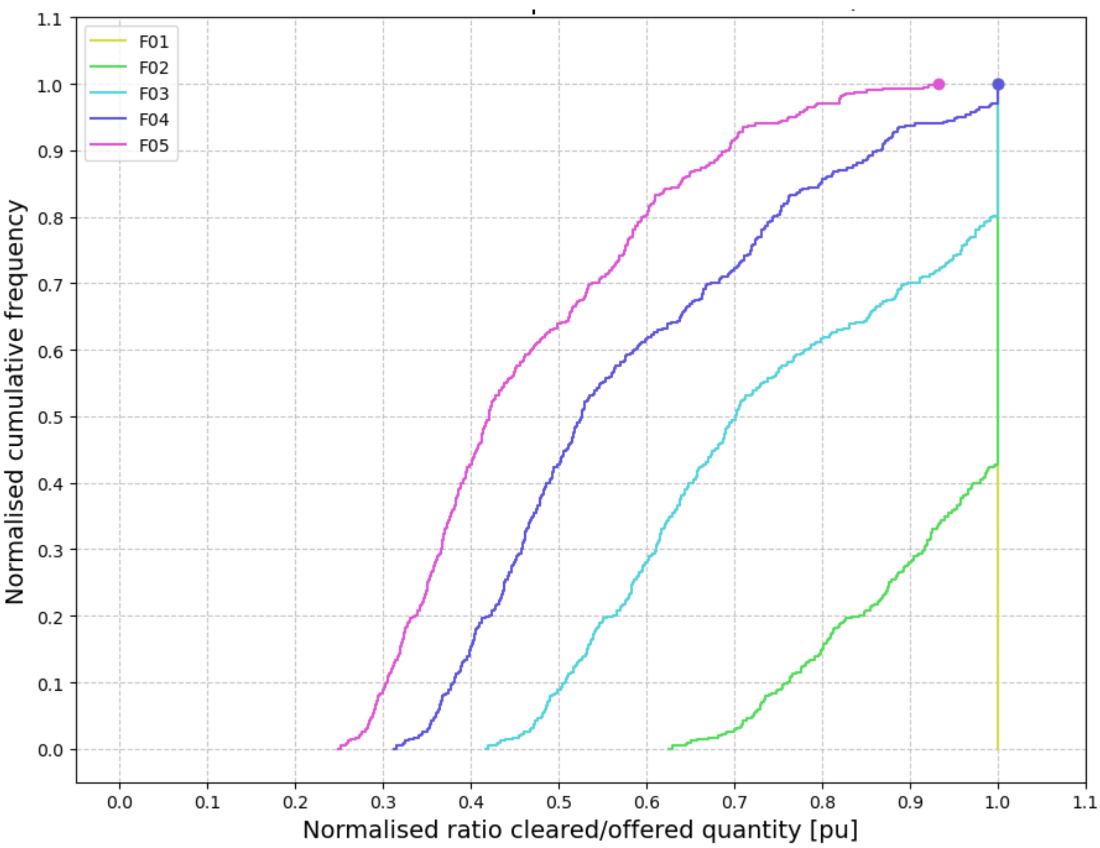

Figure 5.26: Cumulative distribution analysis of the ratio between cleared and offered bid quantities in the market sessions of cases from F01 to F05 – Murcian case study scenario 1

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5.6.3 Results for the Murcia case study – scenario 2

To conduct a thorough SRA of the Murcia case study, a second scenario is crafted. This scenario involves a higher number of SPs connected to the network compared to Case Study 1 outlined in Section 5.6.2. This second case study offers a replicability analysis, evaluating the same market model used for a scenario with an increased number of connected SPs, connected to the MV and LV networks, participating in the local congestion management market. The location of the new SPs is randomly defined considering the busses downstream of congested elements. For comparability, all the other characteristics described for Case Study 1 outlined in Section 5.6.2 remain unchanged.

Table 5.10 presents the SPs characteristics in terms of rated power and the active power upward and downward bids with the corresponding prices valid for the Case 01. Also, in this scenario, it is assumed that the SP loads are willing to provide upward service only (i.e., decrease load) while the generator may provide both upward and downward support (i.e., increase and decrease generation), as defined in Table 2.1,. Only active power products are considered in the local market for congestion management that is simulated.

Figure 5.27 presents the overall results of the local market for congestion management for the simulated Murcia case study. Figure 5.27 illustrates "number of occurrences [nº]," depicting counts of elements (e.g., lines, transformers) on the left and congested elements on the right, multiplied by the respective hours of interest. On the left, it signifies hours with specific loading percentages, while on the right, it indicates hours with congestion. Additionally, "_pre" refers to the ex-ante case before market execution, representing the initial network state for calculating flexibility requirements. Similarly, "_post" denotes ex-post cases after market execution, activating cleared SPs in alignment with market quantities and submitted bids.

Figure 5.27 illustrates the cumulative count of congestions in the Murcia case study, starting at 481 in the pre-market situation. These congestions are gradually resolved through the activation of the SP cleared by the local market. Case F01 corresponds to the scenario with the lowest volume of upward flexibility offered in the market, while F05 represents the case where the upward flexibility offered by the SP in the market is the highest. In Figure 5.27, the right-hand side illustrates a notable difference in the resolution of congestions across various cases. Specifically, the F01 case exhibits already a not negligible resolution of congestions (260 congestions solved). By increasing the flexibility volume available for congestion management, the F02 case demonstrates a progressive increase in technical effectiveness. In cases F04 and F05, all the congestions are solved through the coherent activation of the SPs in the Murcia case study.

Figure 5.28 provides the comparison of the SRA cases for increased volume of flexibility offered in the market for the Scenario 2 of the Murcia case study in terms of avoided congestions. Figure 5.28 shows that the case F01 is able to solve 61.9% of the initial congestions, 89.8% for F02, and F03 99.3%. While F04 and F05 reach the 100% of avoided congestions. Figure 5.28 also highlights that in the studied SRA scenario for Murcia case study, the lines are the only elements congested, while there are not congested transformers.

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Table 5.10: SPs rated power and active power bids for scenario 2 for Murcian case study

Id	Type	Maximum power capacity [MVA]	Active power upward bid Case F01 [%]	Active power downward bid Case F01 [%]
SP01	load	7.550	10	0
SP02	load	0.501	10	0
SP03	load	0.501	10	0
SP04	load	0.056	10	0
SP05	load	0.056	10	0
SP06	load	0.125	10	0
SP07	load	0.038	10	0
SP08	load	0.020	10	0
SP09	load	0.039	10	0
SP10	load	0.035	10	0
SP11	load	0.030	10	0
SP12	load	0.032	10	0
SP13	load	0.021	10	0
SP14	load	0.036	10	0
SP15	load	0.025	10	0
SP16	load	0.004	10	0
SP17	load	0.009	10	0
SP18	load	0.031	10	0
SP19	load	0.005	10	0
SP20	load	0.029	10	0
SP21	load	0.024	10	0
SP22	load	0.022	10	0
SP23	load	0.015	10	0
SP24	load	0.009	10	0
SP25	load	0.008	10	0
SP26	load	0.033	10	0
SP27	load	0.008	10	0
SP28	load	0.042	10	0
SP29	load	0.033	10	0
SP30	load	0.024	10	0
SP31	load	0.037	10	0
SP32	load	0.016	10	0
SP33	load	0.031	10	0
SP34	load	0.022	10	0
SP35	load	0.010	10	0
SP36	load	0.014	10	0
SP37	load	0.042	10	0
SP38	load	0.041	10	0
SP39	load	0.033	10	0
SP40	load	0.025	10	0
SP41	load	0.017	10	0
SP42	load	0.039	10	0

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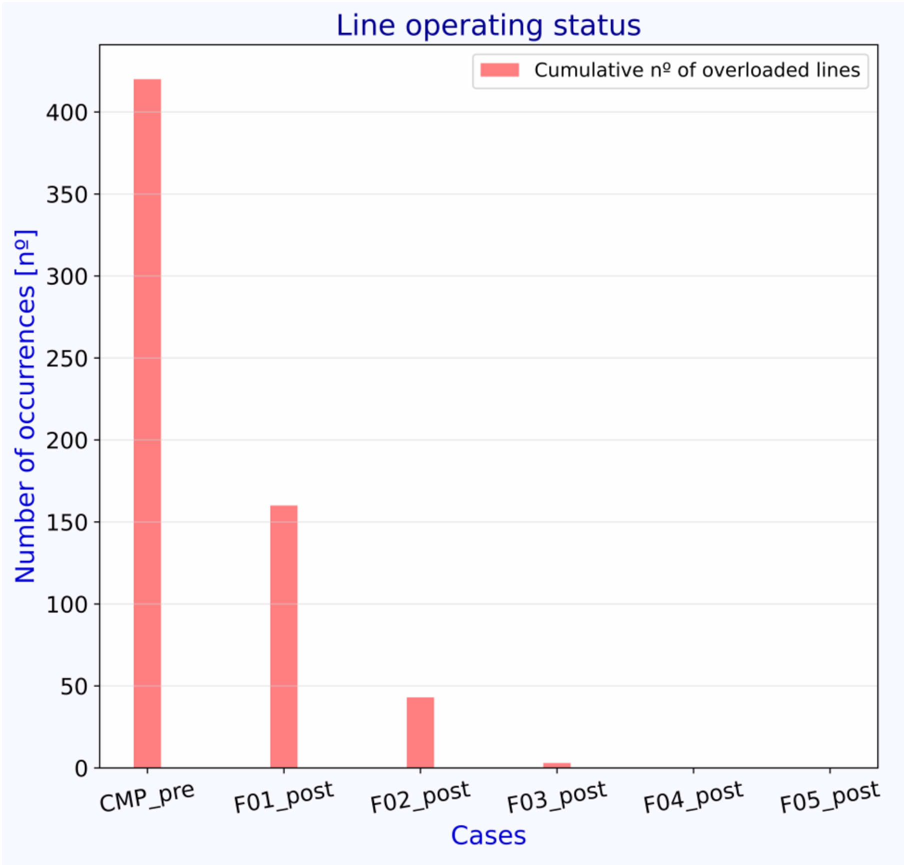

Figure 5.27: Murcian case study – Scenario 2: technical effectiveness of the local market.

On the left-hand side, the loading percentage occurrences for all the lines in the network are shown in the cases before and after the market. On the right-hand side cumulative number of overloaded lines is shown.

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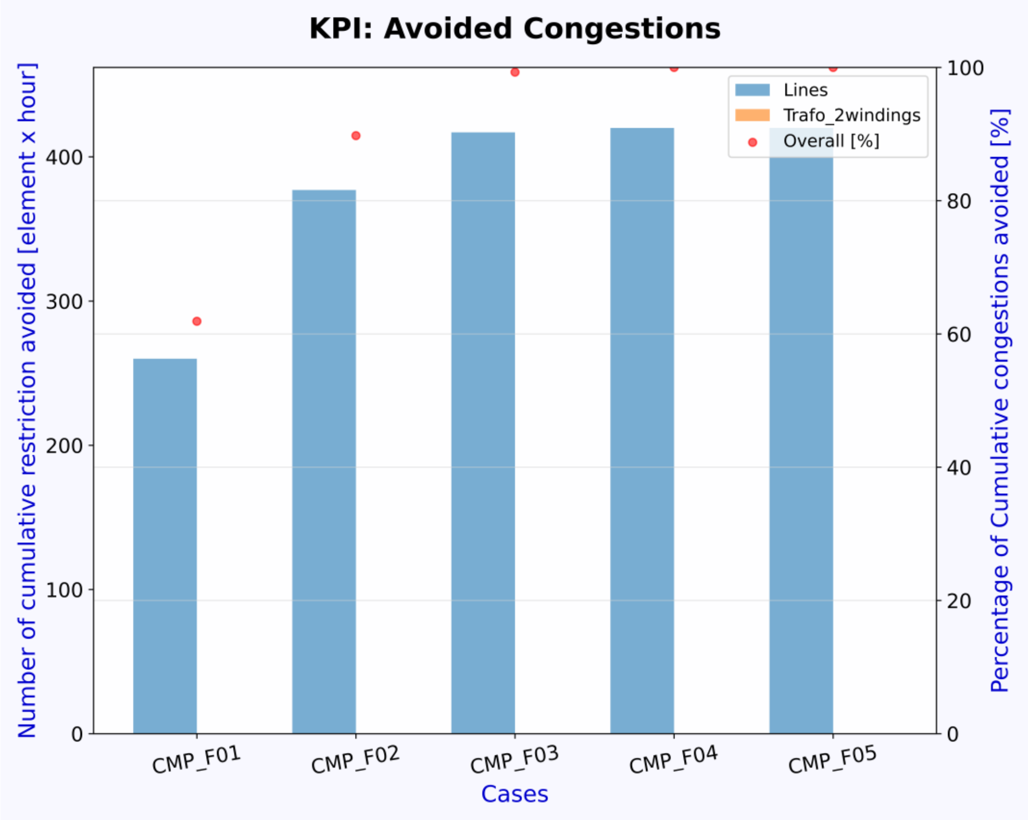

Figure 5.28: Comparison of the SRA cases for increased volume of flexibility offered in the market for the Murcian case study – scenario 2.

Comparing scenario 1 (Figure 5.25) and scenario 2(Figure 5.28) or the Murcia case study, one can see that the market results are slightly improved. Despite the comparatively modest overall active power contribution from the additional SPs compared to the one already presents in Scenario 1; their activation contributes to achieving an increased percentage of avoided congestions

Table 5.11 summarizes the results obtained after the market clearing for each evaluated case. According to the assumptions in section 5.6.1, all the values for each metric are presented in relative terms with respect to value obtained in case F01.

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Table 5.11: Summary of the market clearing for congestion management with active power for the Murcian case study – Scenario 2

	Cases				
	F01	**F02**	**F03**	**F04**	**F05**
Objective function value [%]	100.0%	31.8%	6.1%	1.0%	0.9%
Total system cost [%]	100.0%	31.8%	6.1%	1.0%	0.9%
Active power cost [%]	100.0%	180.4%	210.7%	216.5%	216.6%
Cost of service not provided [%]	100.0%	31.2%	5.3%	0.2%	0.0%
Total active power acquired [%]	100.0%	180.5%	210.9%	216.8%	216.9%
Service not provided [%]	100.0%	31.2%	5.3%	0.2%	0.0%
Percentage of avoided congestions with respect to the total [%]	61.91	89.76	99.29	100.00	100.00

Table 5.12 provide a comparison of the performance obtained by the market clearing for the Scenario 1 and Scenario 2 of the Murcian case study. The entries in Table 5.12 are expressed in relative terms calculated as the ratio between the entry for scenario 2 and the corresponding entry for scenario 1. Hence, in Table 5.12 if one entry is equal to 1, it means that scenarios 1 and 2 show same performance. For entries greater (lower) than one it means that scenario 2 achieved a greater (lower) value for the corresponding metric. Considering Table 5.12, the availability of a larger number of SPs in Scenario 2, hence an augmented volume of downward service potentially available, allows reducing the total system cost since the reduced cost related for the service not supplied in the cases in which the number of avoided congestions is not zero. However, comparing the cases F05 for both scenarios, the scenario 2 allows achieving same results in terms of number of congestions avoided (100%) by acquiring a lower amount of active power product, hence leading to a lower acquisition cost. This result is mainly due to the availability of resources that are characterised by a more favourable sensitivity factor. Regarding the impact on activation costs, to some extend the availability of a slightly cheaper SPs may be considered compensated by the activation of slightly more expensive SPs, as defined by the random assignation of bid prices to the SPs based on the normal distribution methodology described in section 5.6.1. This is motivated by the fact that in scenario 2 we have more SPs than in scenario 1, which has only one. Since the bid prices are randomly assigned according to a normal distribution, but are maintained across scenarios, we have more SPs, so in some cases some SPs are cheaper than the single SP in scenario 1, while others are more expensive. Hence, the availability of more SPs, eventually connected in more favourable positions considered the congestion to be solved, improves the techno-economic performances of the market.

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Table 5.12: Comparison of the results obtained for Scenario 2 with respect to Scenario 1 for the market clearing for congestion management with active power

	Cases				
	F01	F02	F03	F04	F05
Objective function value [pu]	0.938	0.817	0.637	0.674	0.997
Total system cost [pu]	0.938	0.817	0.637	0.674	0.997
Active power cost [pu]	1.084	1.048	1.018	1.001	0.997
Cost of service not provided [pu]	0.937	0.813	0.601	0.254	1.000
Total active power acquired [pu]	1.084	1.048	1.019	1.002	0.999
Service not provided [pu]	0.937	0.813	0.600	0.254	1.000
Avoided congestions [pu]	1.036	1.033	1.007	1.000	1.000

The substantial size variation among SPs in Scenario 2 of the Murcian case study makes the average, standard deviation, and maximum and minimum values non-representative as indicative metrics for baseline power and submitted bids. For brevity, this information is excluded from this section.

Figure 5.29 shows the offered and cleared bid quantities in cases from F01 to F05 for the Murcian case study (scenario 2).

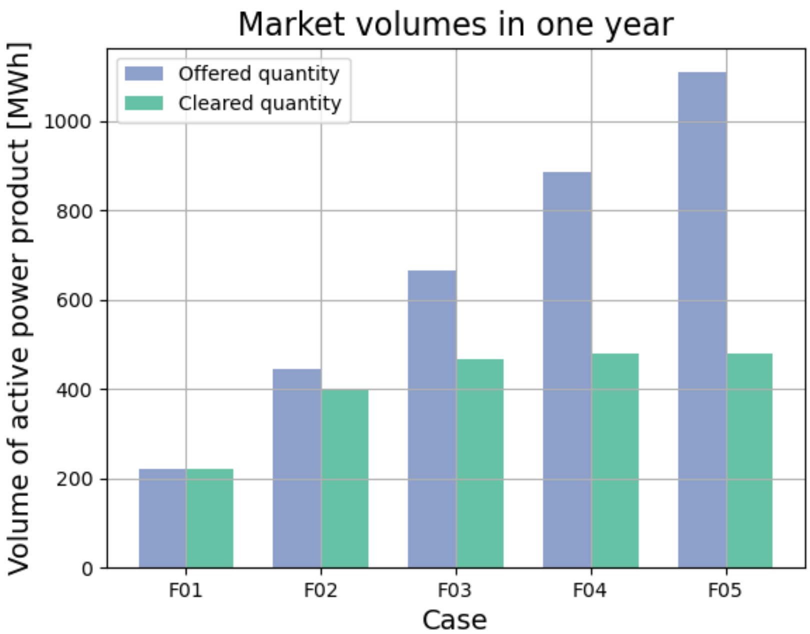

Figure 5.29: Offered and cleared bid quantities in cases from F01 to F05 – Murcian case study (scenario 2)

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Figure 5.30 depicts the cumulative distribution analysis of offered and cleared bid quantities in cases from F01 to F05 for the Murcia case study. The plot provides the comparison bid quantities across the five cases studied, showcasing the distribution patterns and differences between them. Figure 5.30 indicates the variability of the cleared quantities (solid lines) considering the quantity offered in the market (dashed lines). The patterns in Figure 5.30 mirror those in Figure 5.25 for Scenario 1. As anticipated, the quantities offered and cleared are higher due to the increased availability of potential service providers in Scenario 2. Notably, in Case F05, the maximum quantity cleared in a market run is smaller in Scenario 2 compared to Scenario 1. This difference arises from the availability of better-located SPs, enabling the procurement of a lower amount of active power product to achieve the same technical result in terms of avoided congestions, as mentioned above.

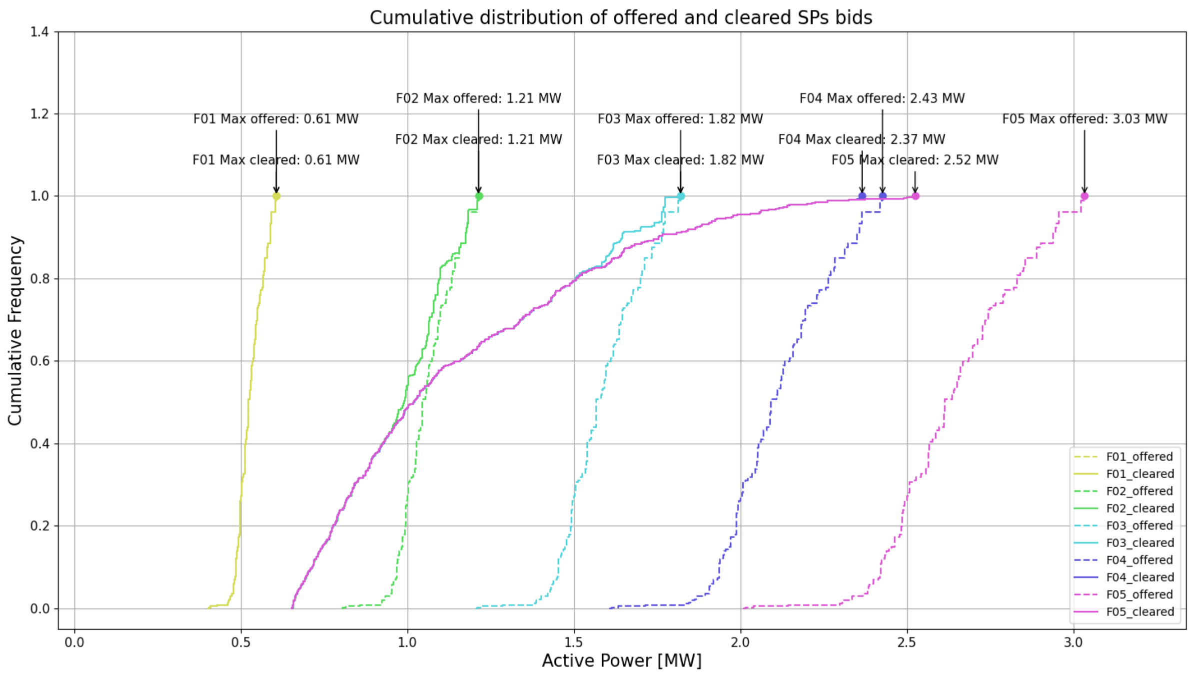

Figure 5.30: Cumulative distribution analysis of offered and cleared bid quantities in cases from F01 to F05 – Murcian case study – scenario 2

Figure 5.31 provides for Scenario 2 insights on the relationship existing between cleared and offered quantities in the market, it represents the cumulative distribution plot of the ratio between those quantities, calculated for each hour of the market. Figure 5.31 highlights that in the case F01 the quantity cleared corresponds to the quantity offered. From F02 to F05, the increased quantity available in the market results in a reduced ratio when considering the cleared quantities.

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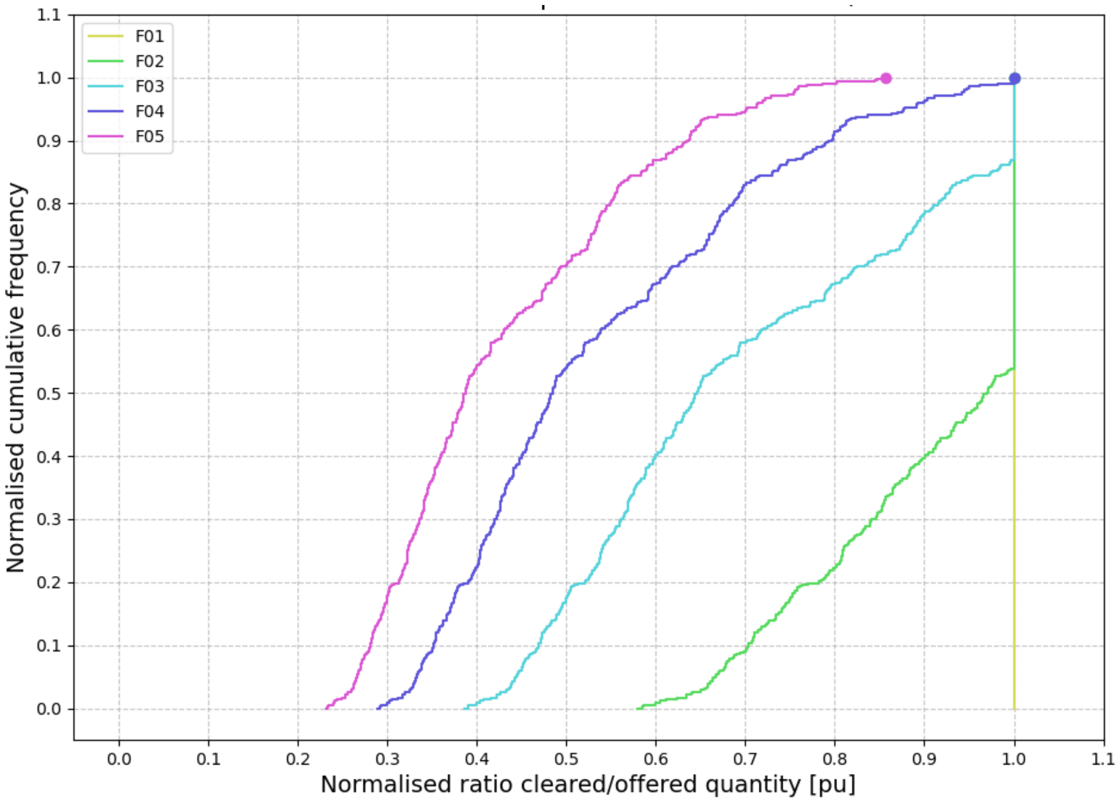

Figure 5.31: Cumulative distribution analysis of the ratio between cleared and offered bid quantities in cases in all market runs for F01 to F05 – Murcian case study scenario 2.

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5.6.4 Results for the Alcalá de Henares case study

To undertake the SRA of the local market for congestion management for Alcalá de Henares case study, hourly power flow calculations are executed over the course of one year using the equivalent network model depicted in Figure 5.32. In this specific scenario, the introduction of high-power loads from the EV charging stations, as detailed in Table 5.5, leads to congestion management needs. These additional loads determine in the exceeding of capacity ratings for some network components at various times during the year. Figure 5.32 visually represents the extent of the congestion issues detected over the year in the studied scenario. The objective of the local market for congestion management is to procure enough congestion management active power products from SPs to avoid the congestion issues.

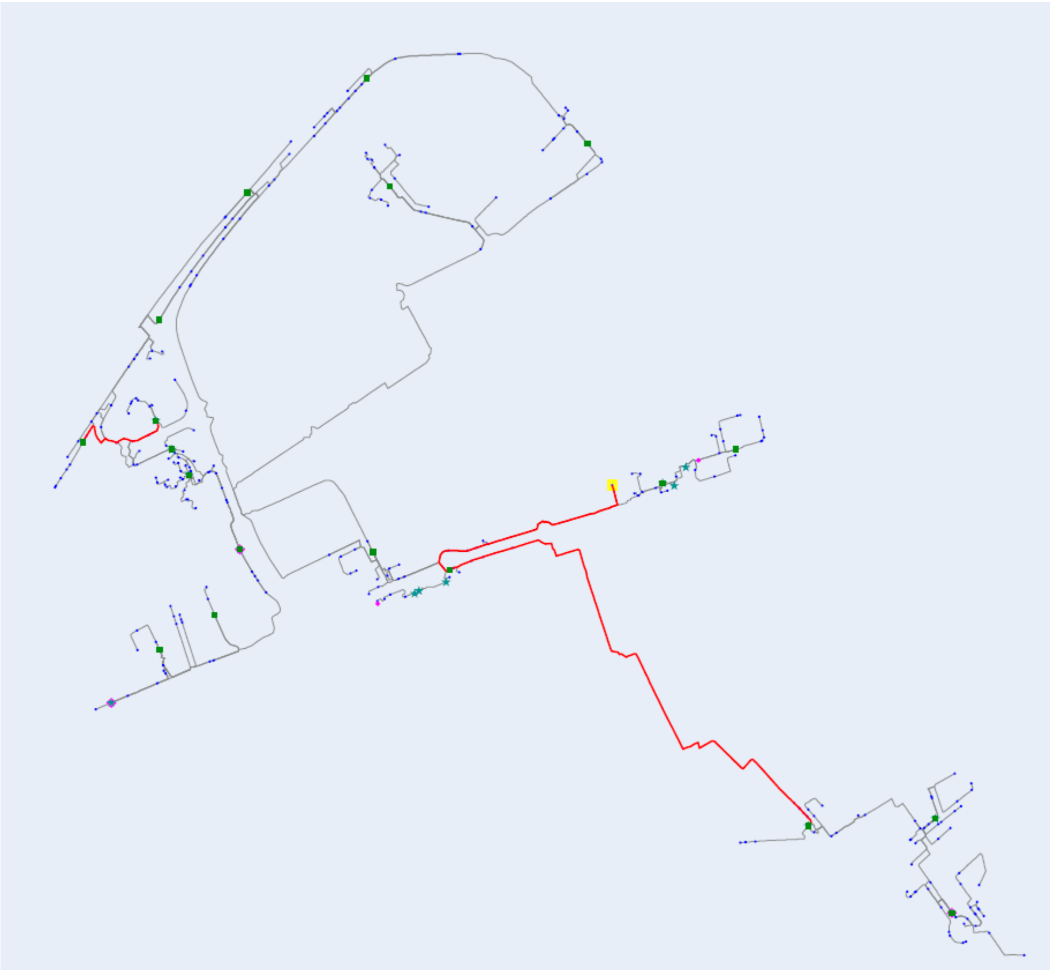

Figure 5.32: Equivalent network for the Alcalá de Henares case study with EV charging station location (green-star markers) and the congested elements (red line) – Scenario 1

In the simulated SRA scenario for the Alcalá case study, the number of hours with congestions and hence, the corresponding nº of occurrences for which the market is called, is equal to 222, that corresponds at 2.5% of the analysed time horizon.

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For case 1, the specific percentages of the baseline active power offered for congestion management by the SPs are detailed in Table 5.13. The quantities are arbitrarily selected to ensure that in case 4, the quantity of the active power bid at the maximum power capacity approximates the amount made available during the demonstration activities described in [3], [12]. Moreover, along with the bid quantity for case 1, Table 5.13 reports the price for the active power upward and downward bids submitted by the SPs. For comparability, the same prices are considered in all the case studies described in this report. It is assumed that the SP loads are willing to provide upward service only while the generator may provide both upward and downward support, as defined in Table 2.1,. Only active power products are considered in the local market for congestion management that is simulated.

Table 5.13: SPs active power bids for scenario 1 for Alcalá de Henares case study

Id	Active power upward bid Case F01 [%]	Active power downward bid Case F01 [%]
SP1	4.75	0
SP2	5.50	0
SP3	3.25	0
SP4	17.50	0
SP5	10.89	10.89

Figure 5.33 presents the overall results of the local market for congestion management for the simulated Alcalá de Henares case study. In Figure 5.33, the "number of occurrences [nº]" represents cumulative counts of elements (e.g., lines, transformers) on both sides, multiplied by corresponding hours of interest (e.g., hours with specific loading percentages or congestion). "_pre" signifies the ex-ante case before market execution, serving as the initial network state for calculating flexibility needs. Similarly, "_post" indicates ex-post cases after market execution, activating cleared SPs based on market quantities and submitted bids.

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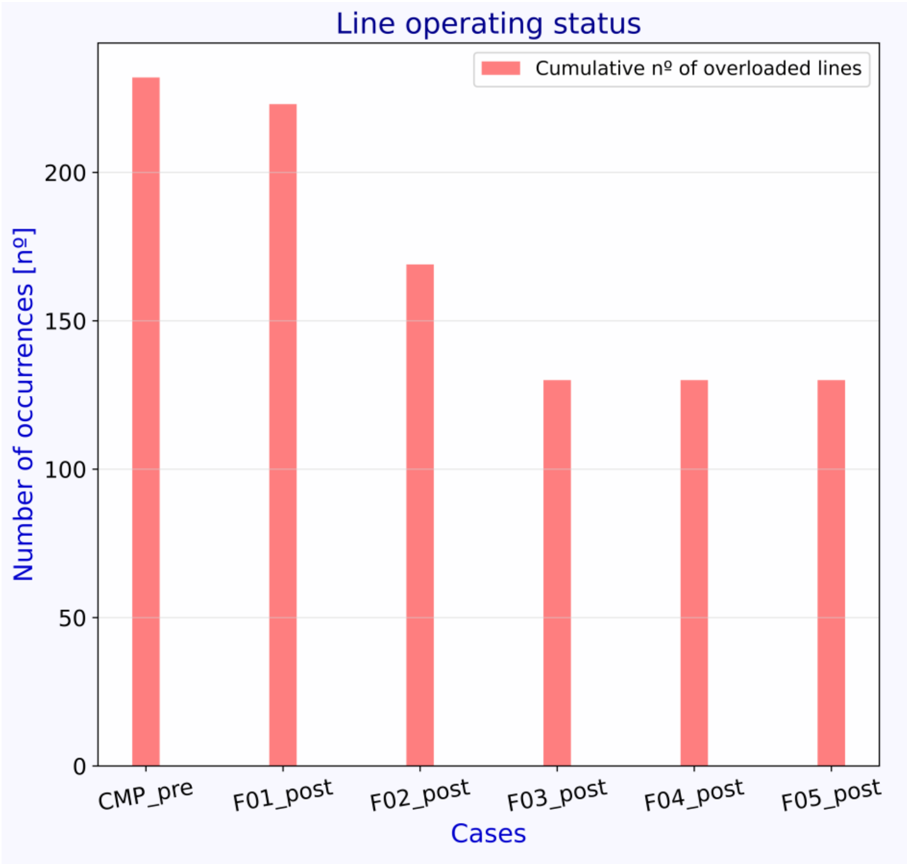

Figure 5.33: Alcalá case study: technical effectiveness of the local market.

On the left-hand side, the loading percentage occurrences for all the lines in the network are shown in the cases before and after the market. On the right-hand side cumulative number of overloaded lines is shown.

Figure 5.33 shows that the cumulative number of congestions in the Alcalá network is initially 232 (pre-market situation); those congestions, are progressively solved thanks to the activation of the SPs cleared by the local market. The case F01 considers the lowest volume of upward flexibility offered in the market, F05 represents the case in which the upward flexibility offered by each SP in the market is the largest. The convention for upward and downward provision for loads and generator is defined in Table 2.1. In Figure 5.33, the right-hand side illustrates a notable difference in the resolution of congestions across various cases. Specifically, the F01 case exhibits only a minimal resolution of congestions. In contrast, the F02 case demonstrates a significant increase in technical effectiveness of the market. However, from F03 to F05, there appears to be a saturation point in the capability to alleviate congestions, despite the availability of a larger volume of upward flexibility from the SPs. This behaviour suggests that resolving all remaining congestions in the network scenario requires engaging SPs located at different nodes, beyond those already connected. The analysis of sensitivity factors helps identify the most suitable bus locations for hosting SPs, ensuring the highest efficiency in congestion resolution for this scenario.

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Figure 5.34 provides the comparison of the SRA cases for increased volume of flexibility offered in the market for the Alcalá case study in terms of avoided congestions. Figure 5.34 shows that the case F01 is able to solve 3.9% of the initial congestions, 27.2% for F02, while from F03 onwards, the percentage of avoided congestions is 44%. Figure 5.34 also highlights that in the studied SRA scenario for Alcalá, the lines are the elements congested, while there are not congested transformers (Trafo_2windings).

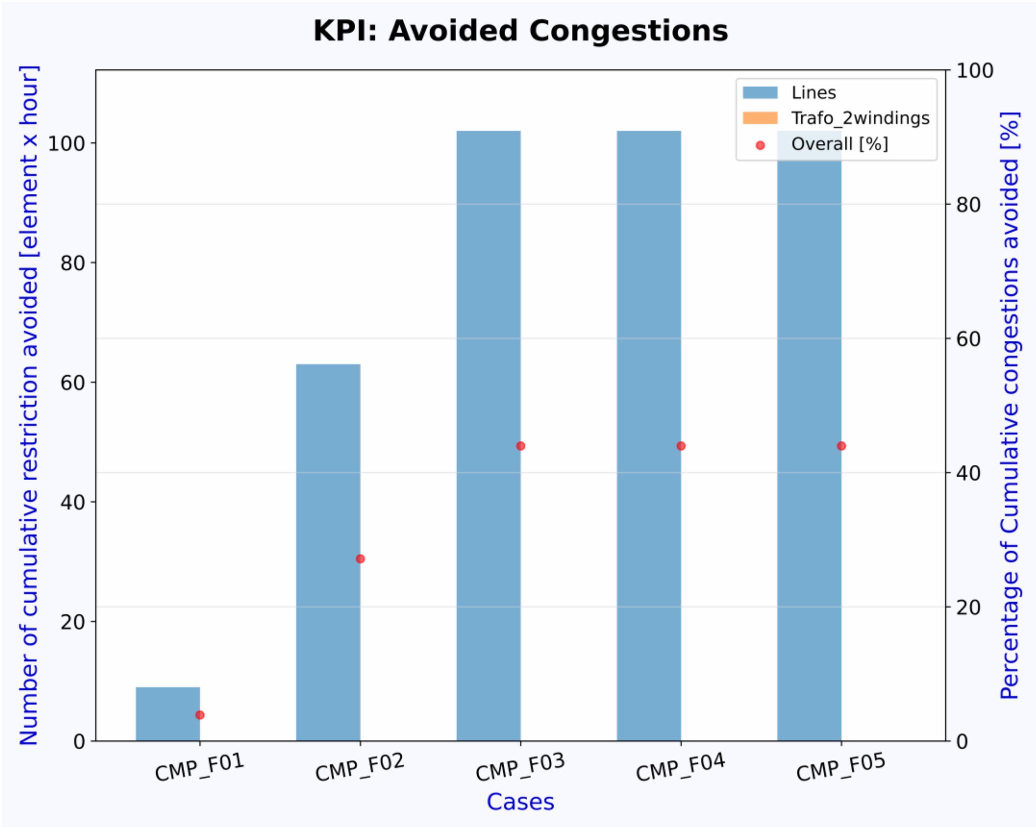

Figure 5.34: Comparison of the SRA cases for increased volume of flexibility offered in the market for the Alcalá case study

Table 5.14 summarizes the results obtained after the market clearing for each case evaluated. In Table 5.14, according to the assumptions in section 5.6.1, all the values for each metric are presented in relative terms with respect to value obtained in case F01. The cost of the Objective Function equals the sum of the costs of the total active power SP's bids cleared in the market plus the cost of the flexibility service not provided (auxiliary variable in the optimisation model of the market), which implies that the model has been satisfactorily solved.

Table 5.14 presents the "total system cost" metric, case F05 shows the best performance, as it is characterised by the lowest value, while F01 shows the worst performance, as the impact of the "cost of service not provided" determines the highest social costs, due to the highest share of non-avoided congestions. Although F03, F04 and F05 achieve the same percentage of congestion avoidance, the total system cost for F05 is the lowest. This superiority is attributed to the larger volume of flexibility available from each SP, enabling more cost-effective allocation of activations among them. Moreover, numerical tolerances incorporated in the

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optimization model, may slightly overestimate the technical performances of F03 and F04. For the Alcalá case study described in this document, in no cases all congestions are solved, leading to a remaining 56% of congestions to be solved in the case F05 that is characterised by the largest volume of active power products offered to the market.

Table 5.14 reveals that on an annual basis, the quantity of active power products activated in case F05 is the 191.6% of the quantity in F01. This corresponds to similar proportionality for the expected yearly costs. However, in both scenarios, the number of residual congestions is not reduced to zero, resulting in an associated cost for the value of lost loads amounting to 1.1% for F05 calculated in reference to F01. Considering the average bid price submitted by the Service Providers (SPs) in the Alcalá case study, defined as specified in section 5.6.1, and assuming the availability of optimally located SPs able to supply the quantity for the service not provided, the additional annual cost for active power acquisition would amount to 1.17% for case F05 and 23.03% for case F02, calculated in reference to F01 that represents the 100%. From a social welfare perspective, this translates to a benefit since the reduction of potentially lost loads.

Considering the results shown in Table 5.14, as it is evident that among the five cases, F05 exhibits the highest techno-economic efficiency. This is attributed to its ability to address the highest percentage of congestion at the lowest total system cost. In comparison to F04 and F03, which demonstrate same technical performance, F05 outperforms in terms of total system cost. On the other side, F01 appears the worst case since the total cost associated are the highest determining solving only a few percent of congestions.

Table 5.14: Summary of the market clearing for congestion management with active power for the Alcalá case study

	Cases				
	F01	F02	F03	F04	F05
Objective function value [%]	100.0%	23.8%	8.5%	4.2%	2.1%
Total system cost [%]	100.0%	23.8%	8.5%	4.2%	2.1%
Active power cost [%]	100.0%	171.2%	185.5%	189.6%	191.7%
Cost of service not provided [%]	100.0%	23.0%	7.6%	3.2%	1.1%
Total active power acquired [%]	100.0%	171.1%	185.7%	189.6%	191.6%
Service not provided [%]	100.0%	23.0%	7.6%	3.2%	1.2%
Percentage of avoided congestions with respect to the total [%]	3.9	27.2	44.0	44.0	44.0

As in the Murcian case study, the five cases analysed are characterised by an increasing quantity of active power available for the market clearing due to the increased the percentage of flexibility offered with respect

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to the initial value of active power (baseline). To describe the market behaviour of the SPs during the time horizon of considered of this study, Table 5.15 provides key statistical measures for the SPs' market participation dataset, including the average, standard deviation, maximum value, and minimum value of the baseline values and quantity values for submitted and cleared bids. For brevity, cases F01 and F05 are reported since represent the two extremes of the SRA analysis.

Table 5.15: Comparative analysis of cases F01 and F05 considering active power baseline (initial) values, submitted bids, and cleared bids

	Average	standard deviation	Maximum value	Minimum value
Baseline value [MW]	0.57	0.49	1.30	0.02
F01 submitted bids [MW]	0.06	0.07	0.17	0.00
F05 submitted bids [MW]	0.32	0.35	0.83	0.00

Figure 5.35 shows the offered and cleared bid quantities in cases from F01 to F05 for the Alcalá case study.

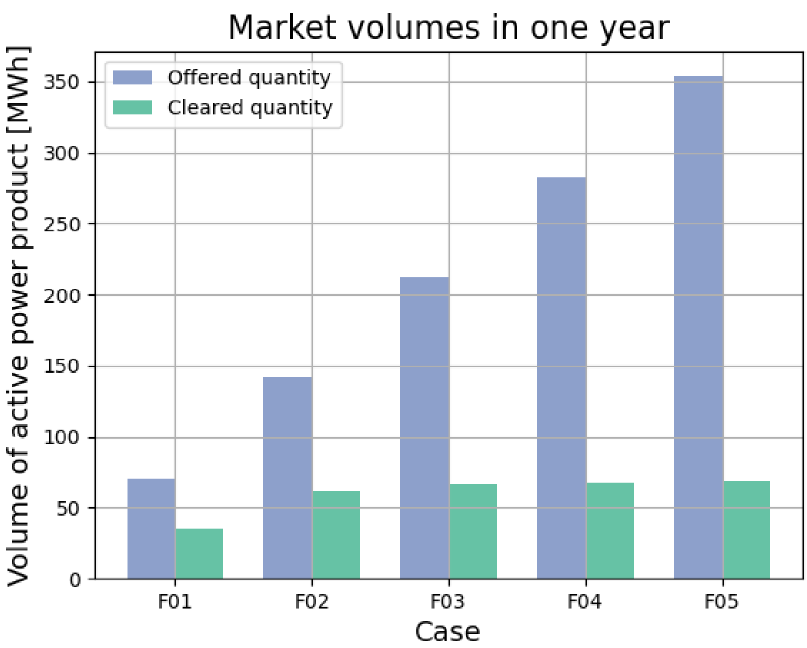

Figure 5.35: Offered and cleared bid quantities in cases from F01 to F05 – Alcalá case study

Figure 5.36 illustrates the cumulative distribution analysis of offered and cleared bid quantities in scenarios from F01 to F05 for the Alcalá case study. The plot provides a comparative examination of bid quantities, showcasing the distribution patterns and differences between the five scenarios analysed.

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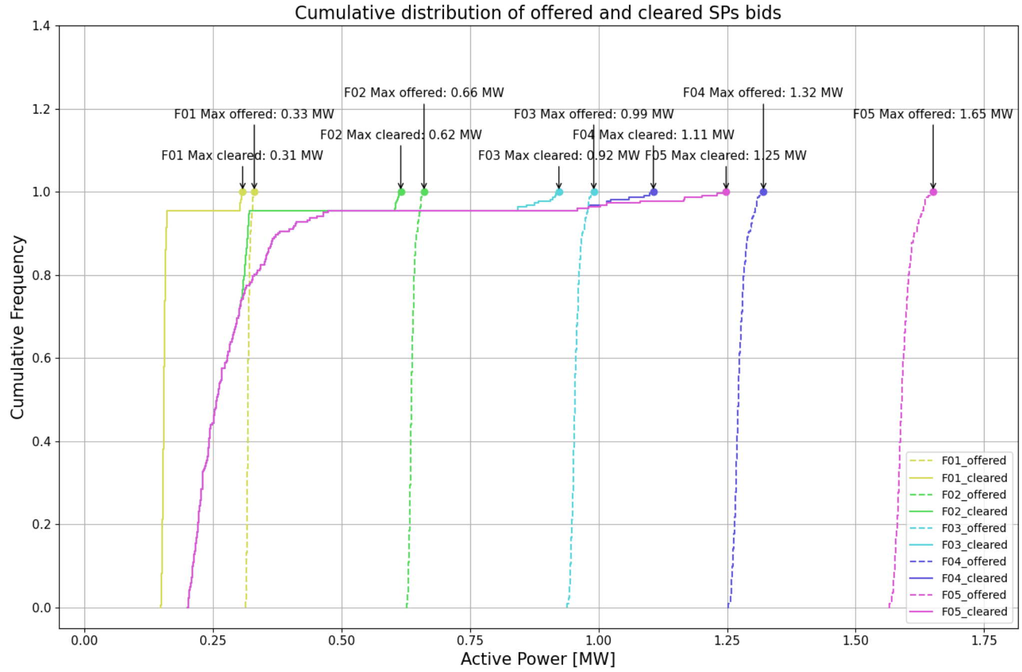

Figure 5.36: Cumulative distribution analysis of offered and cleared bid quantities in cases from F01 to F05 – Alcalá de Henares case study

Figure 5.36 indicates that the variability of the cleared quantity increases as the quantity offered in the market. In no case studied does the quantity cleared match the quantity offered. Considering that, except for cases F04 and F05, the number of residual congestions in greater than zero, it suggests that the location of the SPs is not optimal to contribute to this specific congestion problem studied in presented case study. The offered quantity lines assume a steep shape, indicating that the market is called in hours in which the SPs have the same amount of energy exchange, it makes the quantity available in the market uniform across the different hours of market runs. However, the cleared quantity takes a less steep shape, indicating that the offered quantity is not fully cleared. This is particularly evident when comparing the offered and cleared bids for F04 and F05. The flat zone in the cleared quantity curves indicates that there is a step of about 0.5 in the market clearing considering the market run hours, i.e. there are no market runs in cases F03, F04 and F05 where the total cleared quantity is equal to any value between 0.5 and about 0.8 MWh.

The analysis of Figure 5.37 depicting the cumulative curve of the ratio between the cleared and offered quantities confirms the findings of Figure 5.36. In no case and in no market run does the cleared quantity equal the offered quantity (i.e. ratio equals to 1). In case F05, a clearing ratio lower than 0.2 characterises about the 80% of market runs, only about the 10% of market runs are characterised by a clearing ratio between 0.6 and 0.75.

Moreover, starting from F02, the minimum cleared quantity that the market privileges is about 0.2 MW. For cases F03, F04, F05, the bid size of 0.4 MW represents the quantity below which the 80% of the cleared bids fall. This value is close to 0.3 MW for F02 and to 0.15 MW for F01. The steep ascent of the F01 curve within a narrow

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interval indicates a concentration of cleared bid quantities. This suggests that a significant portion of bids is cleared within a relatively small range, showcasing that the flexibility potential available is entirely cleared. In contrast, the F05 curve's slower ascent over a broader interval on the active power axis suggests a more gradual clearing of bid quantities. This pattern implies a wider spread of bid values along the year, indicating greater variability or diversity in bid clearing thanks to the greater range of flexibility offered to the market by each SPs. Moreover, F01 presents a peculiar shape due to the lack of enough potential active power support available that determines the steep curve showcased Figure 5.37.

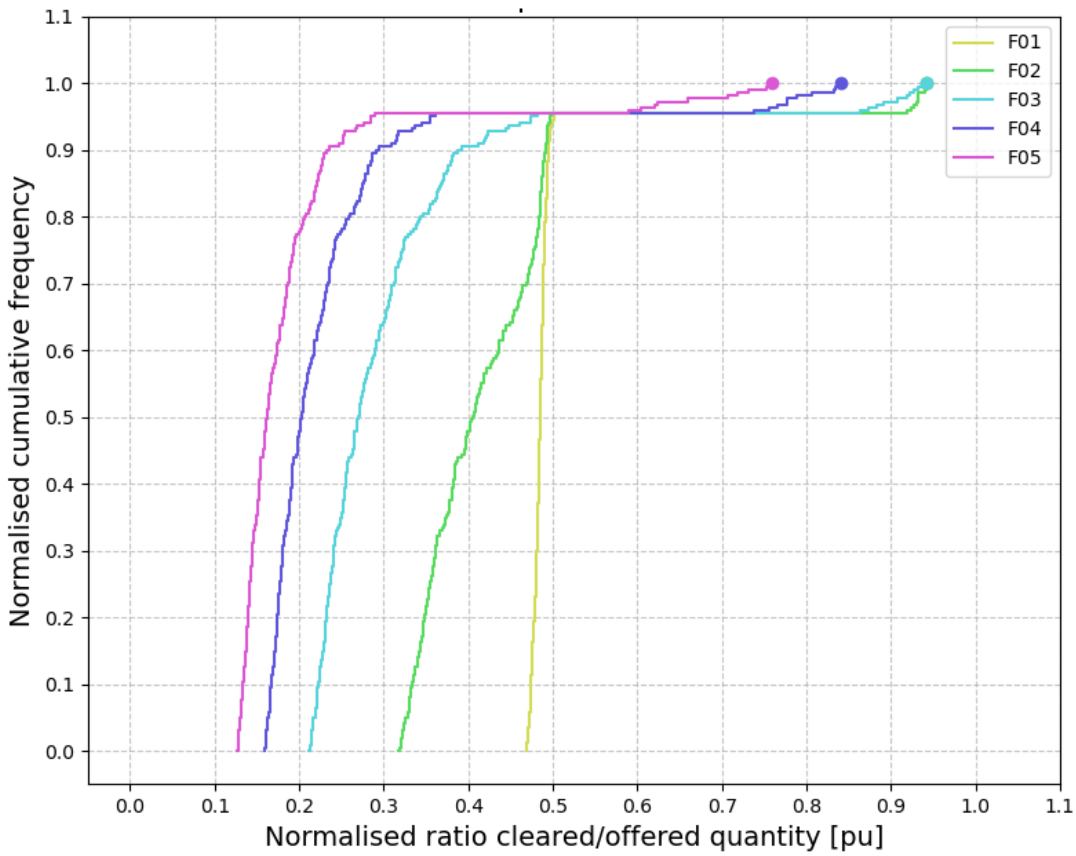

Figure 5.37: Cumulative distribution analysis of the ratio between cleared and offered bid quantities for all market runs in cases from F01 to F05 – Alcala case study

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5.7 Main findings from the quantitative SRA

The simulation results for the two case studies confirms that there are no capacity limit violations in lines and transformers under the conditions of the selected representative year. However, in the hypothetical SRA scenario characterised by the introduction of EV charging stations leads to increased loads, which in turn necessitates congestion management. The response to this challenge differs between the two case studies. In the Murcia case, the available active power capacity for congestion management is sufficient to address all expected congestions during the year under study. Conversely, in the Alcalá de Henares case, not all congestions are resolved even after utilizing the available flexibility from the SPs. This indicates that the involvement of more SPs in the Alcalá de Henares scenario is crucial for effective congestion management. The Alcalá case study underlines the relevance of having optimally located SPs to allow the market solutions to solve all expected technical constraint violation on the network. Therefore, when considering the integration of new SPs, their location becomes a significant factor that should be strategically guided based on the expected congested lines, as the network's sensitivity largely influences the effectiveness of the SPs.

The SRA outcomes for the Murcia case study reveal that by utilizing approximately 40% of the flexible capacity of the demo's SP, all expected congestions in the studied scenario are effectively resolved. However, the scenario characterised by more SPs available in the area allow to meet the needs of congestion management with a better economic performance and to decrease the reliance on the demo SP. This highlights the necessity for more flexibility options, as currently, only one SP is participating in local congestion management at the demo site. A scenario with multiple SPs would not only alter the service provision allocation but would also provide a distinct resolution from the societal cost perspective.

Both case studies highlight the potential of utilizing active power products, procured through a local market, as a means to prevent congestions that might arise during certain hours of the year due to high-power demand loads. To ascertain the economic viability of these flexibility solutions, it is crucial to compare the total cost of procuring the required active power services with the costs associated with alternative measures that could be implemented to avert such congestions.

In conclusion, the discussions above underscore the need for additional flexibility to effectively address congestion events in future scenarios of both case studies. Consequently, alternative flexibility options could be explored. For instance, Distribution System Operators (DSOs) utilizes their own flexible assets, such as network reconfiguration, controlling On-Load Tap Changers (OLTC), and similar strategies. Future research is required to explore the optimal strategies that in each different scenario can coordinate DSO-managed flexibility and the system services offered from third-parties by means of local market mechanisms.

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6 Conclusions

Work Package 9 (WP9) of the OneNet project undertakes a critical evaluation of the technical and economic facets of demonstration activities across Portugal, Spain, and France. Each demonstrator targets unique objectives within the scope of TSO-DSO-customer coordination, adopting diverse approaches to address specific challenges and opportunities in the evolving European energy landscape.

The Success Metric Analysis (SMA) conducted within the OneNet Western Cluster highlights the project's success in meeting pivotal objectives. These include consumer engagement, technical coordination, market environment adaptation, Active System Management (ASM) compliance, and platform evaluation. The analysis of Key Performance Indicators (KPIs) shows notable achievements, such as a 100% success rate in pre-qualification processes and cross-System Operator (SO) acceptance. Technical coordination, a vital component of the project, contributed significantly to forward-looking network operations, evidenced by accurate load and generation forecasting. The flexibility market evaluations exhibited varying levels of customer engagement, with the Spanish demonstrator leading in market operations. Congestion management strategies effectively mitigated technical constraints, especially in Spain, where market-based flexibility solutions proved essential.

Qualitative insights from each demonstrator provide a comprehensive understanding of the diverse strategies and outcomes:

- The Spanish demonstrator excelled in customer engagement and technical coordination among local market actors.
- The Portuguese demonstrator focused on TSO-DSO coordination and forecasting improvements.
- The French demonstrator introduced the innovative STAR platform, enhancing TSO, DSO, and Service Provider (SP) coordination for managing curtailment flexibilities.

The qualitative SRA covers both ICT developments and non-ICT aspects such as regulatory and business model constraints. In ICT, Portuguese APIs demonstrated good adherence to best practices, while the French API excelled in key compliance areas. Security measures such as throttling, quotas, and endpoint verification are recommended for scalability. The Spanish demonstrator's adoption of the AMQP protocol is noted for its reliability and security, with proper broker sizing and clear data model definition being crucial for scalability.

Non-ICT aspects revealed challenges in flexibility markets, including technical and regulatory issues that hinder harmonization. Customer engagement barriers, such as lack of awareness and privacy concerns, are also identified. Technical barriers included insufficient ICT deployment due to non-standardized data interfaces. Regulatory, legal, economic, and social barriers hindered dynamic market development and customer participation. Overcoming these barriers is crucial for replicating and scaling OneNet solutions.

The quantitative SRA, focusing on the Spanish demonstrator, employs a simulation-based approach to assess the techno-economic performance of local market solutions for congestion management. The simulations of

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two case studies – Murcia and Alcalá de Henares – demonstrate the potential benefits of using active power products for congestion prevention. The Murcia case study successfully addressed all expected congestions, while the Alcalá de Henares study indicated the need for more SP involvement. SRA results highlight that in scenarios with for load and generation growth, incorporating more and diverse SPs, and evaluating combinations of local market solutions with alternative flexibility options would be beneficial from the system perspective.

The OneNet project, through WP9, has laid a foundational blueprint for future energy system transformations in Europe. The successes and challenges encountered offer valuable lessons for upcoming projects and policies. The key to future progress lies in enhancing customer engagement, refining technical coordination, and fostering regulatory environments conducive to innovation and flexibility. To realize the full potential of such initiatives, it is imperative to focus on:

- Further standardizing ICT interfaces and protocols for seamless integration across different energy systems.
- Developing more inclusive and attractive business models to encourage broader participation in flexibility markets.
- Continuing to innovate in market-based solutions, leveraging new technologies and platforms for efficient energy management.
- Engaging more and diverse SPs in technology and size, and evaluating combinations of local market solutions with alternative flexibility options.

In conclusion, according to the analysis addressed, the OneNet WP9 demonstrators' experience provides a robust framework for advancing Europe's energy systems.

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Annex A KPIs nomenclature mapping

ASM phases	*KPI groups*	*Spanish IDs*	*Portuguese IDs*	**French Data ID (D2.4)**	**French mapped D2.4**	*KPIs (11.1)*	*description (list of common KPIs)*
flex market	GD	*KPI ID 11*		*N_FSP_FR*	FR_BUC_KPI_01	KPI_H01	Number of FSPs
flex market	GD	*KPI ID 10*			FR_BUC_KPI_05	KPI_H02	Active participation
flex market	E	*KPI ID 1*				KPI_H03	Cost-effectiveness
flex market	E	*KPI ID 2*	KPI_H04			KPI_H04	ICT costs
flex market	ES		KPI_H05			KPI_H05	Reduction in RES curtailment
flex market	ES					KPI_H06	Ease of access
flex market	MP	*KPI ID 8*				KPI_H07	Number of transactions
flex market	MP					KPI_H09	Volume of transactions
flex market	MP	*KPI ID 7*	*KPI_H09A*			KPI_H09A	Volume of transactions (Power)
flex market	MP		*KPI_H09B*			KPI_H09B	Volume of transactions – cleared bids (P or Q Availability)
flex market	MP		*KPI_H09D*		FR_BUC_KPI_06	KPI_H09D	Volume of transactions – cleared bids (P or Q Activation) (Energy)
flex market	MP	*KPI ID 9*				KPI_H11	Number of products per demo
CM	CM	*KPI ID 13*				KPI_H12	Number of avoided technical restrictions (congestions/ voltage violations)
CM	CM	*KPI ID 6*				KPI_H13A	Congestion reduction (magnitude)
CM	CM	*KPI ID 3*	*KPI_H14A*		FR_BUC_KPI_04	KPI_H14A	Available Flexibility
CM	CM		*KPI_H15A*			KPI_H15A	Requested flexibility (Power)
forward looking operation	DP		KPI_H20A (avg)			KPI_H20A	Accuracy of the RES production forecast calculated T hours in advance
forward looking operation	DP		KPI_H20A (solar)			KPI_H20A	-"-
forward looking operation	DP		KPI_H20A (wind)			KPI_H20A	-"-
forward looking operation	DP		KPI_H20A (thermal)			KPI_H20A	-"-
forward looking operation	DP	*KPI ID 4*	KPI_H20B			KPI_H20B	Accuracy of load forecast calculated T hour in advance
forward looking operation	DP		KPI_H21B			KPI_H21B	Share of false positive congestion contingencies
CM	CM	*KPI ID 5*				KPI_H23A	Power exchange deviation
forward looking operation	NO		KPI_N25			KPI_N25	Comparison between the Isc max forecasted for the 63kV by the planning and the maximum short circuit value registered for the series under analysis
CM	DP			KPI_N26	FR_BUC_KPI_02	KPI_N26	Tracked flexibility
CM	DP			N_FLEX_NAZA_FR	FR_BUC_KPI_02	KPI_N26	Tracked flexibility (automatic)
CM	DP			N_FLEX_MAN_FR	FR_BUC_KPI_02	KPI_N26	Tracked flexibility (manual)
CM	CM		KPI_N27			KPI_N27	Total power of avoided congestions through flexibility activation.
CM	DP		KPI_N28			KPI_N28	Maximum ratio of false-positive and negative congestion forecasts
forward looking operation	NO		KPI_N30			KPI_N30	Comparison of the rated short circuit current of the circuit breakers for the 63kV and maximum short circuit value registered for the series under analysis
CM	CM		KPI_N31			KPI_N31	Nº of congestions/violations on DSO network
CM	CM		KPI_N32			KPI_N32	Nº of congestions/violations on TSO network
forward looking operation	DP		KPI_N33 (avg)	KPI_N33 (avg)		KPI_N33 (avg)	KPI_N33: Improvement of the forecast
forward looking operation	DP		KPI_N33 (load)	KPI_N33 (load)		KPI_N33 (load)	
forward looking operation	DP		KPI_N33 (solar)	KPI_N33 (solar)		KPI_N33 (solar)	

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forward looking operation	DP		KPI_N33 (thermal)	KPI_N33 (thermal)		KPI_N33 (thermal)	
forward looking operation	DP		KPI_N33 (wind)	KPI_N33 (wind)		KPI_N33 (wind)	
PP	PP		KPI_N34			KPI_N34	Successful ending of prequalification process
PP	PP		KPI_N46			KPI_N46	Nº prequalification process that need additional information
PP	GD					KPI_N48	FSP acceptance
PP	DP					KPI_N49	Average Processing Time
PP	PP					KPI_N50	Cross SO Prequalification Acceptance
PP	PP					KPI_N51	Need for additional information for cross SO Prequalification

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