INDUSTRIAL ENGINEERING MASTER

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Design of local markets for Energy Communities

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Madrid, July 2024

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título
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Fdo.: José Luis Alcañiz Pérez Fecha: 15/7/2024

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DESIGN OF LOCAL MARKETS FOR ENERGY COMMUNITIES

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ABSTRACT

This project investigates the participation of energy communities (ECs) in the Spanish electricity markets, analyzing regulatory, qualitative, and quantitative perspectives. It begins with a comprehensive review of the current regulatory framework, including both European and Spanish regulations, and examines their implications for local communities. The qualitative analysis focuses on the characteristics and operational models of ECs in Spain, identifying key factors such as size, generation capacity, and types of renewable energy sources used. Quantitatively, optimization models are developed to enhance the efficiency and integration of ECs into the electricity market. These models optimize the size and power of battery storage systems and the sale of energy in the daily market. The analysis reveals significant variations in battery size and power requirements among different ECs, correlating these variations with their installed power capacities. The study's recommendations include effective aggregation strategies, revisions of minimum bid size requirements, removal of aggregation restrictions, and improvements in market flexibility.

Keywords: Energy communities, electricity markets, regulatory framework, optimization models, market participation, battery storage systems, aggregation strategies, renewable energy.

1. Introduction

The transition towards more sustainable and resilient energy systems has increased interest in energy communities (ECs) [1], which play a crucial role in this process. ECs are local organizations that manage the production, consumption, and storage of energy, typically from renewable sources. Despite their potential, ECs face significant challenges in effectively integrating into electricity markets. These challenges include regulatory, technical, and economic barriers. The objective of this work is to analyze these barriers and propose solutions to overcome them, facilitating greater participation of ECs in the Spanish electricity markets. The study examines the characteristics and operational models of ECs, as well as the regulations that affect them, to provide a comprehensive view of their current situation and future possibilities.

2. Methodology

The study's methodology is structured into several key phases:

1. Literature Review: Conducting a thorough review of academic documents, regulatory reports, and case studies related to ECs and their participation in electricity markets. This includes the analysis of European and Spanish regulations impacting ECs [2].
2. Survey Design and Data Collection: Designing surveys targeted at EC members to collect qualitative and quantitative data on their operations, challenges, and opportunities [3].
3. Market Characterization: Studying the structural aspects of the Spanish electricity markets to better understand the dynamics and specific requirements of each.
4. Barrier Identification: Identifying and analyzing the regulatory, technological, and market barriers that ECs face in participating in electricity markets. This includes restrictions on generation and consumption aggregation as well as minimum bid size requirements.
5. Model Development and Optimization: Developing mathematical models to optimize the size and power of battery storage systems for ECs. These models consider various variables and scenarios to improve efficiency and market integration.
6. Analysis and Visualization: Using graphs and diagrams to illustrate key findings and trends based on the optimization performed. This helps visualize variations in battery size and power requirements among different ECs and their correlations with installed power capacities.

3. Results

The detailed market analysis evaluated the participation capacities of 33 ECs in various Spanish electricity markets, including the daily market, intraday auction, continuous intraday market, and DSO congestion management. The findings highlight several key points:

- Aggregation Strategies

Smaller ECs need effective aggregation strategies to meet market participation thresholds. Without aggregation, many ECs cannot meet the minimum bid size requirements, limiting their market entry.

- Battery Storage Optimization

Significant variations were identified in the battery storage system size and power requirements among ECs. These variations depend on the installed power capacities and consumption patterns of each community. The optimization models developed in the study provide tailored solutions for enhancing battery storage efficiency and market participation capabilities.

- Market Participation Barriers

Current restrictions on the aggregation of generation and consumption pose significant barriers to ECs. These restrictions prevent ECs from fully exploiting their potential in electricity markets. The study also found that the minimum bid size requirements are a major obstacle for smaller ECs, limiting their ability to participate independently in various market segments.

- Policy Recommendations

To facilitate greater EC participation, the study recommends revising the minimum bid size requirements and removing restrictions on the aggregation of generation and consumption. These changes would enable more flexible and inclusive participation of ECs in the energy markets.

- Optimization Model Findings

Two distinct optimization versions of a model were evaluated. The first version focuses on determining the optimal size and power capacity of battery storage systems, maximizing efficiency and meeting community-specific requirements. The second version optimizes energy profiles within fixed parameters, enhancing the operational efficiency of existing battery systems. The results from these models reveal significant insights into the variability of battery storage needs across different ECs.

- Implications for EC Development

The optimized battery storage systems have the potential to significantly enhance EC participation in various electricity markets. By improving operational efficiency, ECs can contribute more effectively to a decentralized and renewable energy system in Spain.

4. Conclusions

This study has provided an in-depth analysis of the participation potential of Spanish Energy Communities (ECs) in various electricity markets. The findings underscore several critical insights and actionable recommendations:

- Qualitative Analysis:

The survey revealed the diverse nature of ECs in Spain, showcasing variations in size, resource-sharing practices, and technological adoption.

Most ECs are relatively small, with fewer than 100 participants, indicating a grassroots approach to energy management.

The predominant activities within these communities include collective photovoltaic self-consumption and advisory services, emphasizing a strong focus on solar energy and community education.

The detailed market analysis highlighted the significance of aggregation strategies for smaller ECs to participate effectively in the Spanish electricity markets.

Key barriers identified include minimum bid sizes, restrictions on aggregating generation and consumption, and technological requirements.

Addressing these barriers through policy changes and market reforms is essential for enabling broader participation of ECs in various market segments, such as the Day-ahead market, Intraday auction, Intraday continuous market, and DSO Congestion Management.

Even if regulations allow aggregation, communities must invest in automation to meet the technical requirements of the products necessary for system operators to operate effectively.

- Quantitative Analysis of Market Participation:

Two optimization models versiosn were developed to provide actionable insights into the market participation potential of battery storage systems within ECs.

The first version, focusing on optimizing battery size and power, highlighted significant variations in storage needs across different communities. Tailoring battery capacities to the specific requirements of each EC demonstrated potential improvements in energy management cost-effectiveness.

The second version, which optimizes energy profiles within fixed battery parameters, emphasized the importance of advanced charge and discharge logics and better alignment with market participation opportunities.

- Key Recommendations:

Implement aggregation strategies to enable smaller ECs to meet market participation thresholds where technically possible.

Revise minimum bid size requirements and remove restrictions on the aggregation of generation and consumption where technically feasible.

Offer financial guarantees for installing renewable energy systems and battery storage solutions, allowing ECs to participate with larger market bids.

Encourage investment in automation technologies to help ECs meet the technical requirements necessary for effective market participation.

By addressing these key findings and implementing the recommended strategies, ECs can enhance their market participation, optimize their energy management, and contribute more effectively to the overall energy system.

5. References

[1] «Energy communities: what are they and what advantages do they have», REPSOL. Accedido: 10 de junio de 2024. [En línea]. Disponible en: https://www.repsol.com/en/energy-and-the-future/future-of-the-world/energy-communities/index.cshtml

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DISEÑO DE MERCADOS LOCALES PARA COMUNIDADES ENERGÉTICAS

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ABSTRACT

Este proyecto investiga la participación de las comunidades de energía (CE) en los mercados eléctricos españoles, analizando perspectivas regulatorias, cualitativas y cuantitativas. Comienza con una revisión exhaustiva del marco regulatorio actual, incluyendo tanto la normativa europea como la española, y examina sus implicaciones para las comunidades locales. El análisis cualitativo se centra en las características y modelos operativos de las CE en España, identificando factores clave como el tamaño, la capacidad de generación y los tipos de fuentes de energía renovables utilizados. Cuantitativamente, se desarrollan modelos de optimización para mejorar la eficiencia y la integración de las CE en el mercado eléctrico. Estos modelos optimizan el tamaño y la potencia de los sistemas de almacenamiento en baterías y la venta de energía en el mercado diario. El análisis revela variaciones significativas en el tamaño de las baterías y los requisitos de potencia entre las distintas CE, correlacionando estas variaciones con sus capacidades de potencia instalada. Las recomendaciones del estudio incluyen estrategias eficaces de agregación, revisiones de los requisitos de tamaño mínimo de las ofertas, eliminación de las restricciones a la agregación y mejoras en la flexibilidad del mercado.

Palabras clave: Comunidades energéticas, mercados eléctricos, marco regulatorio, modelos de optimización, participación en el mercado, sistemas de almacenamiento en baterías, estrategias de agregación, energías renovables.

1. Introducción

La transición hacia sistemas energéticos más sostenibles y resilientes ha aumentado el interés en las comunidades energéticas (CE) [1], que desempeñan un papel crucial en este proceso. Las CE son organizaciones locales que gestionan la producción, el consumo y el almacenamiento de energía, normalmente procedente de fuentes renovables. A pesar de su potencial, las CE enfrentan desafíos importantes para integrarse efectivamente en los mercados de electricidad. Estos desafíos incluyen barreras regulatorias, técnicas y económicas. El objetivo de este trabajo es analizar estas barreras y proponer soluciones para superarlas, facilitando una mayor participación de las CE en los mercados eléctricos españoles. El estudio examina las características y modelos operativos de las CE, así como la normativa que les afecta, para proporcionar una visión integral de su situación actual y posibilidades futuras.

2. Metodología

La metodología del estudio se estructura en varias fases clave:

1. Revisión bibliografica: realizar una revisión exhaustiva de documentos académicos, informes regulatorios y estudios de casos relacionados con las CE y su participación en los mercados eléctricos. Esto incluye el análisis de la normativa europea y española que afecta a las CE [2].

2. Diseño de encuestas y recopilación de datos: Diseño de encuestas dirigidas a los miembros de la CE para recopilar datos cualitativos y cuantitativos sobre sus operaciones, desafíos y oportunidades. Además se recopilan datos de una base de datos de CE nacional [3].

3. Caracterización del Mercado: Estudiar los aspectos estructurales de los mercados eléctricos españoles para comprender mejor la dinámica y los requisitos específicos de cada uno.

4. Identificación de barreras: Identificar y analizar las barreras regulatorias, tecnológicas y de mercado que enfrentan las CE al participar en los mercados de electricidad. Esto incluye restricciones a la generación y agregación del consumo, así como requisitos de tamaño mínimo de oferta.

5. Desarrollo y optimización de modelos: desarrollo de modelos matemáticos para optimizar el tamaño y la potencia de los sistemas de almacenamiento de baterías para EC. Estos modelos consideran diversas variables y escenarios para mejorar la eficiencia y la integración del mercado.

6. Análisis y visualización: uso de gráficos y diagramas para ilustrar hallazgos y tendencias clave basados en la optimización realizada. Esto ayuda a visualizar las variaciones en el tamaño de la batería y los requisitos de energía entre diferentes EC y sus correlaciones con las capacidades de energía instaladas.

3. Resultados

El análisis detallado del mercado evaluó las capacidades de participación de 33 CE en diversos mercados eléctricos españoles, incluidos el mercado diario, la subasta intradiaria, el mercado intradiario continuo y el mercado local. Las conclusiones destacan varios puntos clave:

- Estrategias de agregación:

Las CE más pequeñas necesitan estrategias de agregación eficaces para alcanzar los umbrales de participación en el mercado. Sin agregación, muchas CE no pueden cumplir los requisitos de tamaño mínimo de oferta, lo que limita su entrada en el mercado.

- Optimización del almacenamiento en batería:

Se identificaron variaciones significativas en el tamaño del sistema de almacenamiento de baterías y los requisitos de potencia entre las CE. Estas variaciones dependen de las capacidades de potencia instalada y de los patrones de consumo de cada comunidad. Los modelos de optimización desarrollados en el estudio ofrecen soluciones a medida para mejorar la eficiencia del almacenamiento en baterías y la capacidad de participación en el mercado.

- Barreras a la participación en el mercado:

Las restricciones actuales a la agregación de generación y consumo suponen importantes barreras para las CE. Estas restricciones impiden que las CE aprovechen plenamente su potencial en los mercados eléctricos. El estudio también concluyó que los requisitos de tamaño mínimo de las ofertas son un obstáculo importante para las CE más pequeñas, ya que limitan su capacidad de participar de forma independiente en varios segmentos del mercado.

- Resultados del modelo de optimización:

Se evaluaron dos versiones de modelo de optimización distintas. La primera versión se centra en determinar el tamaño y la capacidad de potencia óptimos de los sistemas de almacenamiento en batería, maximizando la eficiencia y cumpliendo los requisitos específicos de la comunidad. La segunda versión optimiza los perfiles energéticos dentro de unos parámetros fijos, mejorando la eficiencia operativa de los sistemas de baterías existentes. Los resultados de estos modelos revelan datos significativos sobre la variabilidad de las necesidades de almacenamiento de baterías en las distintas CE.

- Implicaciones para el desarrollo de las CE:

Los sistemas optimizados de almacenamiento en baterías tienen el potencial de mejorar significativamente la participación de las CE en diversos mercados de electricidad. Al mejorar la eficiencia operativa, las CE pueden contribuir más eficazmente a un sistema energético descentralizado y renovable en España.

4. Conclusiones

Este estudio ha proporcionado un análisis en profundidad del potencial de participación de las CE españolas en diversos mercados eléctricos. Los resultados ponen de relieve varias ideas fundamentales y recomendaciones prácticas:

- Análisis cualitativo:

La encuesta reveló la naturaleza diversa de las CE en España, mostrando variaciones en tamaño, prácticas de reparto de recursos y adopción tecnológica.

La mayoría de las CE son relativamente pequeñas, con menos de 100 participantes, lo que indica un enfoque de base para la gestión de la energía.

Las actividades predominantes dentro de estas comunidades incluyen el autoconsumo fotovoltaico colectivo y servicios de asesoramiento, destacando un fuerte enfoque en la energía solar y la educación comunitaria.

El análisis detallado del mercado puso de relieve la importancia de las estrategias de agregación para que las CE más pequeñas participen eficazmente en los mercados eléctricos españoles.

Entre las principales barreras identificadas se encuentran el tamaño mínimo de las ofertas, las restricciones a la agregación de generación y consumo y los requisitos tecnológicos.

Resolver estas barreras mediante cambios en las políticas y reformas del mercado es esencial para permitir una participación más amplia de las CE en varios segmentos del mercado, como el mercado diario, la subasta intradiaria, el mercado continuo intradiario y la gestión de la congestión de los gestores de redes de distribución.

Incluso si la normativa permite la agregación, las comunidades deben invertir en automatización para cumplir los requisitos técnicos de los productos necesarios para que los operadores del sistema operen con eficacia.

- Análisis cuantitativo de la participación en el mercado:

Se desarrollaron dos versiones de modelos de optimización para proporcionar información procesable sobre el potencial de participación en el mercado de los sistemas de almacenamiento en batería dentro de las CE.

La primera versión, centrada en la optimización del tamaño y la potencia de las baterías, puso de manifiesto variaciones significativas en las necesidades de almacenamiento de las distintas comunidades. La adaptación de las capacidades de las baterías a los requisitos específicos de cada CE demostró mejoras potenciales en la rentabilidad de la gestión energética.

La segunda versión, que optimiza los perfiles energéticos dentro de unos parámetros de batería fijos, se subraya la importancia de las lógicas avanzadas de carga y descarga y de una mejor alineación con las oportunidades de participación en el mercado.

- Recomendaciones clave:

Aplicar estrategias de agregación que permitan a las CE más pequeñas alcanzar los umbrales de participación en el mercado cuando sea técnicamente posible.

Revisar los requisitos de tamaño mínimo de las ofertas y eliminar las restricciones a la agregación de generación y consumo cuando sea técnicamente viable.

Ofrecer garantías financieras para la instalación de sistemas de energía renovable y soluciones de almacenamiento en baterías, permitiendo a las CE participar con ofertas de mercado más grandes.

Fomentar la inversión en tecnologías de automatización para ayudar a las CE a cumplir los requisitos técnicos necesarios para una participación efectiva en el mercado.

Si se tienen en cuenta estas conclusiones clave y se aplican las estrategias recomendadas, las CE pueden mejorar su participación en el mercado, optimizar su gestión energética y contribuir más eficazmente al sistema energético global.

5. Referencias

[1] «Energy communities: what are they and what advantages do they have», REPSOL. Accedido: 10 de junio de 2024. [En línea]. Disponible en: https://www.repsol.com/en/energy-and-the-future/future-of-the-world/energy-communities/index.cshtml

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Content

Index of Figures

Index of Tables

List of Acronyms

EC	Energy Community
SDG	Sustainable Development Goals
DSO	Distribution System Operator
EU	European Union
REC	Renewable Energy Community
LEC	Local Energy Community
CEC	Citizen Energy Community
SDG	Sustainable Development Goals
AMPA	Parents' association (Asociación de Madres y Padres de Alumnos)
AAVV	Neighborhood association (Asociacion de Vecinos)
ID	Identification
SL	Enterprise Limited Companies (Sociedad Limitada)
CNMC	Spanish National Markets and Competition Commission (Comisión Nacional de los Mercados y la Competencia)
REE	Spanish electrical network (Red Eléctrica Española)
FAT	Full Activation Time
PPA	Purchase Power Agreement
OMIE	Operator of the Iberian Energy Market (Operador del Mercado Ibérico de Energía)
MFRR	Manual Frequency Replacement Reservce
AFRR	Automatic Frequency Replacement Reserve
RR	Replacement Reserve
SRAD	Active demand response service (Servicio de Respuesta Activa de la Demanda)
TSO	Transmission System Operator
GCT	Gate Closure Time
INJ	Injection
W	Withdrawals

1. Introduction

1.1 Motivation and Objectives

The pressing need to address climate change has driven the development of innovative solutions to enhance energy sustainability. EC represent a transformative approach to energy management, allowing local communities to produce, consume, and share renewable energy [1]. The motivation behind this study stems from the urgent need to mitigate climate change impacts and achieve the Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). By promoting local renewable energy generation and consumption, ECs can reduce greenhouse gas emissions, enhance energy security, and foster social cohesion through community engagement [2], [3].

The primary objectives of this thesis are to:

- Analyze the current landscape of ECs in Spain
- Identify and address the regulatory, technological, and market barriers faced by ECs.
- Propose optimized solutions for enhancing the efficiency and market participation of ECs.
- Provide recommendations for policymakers, stakeholders, and communities to support the growth and effectiveness of ECs.

1.2 Thesis structure

In this chapter, we introduce the concept of ECs, highlighting their growing importance and the motivations behind this research. It defines the research objectives and provides a roadmap for the structure of the thesis.

Chapter 2 delves deeper into the theoretical framework of ECs. It discusses the core concepts, methodologies, and regulatory environments that govern them, specifically focusing on the European and Spanish contexts.

Building upon the foundation laid in Chapter 2, Chapter 3 outlines the comprehensive methodology used in this research, including the survey design aimed at addressing information gaps about ECs, the characterization of Spanish electricity markets, and the development of an optimization model.

Chapter 4 shifts the focus to the case study, presenting the survey ECs in Spain and detailing the criteria used for the market characterisation and model development.

Chapter 5 explores the results of the three pillars of the thesis, first the survey results, secondly the characterization of the Spanish electricity market and lastly the model development with the key elements identification and specific barriers ECs may face in markets such as the Day-ahead, Intraday auction, Intraday continuous, and DSO Congestion Management.

The Chapter 6, summarizes the key findings of the research, provides recommendations based on the analysis, and suggests potential avenues for further research in the field of EC.

2. State of the art

The analysis of the state of the art in this study is structured to provide a comprehensive overview of EC both from a definitional and a characterization perspective. This section is divided into two main subsections:

Firstly, in subsection 2.1, we delve into the definition of EC, exploring the regulatory frameworks at both the European and Spanish levels. This includes a detailed examination of key legislative measures such as Directive (EU) 2019/944, which pertains to Citizen EC (CECs), and Directive (EU) 2018/2001, focused on Renewable EC (RECs). Additionally, the Spanish regulatory framework, including laws and royal decrees, are discussed to understand how these communities are legally structured and supported in Spain.

Secondly, subsection 2.2 characterizes the EC in Spain. This involves an in-depth analysis of their features, such as geographical distribution, types of participants, installed capacity, and activities undertaken. This subsection presents a detailed portrayal of the current state of ECs in Spain, highlighting their operational characteristics, developmental stages, and the various social, economic, and technical aspects influencing their implementation and success.

By addressing both the definitional and characterization aspects, this section provides a holistic understanding of the foundational and practical elements of EC, setting the stage for the subsequent analysis and recommendations aimed at enhancing their effectiveness and integration into the Spanish energy market.

2.1 Definition

2.1.1 European Regulatory framework

The European Union has introduced pivotal legislative measures to foster the development of EC, recognizing their potential to revolutionize energy systems and enhance community participation. Two key directives underpin this framework: Directive (EU) 2019/944, which pertains to Citizen EC (CECs), and Directive (EU) 2018/2001, focused on Renewable EC (RECs) [4], [5]. These directives establish comprehensive legal frameworks that define the operation, rights, and obligations of ECs, thereby facilitating their integration into the energy market and supporting the transition to renewable energy sources.

Citizen EC (CECs) - Directive (EU) 2019/944

Directive (EU) 2019/944, commonly referred to as the Electricity Directive, is a cornerstone of the EU’s "Clean Energy for All Europeans" package. This directive aims to create a more integrated and competitive electricity market, while empowering citizens to actively engage in energy production and consumption [4].

The directive defines CECs as legal entities characterized by voluntary and open participation. They are controlled by members or shareholders, which can be natural persons, local authorities, or small enterprises. The primary objective of CECs is to provide environmental, economic, or social community benefits rather than prioritizing financial profits [6]. This focus on community welfare ensures that the benefits of energy projects are distributed locally, fostering greater social cohesion and local empowerment.

One of the significant rights conferred upon CECs by this directive is the ability to generate, consume, store, and sell electricity. They can access all electricity markets either directly or through aggregation, which allows them to operate on a level playing field with other market participants. This is crucial for removing barriers to entry and ensuring that CECs can compete fairly in the energy market [7].

Moreover, the directive emphasizes the protection of consumers involved in CECs. It ensures that their rights are safeguarded and that they receive transparent and non-discriminatory treatment. This consumer-centric approach is designed to build trust and encourage broader participation in EC [8].

Integration into the national electricity grid is another critical aspect addressed by the directive. Provisions are made to facilitate the seamless incorporation of CECs into the grid, ensuring that they contribute to the flexibility and reliability of the energy system. By doing so, CECs can play a pivotal role in balancing supply and demand, especially as the share of intermittent renewable energy sources increases [9].

Overall, Directive (EU) 2019/944 seeks to democratize the energy sector, allowing citizens to take control of their energy production and consumption. By supporting local renewable energy projects, the directive not only helps reduce greenhouse gas emissions but also promotes energy security and community resilience.

Renewable EC (RECs) - Directive (EU) 2018/2001

Directive (EU) 2018/2001, also known as the Renewable Energy Directive (RED II), is a fundamental component of the EU's strategy to increase the adoption of renewable energy and achieve its climate and energy targets for 2030 and beyond. This directive specifically targets Renewable EC, setting the stage for their development and operation [5].

RECs are defined as legal entities that operate based on open and voluntary participation. They are controlled by shareholders or members who are located in proximity to the renewable energy projects developed by the community. Similar to CECs, the primary goal of RECs is to provide environmental, economic, or social community benefits rather than financial profits. This proximity principle ensures that the benefits of renewable energy projects remain within the local area, supporting regional development and sustainability [10].

Under this directive, RECs have the right to produce, consume, store, and sell renewable energy. They can enter into renewable power purchase agreements, providing a stable revenue stream that supports their operations. The directive mandates Member States to create an enabling framework that promotes and facilitates the development of RECs. This includes ensuring access to appropriate incentives and support schemes, which are essential for overcoming initial financial barriers and fostering the growth of these communities [11].

Addressing regulatory and administrative barriers is a key focus of the directive. Member States are required to remove unjustified obstacles that hinder the development of RECs. By streamlining regulatory processes and providing clear guidelines, the directive aims to simplify the establishment and operation of RECs, making it easier for communities to embark on renewable energy projects [7].

Furthermore, the directive encourages Member States to provide technical and financial support to RECs. This support can take various forms, such as grants, low-interest loans, and advisory services, which are critical for the successful implementation and scaling of renewable energy projects [8].

Directive (EU) 2018/2001 thus plays a crucial role in accelerating the adoption of renewable energy at the community level. By empowering local entities to produce and manage renewable energy, the directive contributes to the EU's broader goals of reducing carbon emissions, enhancing energy security, and fostering sustainable development.

In summary, both Directive (EU) 2019/944 and Directive (EU) 2018/2001 establish robust frameworks that facilitate the creation and operation of EC. By defining clear rights and obligations, removing barriers, and providing support mechanisms, these directives enable communities across Europe to actively participate in the energy transition, promoting a more sustainable and decentralized energy future.

2.1.2 Spanish Regulatory framework

Spain has actively engaged in the transposition of European directives concerning EC, adapting its national legislation to facilitate the creation and operation of Renewable EC (RECs) and Citizen EC (CECs). The Spanish regulatory framework is designed to align with Directive (EU) 2018/2001 (RED II) and Directive (EU) 2019/944, ensuring that local communities can participate effectively in the energy market and contribute to the renewable energy transition.

Renewable Energy Community - Law No. 24/2013

Law No. 24/2013, which governs the electricity sector in Spain, lays the foundation for integrating renewable energy sources into the national grid. This law emphasizes the importance of sustainability and the promotion of renewable energy, aligning with the objectives of Directive (EU) 2018/2001.

Under this law, RECs are recognized as key players in the renewable energy landscape. They are defined as legal entities that aim to generate, consume, store, and sell renewable energy, with a focus on providing environmental, economic, or social benefits to their members. This definition mirrors the one provided by RED II, ensuring consistency in regulatory approaches across the EU.

Citizen Energy Community - Law No. 24/2013

Law No. 24/2013 also addresses the framework for Citizen EC (CECs). Similar to RECs, CECs are defined as entities that are based on voluntary and open participation and are controlled by members who are natural persons, local authorities, or small enterprises. The primary objective of CECs is to provide community benefits rather than financial profits, aligning with the principles outlined in Directive (EU) 2019/944.

The law ensures that CECs have the right to generate, consume, store, and sell electricity, thereby participating fully in the energy market. This includes access to market mechanisms and support for grid integration, facilitating the active involvement of citizens in the energy transition.

Royal Decree-Law 29/2021

Royal Decree-Law 29/2021 further facilitates the development of RECs by removing administrative and regulatory barriers. This decree streamlines the processes for establishing RECs, making it easier for communities to initiate and manage renewable energy projects. It includes provisions for simplifying grid connection procedures, ensuring that RECs can integrate their renewable energy systems into the national grid without undue delays or complications.

Additionally, Royal Decree-Law 29/2021 provides financial incentives and support schemes for RECs, such as grants and subsidies for renewable energy installations. This support is crucial for overcoming the initial financial hurdles that often impede the development of community energy projects.

Royal Decree-Law 29/2021 also applies to CECs, providing similar regulatory relief and support as it does for RECs. By reducing administrative burdens and offering financial incentives, the decree encourages the establishment and growth of CECs across Spain. This regulatory support helps to democratize energy production, allowing citizens to take control of their energy needs and contribute to the broader goals of energy sustainability and security.

Local Energy Community and Collective Self-Consumption

- Local Energy Community

The concept of a Local Energy Community (LEC) is also embedded within the Spanish regulatory framework. LECs focus on localized energy production and consumption, fostering energy independence and resilience at the community level. These communities can encompass both Renewable EC (REC) and Citizen EC (CEC), depending on their specific focus and objectives.

This concept is primarily regulated by Law 24/2013 of the Electricity Sector [12], which establishes the foundations for the integration of renewable energies and the participation of EC in the electricity market. Additionally, Royal Decree-Law 23/2020 [13], which includes urgent measures in energy and other areas for economic reactivation, contains specific provisions to facilitate the creation and operation of EC. Royal Decree 244/2019 [14], which regulates the administrative, technical, and economic conditions of self-consumption of electrical energy, also facilitates the development of shared self-consumption projects by EC.

- Collective Self-Consumption

Collective self-consumption is another important aspect of Spain's approach to EC. This model allows multiple consumers, typically within a close geographical proximity, to share the energy generated from a common renewable energy source, such as a solar panel installation on a shared building. The regulatory framework supports collective self-consumption primarily through Royal Decree 244/2019 [14], which regulates the administrative, technical, and economic conditions for self-consumption of electrical energy. This decree simplifies administrative procedures and provides clear guidelines for energy sharing and distribution. Additionally, Royal Decree-Law 15/2018 [15] on urgent measures for the energy transition and consumer protection introduced significant changes to promote self-consumption, including the elimination of the "sun tax" and other barriers.

Integration with European Directives

Spain’s regulatory framework is aligned with European directives, ensuring that national policies support the overarching goals of the EU. The transposition of Directive (EU) 2018/2001 and Directive (EU) 2019/944 into Spanish law provides a robust legal foundation for the development of ECs. This alignment ensures that Spanish ECs can benefit from the same rights and protections as their counterparts across Europe, fostering a cohesive and integrated approach to EC development.

By implementing supportive legislation such as Law No. 24/2013 and Royal Decree-Law 29/2021, Spain not only complies with European directives but also paves the way for a vibrant and resilient EC sector. These regulatory measures ensure that both RECs and CECs can thrive, contributing to the sustainable energy transition and empowering local communities to take an active role in shaping their energy futures.

2.1.3 Comparison between the two main Spanish definitions: Citizen EC and Renewable EC

The Spanish regulatory framework for EC includes specific provisions for both Citizen EC (CECs) and Renewable EC (RECs). While both types of communities aim to promote local engagement in energy production and consumption, there are distinct differences in their structure, scope, and operational characteristics. Table 1 presents a detailed comparison of these two types of communities, and the results are described, highlighting their attributes and regulatory requirements.

Table 1: Comparison between CEC and REC Spanish definitions.

Aspect	Citizen Energy Community (CEC)	Renewable Energy Community (REC)
Geographical Scope	The geographical scope of CECs is not limited by vicinity. CECs can operate without being geographically bound to a specific location, allowing for broader and more flexible participation.	RECs must be located within the vicinity of the renewable energy project. This geographical proximity ensures that the benefits of the renewable energy generated remain local. However, it is important to note that the specific distance defining "vicinity" is not clearly defined in the Spanish regulations. The Royal-Decree Law 244/2019 and Law No. 24/2013 refer to installations being "próximas" (nearby) without specifying an exact numerical distance. This generally implies that the installations should be within a range that allows efficient energy distribution through the local low-voltage network, which can vary depending on the specific circumstances and infrastructure of the area.
Activities	CECs operate primarily in the electricity sector and are technology neutral. They can engage in various activities related to electricity generation, distribution, and consumption, without being restricted to specific technologies or energy sources.	RECs have a broader range of activities related to all forms of renewable energy, not just electricity. This includes solar, wind, hydro, and other renewable energy sources.
Participants	Participation in CECs is open to any actor, including individuals, local authorities, and small enterprises. However, large-scale energy firms are excluded from decision-making processes to	Membership in RECs is more restricted compared to CECs. It typically includes individuals and entities that are directly involved in or impacted by the renewable energy projects.

	ensure the community remains focused on local and citizen-led initiatives.	
Autonomy	Decision-making powers within CECs are limited to their members. This member-centric governance structure ensures that the community's operations and strategies align with the interests and needs of its participants.	RECs are capable of being autonomous from individual members. This autonomy allows RECs to operate independently, ensuring that the renewable energy projects are managed efficiently and sustainably.
Effective Control	CECs exclude medium-sized and large enterprises from effective control. This exclusion is designed to maintain the community's focus on local, citizen-led energy projects and prevent dominance by larger, profit-driven entities.	RECs are in the proximity of the renewable energy project, which means that the control and benefits of the project are localized. This proximity requirement ensures that the renewable energy projects directly benefit the surrounding community.

At the end Citizen EC and Renewable EC highlights their distinct approaches and regulatory frameworks. CECs offer a more flexible and inclusive participation model, allowing broader community engagement across various locations and technologies. In contrast, RECs emphasize localized renewable energy production, ensuring that the benefits remain within the community and promoting sustainable development.

Both types of communities play a crucial role in Spain's energy transition, supporting the goals of decentralization, democratization, and sustainability in the energy sector. By understanding the unique characteristics and regulatory requirements of CECs and RECs, policymakers and stakeholders can better design and implement energy initiatives that leverage the strengths of each community type.

2.2 Solutions of EC for climate change (SDG)

- **SDG 7: Affordable and Clean Energy**

In many Spanish municipalities, solar energy cooperatives have been established, enabling communities to invest in shared solar panels. These cooperatives reduce reliance on fossil fuels and lower energy costs for members, making clean energy more accessible and affordable [16].

On the other hand, developing local microgrids, ECs can ensure a stable and reliable supply of renewable energy. These microgrids can operate independently or in conjunction with the main grid, enhancing energy security and resilience [17].

- **SDG 13: Climate Action**

ECs that focus on renewable energy generation, such as wind or solar farms, contribute significantly to reducing greenhouse gas emissions. For example, a wind ECenable the local community to power homes and businesses with clean energy, thus cutting down CO2 emissions [18].

Implementing energy efficiency measures, such as smart meters and energy-saving appliances, helps communities reduce energy consumption and lower their carbon footprint [19].

- **SDG 11: Sustainable Cities and Communities**

ECs often collaborate with local governments to integrate renewable energy solutions into urban planning. In Valencia, for instance, ECs have been involved in developing eco-districts where energy is generated and managed locally, supporting sustainable living [20].

By promoting decentralized energy production and storage, ECs enhance the resilience of communities to climate-related disruptions [21].

- **SDG 8: Decent Work and Economic Growth**

The establishment and operation of ECs create local jobs in the renewable energy sector, from installation and maintenance to administration and community engagement. For example, the establishment of a solar farm in Extremadura has created numerous jobs for local residents, boosting the local economy [22].

ECs enable communities to take control of their energy resources, fostering economic empowerment and resilience. In Aragon, community-owned wind projects have not only provided clean energy but also generated revenue that is reinvested into local development projects [23].

- **SDG 12: Responsible Consumption and Production**

ECs encourage responsible consumption by educating members about energy efficiency and sustainability. Initiatives such as community workshops and information campaigns in Madrid have raised awareness about sustainable energy practices, leading to behavioral changes that reduce energy waste [24].

ECs can support the circular economy by using local materials and resources in their projects. An example is the use of locally sourced materials for constructing renewable energy infrastructure, reducing the carbon footprint associated with transportation and supporting local businesses [21].

By integrating these solutions, ECs not only contribute to the achievement of the SDGs but also demonstrate the practical benefits of community-led energy initiatives. These examples illustrate how ECs can serve as a blueprint for sustainable development, promoting environmental stewardship, social equity, and economic prosperity at the local level.

3. Methodology for the Analysis of EC and Spanish Electricity Markets

This chapter describes the comprehensive methodology adopted for this master's thesis on the review of Spanish electricity markets for participation in EC. The methodology is structured to analyze the potential of EC to participate in these Spanish electricity markets. The methodological framework consists of several key steps, which are depicted in the Figure *1*:

Figure 1: General thesis methodology.

The steps are as follows:

1. **Literature Review:** Conduct a review of existing literature on the structure and design of Spanish electricity markets. This involves analyzing reports, academic papers, regulatory documents, and case studies related to EC and their participation in electricity markets.

2. **Survey Design and Data Collection:** Develop and administer a survey to cover the characterize the Spanish landscape regarding EC. This survey targets a diverse range of EC members. The survey is designed to gather both qualitative and quantitative data through structured questionnaires and semi-structured interviews.

3. **Market Characterization:** Perform a study of the structural aspects of the Spanish electricity markets, including wholesale, retail, and system service markets with a particular focus on the integration and participation of EC.

4. **Barriers to participating in electricity markets identification:** Identify and analyze the regulatory, technological, and market barriers faced by EC. This involves analyzing data from the surveys and interviews to highlight key challenges and obstacles. Specific market barriers include minimum bid size requirements, limitations on the aggregation of generation and consumption, access to market mechanisms, administrative procedures for grid connection, financial barriers for initial investments, and regulatory restrictions on self-consumption and energy sharing.

5. **Model Development and Optimization:** Develop models aimed at analyzing the participation in the electricity markets of the EC by optimizing the size and power of battery storage systems for EC. Propose strategies to enhance their participation in the market. This includes mathematical modeling and simulations to derive optimal solutions for energy management and market integration.

6. **Analysis and Visualization:** Illustrate the analysis through various graphs and charts to visualize key findings and trends based on the optimization made. The objective is to know the capability of each EC to participate in the following Spanish electricity markets: day-ahead, intraday, and congestion management. To do this, the graphs will show the minimum bid size of each market and the curve of energy or capacity available in number of hours for each EC.

7. **Recommendations and Future Research:** Provide recommendations for policymakers, stakeholders, and communities to achieve the participation of EC in the Spanish electricity markets. Suggest areas for future research to further explore the EC integration and optimization in electricity markets.

3.1 Methodology for the qualitative analysis of EC's market participation potential the Spanish EC landscape characterisation

3.1.1 Methodology for the survey

The methodology for this survey is designed to address the gaps in knowledge about ECs, specifically focusing on technical and operational capabilities, market participation and financial viability, and regulatory and network integration issues, by utilizing a combination of qualitative and quantitative data collection techniques. The key steps are included in Figure *2*:

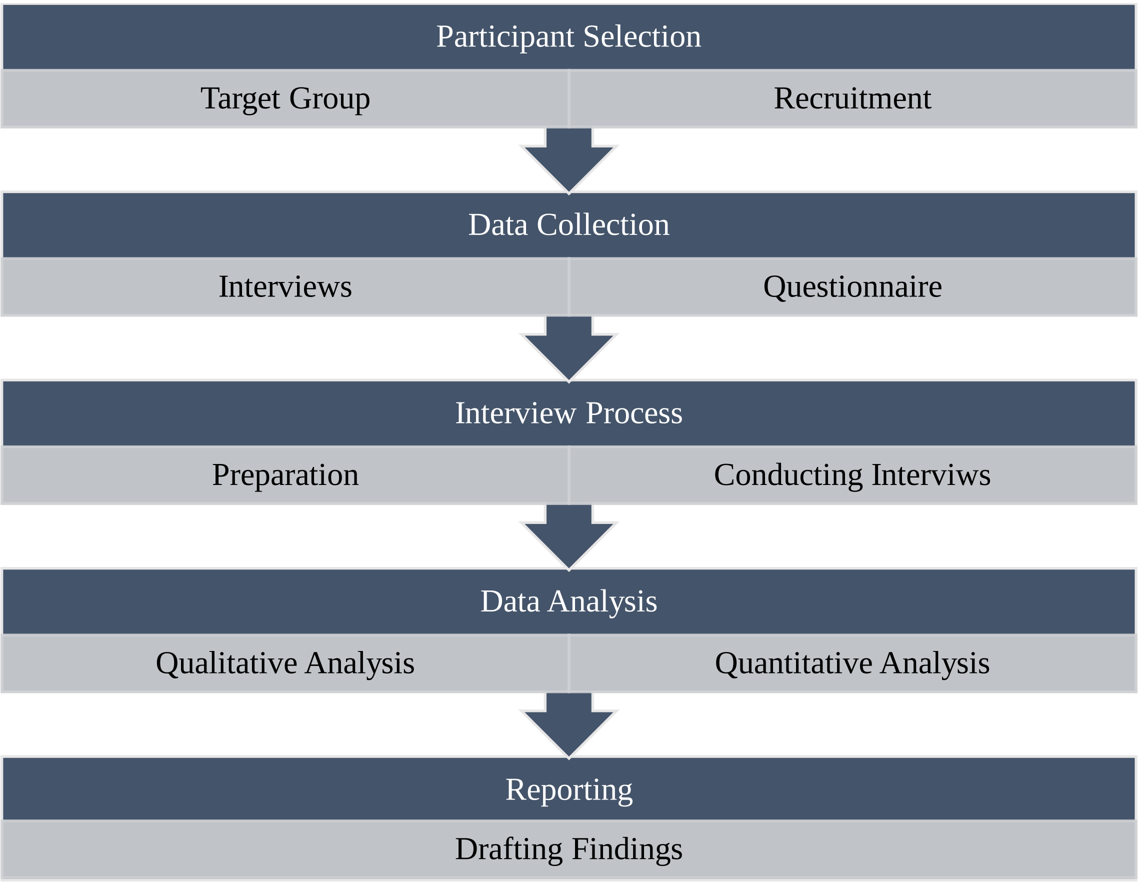


Figure 2: Survey methodology.

Participant Selection:

- **Target Group:** The survey targets a diverse range of participants involved in ECs, including community leaders, members, local government representatives, technical experts, and other relevant stakeholders.
- **Recruitment:** Participants are recruited through direct invitations sent to ECs identified from the Energia Comun database [25]and other relevant networks.

Data Collection:

- **Interviews:** Semi-structured interviews are conducted via videoconference or phone calls. This method allows for in-depth discussions and flexibility in exploring various issues.
- **Questionnaire:** A structured questionnaire is designed to capture specific information about the challenges and gaps in knowledge faced by ECs. The questionnaire includes both closed and open-ended questions to gather quantitative and qualitative data.

Interview Process:

- **Preparation:** Interview guides are prepared to ensure that all relevant topics are systematically covered. These guides are based on the objectives of the survey and include prompts for further probing.

- **Conducting Interviews:** Interviews are conducted to ensure that participants feel comfortable and encouraged to share their experiences openly and to clarify the received answers, if is needed.

Data Analysis:

- **Qualitative Analysis:** A qualitative analysis is used to identify common themes and patterns in the qualitative data. This involve coding the transcribed interviews and grouping similar responses to highlight key issues and knowledge gaps.
- **Quantitative Analysis:** Descriptive statistics are used to analyze the quantitative data from the questionnaire. This provides an overview of the frequency and distribution of various challenges and knowledge gaps reported by ECs.

Reporting:

- **Drafting Findings:** The findings from the survey are compiled into a comprehensive report that presents both the qualitative and quantitative insights. This report includes detailed descriptions of the challenges and knowledge gaps faced by ECs, supported by quotes from the interviews and data from the questionnaire.

3.1.2 Methodology for the Spanish Electricity Markets Characterisation

The electricity markets characterization methodology aims to identify barriers that the current characteristics of the Spanish electricity markets pose for the participation and integration of EC. The key steps are included in the Figure *3*:

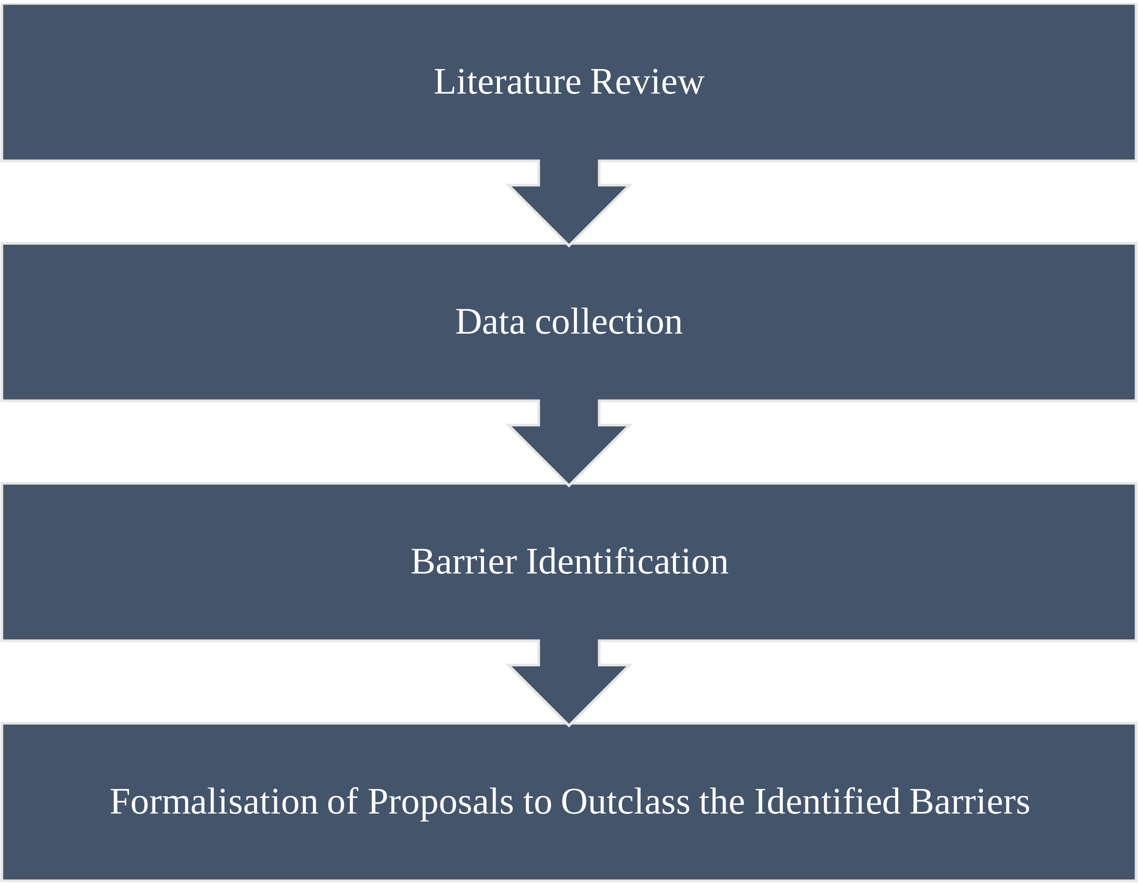


Figure 3: Market characterisation methodology.

Literature Review:

Conduct an in-depth review of scholarly articles, regulatory documents, industry reports, and case studies specifically focused on the development, implementation, and operation of EC within Spanish electricity markets. Examine and detail specific market structures, regulatory frameworks, and best practices currently employed in Spain. This includes analyzing Spanish laws and regulations related to ECs, as well as the roles and interactions of various market participants and stakeholders within the electricity market.

Data Collection:

- Quantitative Analysis: Analyze existing market data from CNMC, REE, and other relevant sources, including market prices, participation thresholds, and transaction volumes to assess the potential for EC participation in electricity markets.
- Qualitative Analysis: Conduct in-depth interviews and focus groups with key stakeholders, including community leaders, EC members, to analyse opportunities, and experiences related to EC participation in electricity markets. This analysis provide a nuanced understanding of the social, regulatory, and operational factors influencing ECs.

Barrier Identification:

- Conduct a thorough review of existing academic papers, technical reports, and regulatory documents to identify known barriers and challenges faced by EC.
- Utilize semi-structured interviews and focus groups with EC members, community leaders, and technical experts to gather detailed insights into regulatory, technical, economic, and social barriers.
- Analyze the structural aspects of the Spanish electricity markets to identify specific obstacles such as minimum bid sizes, market access restrictions, and grid integration challenges that impact EC participation.

Formalisation of Proposals to Outclass the Identified Barriers:

- Propose strategies to leverage these opportunities to improve EC integration and market participation.

3.2 Methodology for the Quantitative Analysis for the EC Market Participation in the Day-Ahead, Intraday and Local Flexibility Market.

The model development and optimization methodology aim to quantitatively evaluate the participation potential of EC to a selection of electricity markets. The goal is to quantitatively assess the feasibility of EC participation in the day-ahead market, intraday market, and local congestion management market. A knowledge of the capability of participation for each EC is achieved with the model considering the solutions identified in qualitative analysis for market participation. The key steps are included in the Figure *4*.

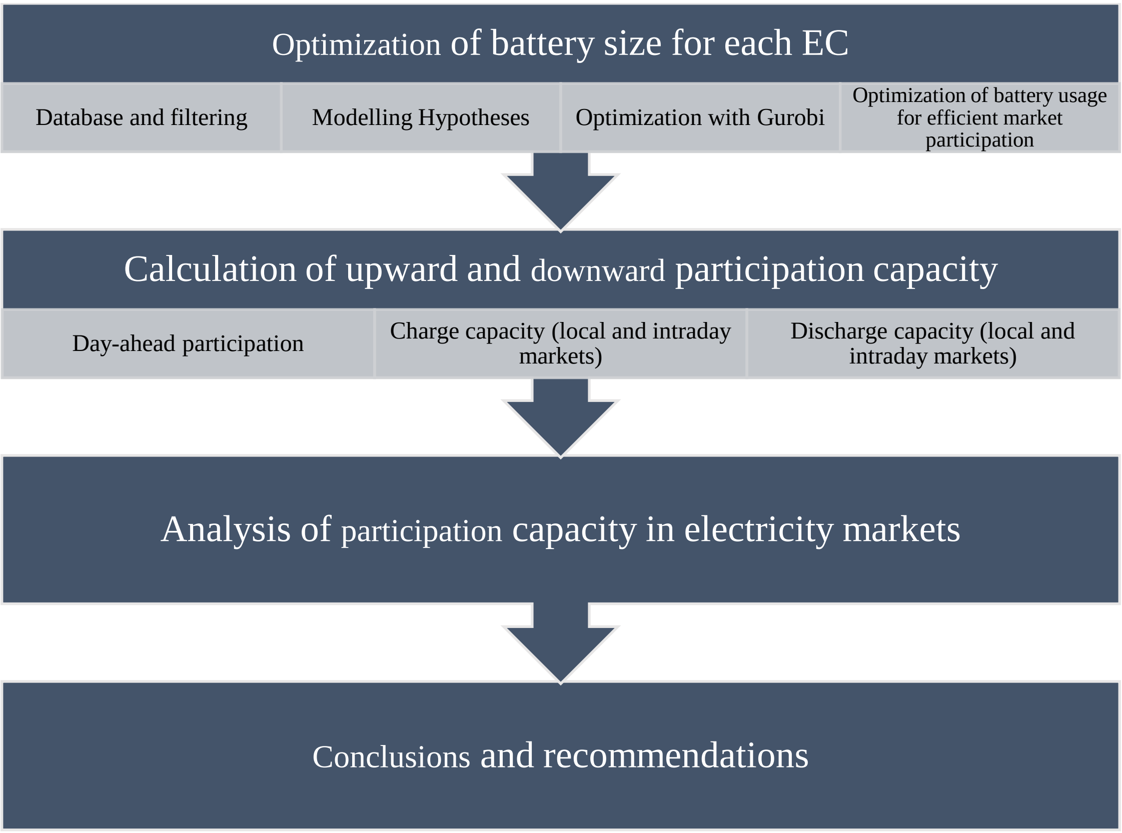


Figure 4: Model Development and Optimization methodology.

Optimization of Battery Size and Power for Each EC

The optimization of battery size and power for each EC has been addressed to tailor the battery capacities according to each community's specific needs and constraints. The primary aim is to enhance the efficiency of energy storage and improve market participation within the Spanish electricity markets.

- **Database and Filtering**:

From the original database of EnergiaComun with 366 ECs [25], 33 ECs were selected, filtered by development phase: operational and generation capacity: photovoltaic.

- **Modelling Hypotheses:**

Energy Profiles: Each EC's net energy profile is calculated by subtracting the total energy demand from the total energy generation. This profile is used to understand the energy surplus and deficit scenarios for each community.

Network Considerations: The optimization assumes a stable and reliable network connection, with the ability to exchange energy with the grid as needed. The impact of network constraints on battery operation is considered minimal.

Market Prices: The model uses 2023 Spanish electricity market prices, including PVPC prices for buying and day-ahead market prices for selling, as a basis for economic optimization.

Battery Characteristics: Assumptions about battery efficiency (both charging and discharging), initial state of charge, and degradation rates are incorporated into the model. The optimization aims to maximize economic returns.

Once the charge and discharge capacity data are obtained, the participation capacity is analyzed in the study markets:

- Day-ahead market
- Intraday markets
- Local congestion management (DSO - Distribution System Operator)

- **Optimization Algorithm in Gurobi**:

An optimization algorithm implemented in Gurobi determines the optimal battery size and power based on the net profile and 2023 Spanish electricity market prices (PVPC for buying and day-ahead market prices for selling). This algorithm is implemented in the Python programming language.

- **Optimization of Battery Usage for Efficient Market Participation**:

Once the optimal battery size and power are determined, the algorithm was modified to optimize battery usage to achieve efficient market participation. For this reason, battery size and battery power are now considered parameters and not variables.

Calculation of Upward and Downward Participation Capacity

To determine the charge and discharge capability of the batteries in the ECs, which are critical for optimizing electricity market participation potential in the case of the EC to reach the minimum bid size, the following equations are used:

- **Charge Capacity**:

The charge capacity is calculated using the equation:

$$\min\left(Size_{Battery} - \Delta Energy_{Battery_t}, \Delta P_{Battery_t}\right) \cdot \left(1 - aux_{Battery}\right)$$

This formula indicates how much the battery can be charged, considering both its total size and the energy already stored at a given moment, limiting the additional charge to the maximum power of the battery and adjusting the value with the auxiliary battery factor. If $aux_{Battery}$ is 1, it means the battery is discharging and cannot charge during that period.

- **Discharge Capacity**:

The discharge capacity is determined using the equation:

$$\min\left(\Delta Energy_{Battery_t}, \Delta P_{Battery_t}\right) \cdot \left(1 - aux_{Battery}\right)$$

This formula indicates how much energy can be discharged from the battery at a specific moment, considering both the available energy in the battery and the maximum allowable discharge power, adjusting the value with the auxiliary battery factor. If $aux_{Battery}$ is 0, it means the battery is charging and cannot discharge during that period.

Conclusions and Recommendations

The process concludes with a series of conclusions and recommendations based on the findings obtained to achieve the participation of the EC on the Spanish electricity markets.

4. Case study: EC in Spain

4.1 Case Study of the Qualitative Analysis

4.1.1 Spanish EC Characterisation

This section outlines the features used to analyze the EC in Spain. The features selected are those necessary to study the electricity market participation potential based on the availability of information from the Energia Comun database [26], which currently includes 366 EC, and other relevant sources. Each feature provides critical insights into various aspects of the ECs, from their geographical location and operational status to their socio-economic impact and technological capabilities. These features are essential for the analysis required by the adopted methodology. The following features have been selected for the analysis of EC in Spain [26]:

The features selected for this analysis are based on the availability of comprehensive data from the Energia Comun website [26] and their relevance to understanding the operation and impact of EC in Spain. These features cover various aspects, including geographical location, organizational structure, member participation, technological implementation, and socio-economic impacts. By analyzing these features, we can gain a holistic view of the state of EC in Spain and identify key factors that contribute to their success or present challenges. This understanding is crucial for developing strategies to support their growth and integration into the Spanish electricity market.

Table 2: Characterisation features of the Spanish ECs landscape.

Number	Name	Definition
1	ID	A unique identifier for each EC, used for data management and reference purposes.
2	Name	The name of the EC, which helps in identifying and differentiating between various communities.
3	Province	The province in which the EC is located, providing geographical context and allowing for regional comparisons.
4	Province ID	A numerical identifier for the province, used for database management.
5	Locality	The specific locality or municipality where the EC operates, giving more precise geographical information.
6	Locality ID	A numerical identifier for the locality, used for database management.

7	Phase	Indicates the development phase of the EC (e.g., planning, implementation, operational). This feature helps to understand the maturity and progress of different communities.
8	Number of Members	The number of members participating in the EC, providing insights into the scale and community engagement level.
9	Type of Members	*Citizens*: The involvement of individual citizens in EC, highlighting the grassroots participation level. *Commercial Establishments*: The participation of local businesses, which can indicate the economic integration and support for the community. *City Council*: The involvement of municipal governments, reflecting the level of public sector support and collaboration. *Civil Society Entities*: The involvement of civil society organizations such as AMPA (parents' associations), AAVV (neighborhood associations), and other social entities, showing the breadth of community engagement. *Companies and Industrial Parks*: The participation of companies and industrial zones, indicating the extent of industrial integration and support for the EC.
10	Activities	*Electric Mobility:* The presence of electric mobility initiatives within the community, highlighting efforts to promote sustainable transportation. *Storage/Demand Management*: The implementation of energy storage solutions and demand management practices, showcasing technological advancements and efficiency measures. *Collective Photovoltaic Self-consumption*: The presence of collective self-consumption photovoltaic systems, emphasizing community

		efforts in sustainable energy generation and consumption. *Energy Rehabilitation*: Initiatives aimed at improving the energy efficiency of buildings within the community, highlighting efforts to reduce energy consumption and improve sustainability. *Thermal Renewable Energies*: The use of thermal renewable energy sources, such as solar thermal or geothermal energy, indicating diversification in renewable energy use. *Other Renewable Electrical Energies*: The implementation of other forms of renewable electrical energy, such as wind or hydroelectric power, showcasing the community's commitment to a diverse energy portfolio.
11	Installed Capacity [kW]	The total installed capacity of renewable energy within the community, measured in kilowatts. This feature indicates the scale of renewable energy infrastructure.

In this section, we present a detailed analysis of the collected data on EC in Spain. The analysis aims to provide a deeper understanding of the operational characteristics, geographical distribution, member participation, and technological implementation of ECs. By examining these aspects, we can identify the strengths, challenges, and opportunities for the development of ECs in Spain, thereby informing strategies for their enhanced participation in the Spanish electricity market. This analysis illustrates through various graphs and charts, which help to visualize the key findings and trends. Bar charts may represent non-exclusive categories, meaning that an EC can select multiple variables, whereas pie charts present data for mutually exclusive options. Each graphical representation is accompanied by a comprehensive commentary to elucidate the insights derived from the data.

Geographical Distribution of EC in Spain

The map in Figure 5 illustrates the geographical distribution of ECs across Spain. The color gradient indicates the number of ECs in each province, with darker shades representing a higher number of communities. From the map, several key observations can be made:

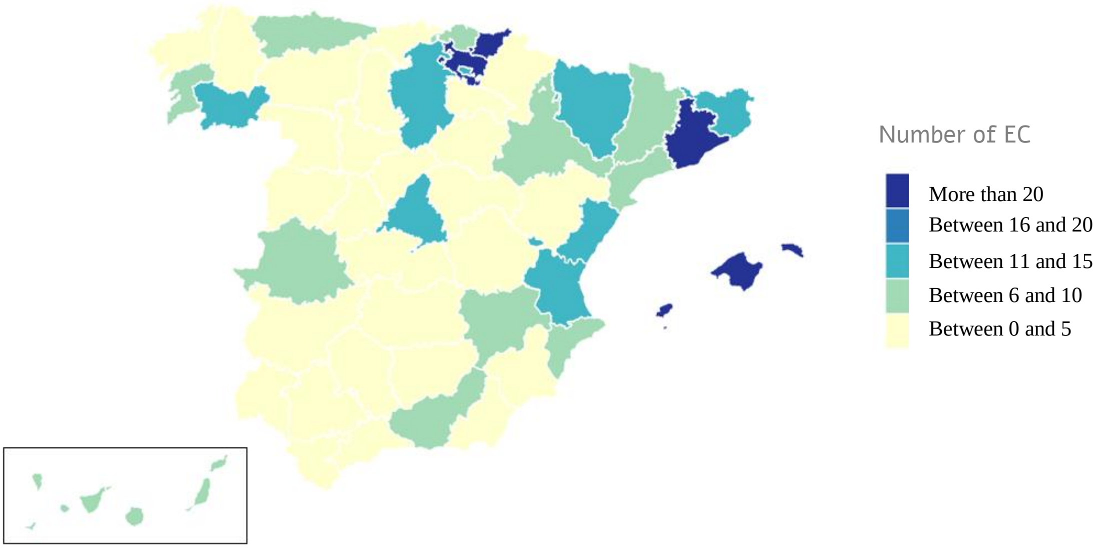


Figure 5: EC distribution in Spain.

High Concentration Areas: Provinces with the darkest shades, such as those in the Basque Country and parts of Aragón and Galicia, indicate a higher concentration of EC. These regions appear to be leading in the adoption and implementation of ECs.

Moderate Concentration Areas: Provinces with moderate shading, such as those in the northeastern and eastern parts of Spain, show a significant presence of ECs but not as high as the leading provinces. This suggests ongoing efforts to establish and expand ECs in these areas.

Low Concentration Areas: The lighter-shaded provinces, particularly in the central and southwestern regions, have fewer EC. This could indicate either a slower adoption rate or potentially less favorable conditions for developing ECs.

Number of Participants in EC

The Figure 6 above illustrates the distribution of EC in Spain based on the number of participants. The data is categorized into six groups: less than 20, between 21 and 50, between 51 and 100, between 101 and 200, between 201 and 500, and more than 500 participants. Several key observations can be made from this chart:

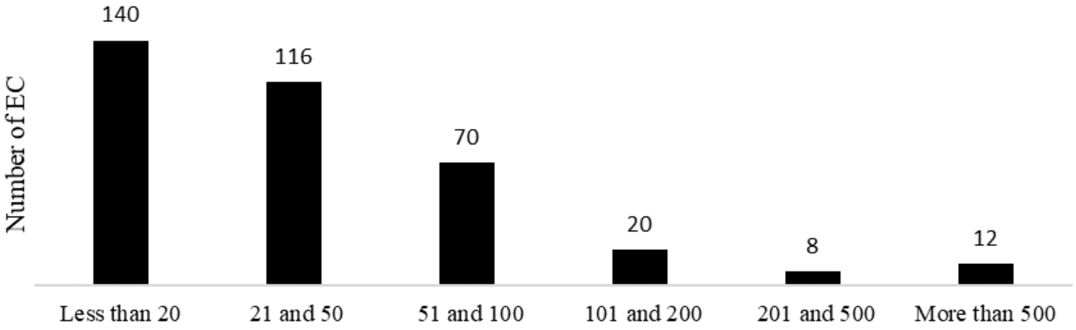


Figure 6: Number of EC per number of participants.

Predominance of Smaller Communities: The largest group of ECs has less than 20 participants, with 140 communities falling into this category.

Moderate-Sized Communities: The second largest group consists of ECs with 21 to 50 participants, accounting for 116 communities.

Communities with 51 to 100 Participants: There are 70 ECs with 51 to 100 participants. These communities will likely have a more substantial impact on collective energy generation and consumption.

Larger Communities: A smaller number of ECs fall into the larger categories, with 20 communities having 101 to 200 participants, 8 communities having 201 to 500 participants, and 12 communities having more than 500 participants. These larger ECs may represent more mature and extensive projects with significant resources and organizational capabilities.

The overall distribution shows that the majority of ECs have fewer than 100 participants, which highlights a trend towards smaller and more localized energy projects. This distribution suggests that while there is considerable interest and activity in establishing ECs, many are still developing and expanding their participant base.

Participants in EC

The Figure 7 chart above shows the distribution of participants in EC across Spain. The data is categorized into six participant groups: citizens, commercial premises, companies and industrial estates, city halls, civil society entities (such as AMPA and AAVV), and others. Key observations from the chart include:

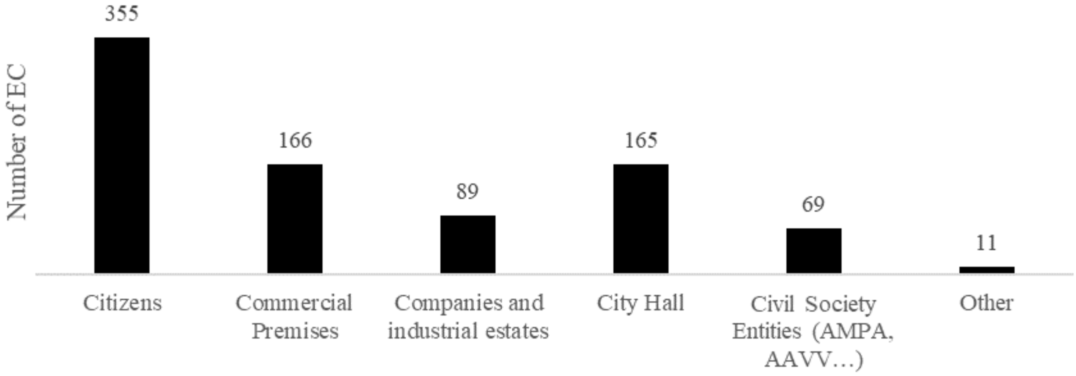


Figure 7: Number of ECs per type of participants.

Citizens as Primary Participants: Citizens form the largest group of participants in ECs, with 355 communities involving individual citizens. This indicates strong grassroots engagement and public interest in community energy initiatives.

Commercial Premises: The second largest group comprises commercial premises, with 166 ECs involving local businesses. This highlights the role of the commercial sector in supporting and benefiting from renewable energy projects

City Hall Involvement: City halls participate in 165 ECs, reflecting substantial local government support and involvement in promoting community-based energy solutions. This collaboration is crucial for regulatory support and resource allocation.

Companies and Industrial Estates: A smaller but significant number of ECs, totaling 89, involve companies and industrial estates. This participation suggests that industrial stakeholders recognize the benefits of engaging in renewable energy projects.

Civil Society Entities: Civil society entities, including associations such as AMPA and AAVV, are involved in 69 ECs. These organizations often play a critical role in mobilizing community efforts and advocating for sustainable practices.

Other Participants: The "Other" category, with 11 participants, includes various entities that do not fall into the above categories but still contribute to the development of ECs.

Generation capacity in EC

The Figure 8 illustrates the distribution of EC in Spain based on their generation capacity, measured in kilowatts (kW). The data is categorized into seven ranges: [10, 175], (175, 340], (340, 505], (505, 670], (670, 835], (835, 1000], and >1000 kW. Key observations from the chart include:

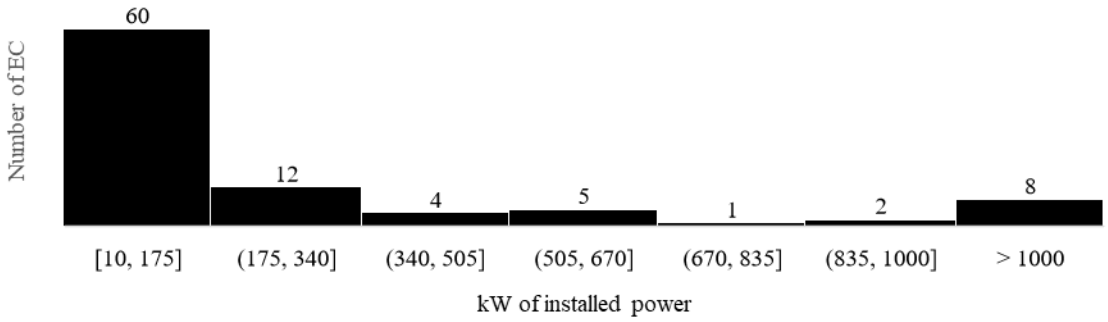


Figure 8: Generation Capacity Distribution of Spanish ECs.

Small-Scale Installations Dominance: The majority of ECs, 60 in total, have a generation capacity in the range of 10 to 175 kW. This suggests that many ECs are starting with relatively small renewable energy projects, likely due to lower initial costs and simpler implementation.

Medium-Scale Installations: There are 12 ECs with generation capacity ranging from 175 to 340 kW, and 4 ECs in the 340 to 505 kW range. This indicates a moderate presence of mid-sized energy projects that are somewhat larger in scale but still manageable for community-based operations.

Larger Installations: The chart shows a smaller number of ECs with larger generation capacity representing large-scale community energy projects with substantial renewable energy generation capabilities.

Activities of EC

The Figure 9 illustrates the range of activities undertaken by EC in Spain. The activities are categorized into several types: advising, collective photovoltaic self-consumption, electric mobility, storage, energy rehabilitation, thermal renewable energies, and wind/hydroelectric projects.

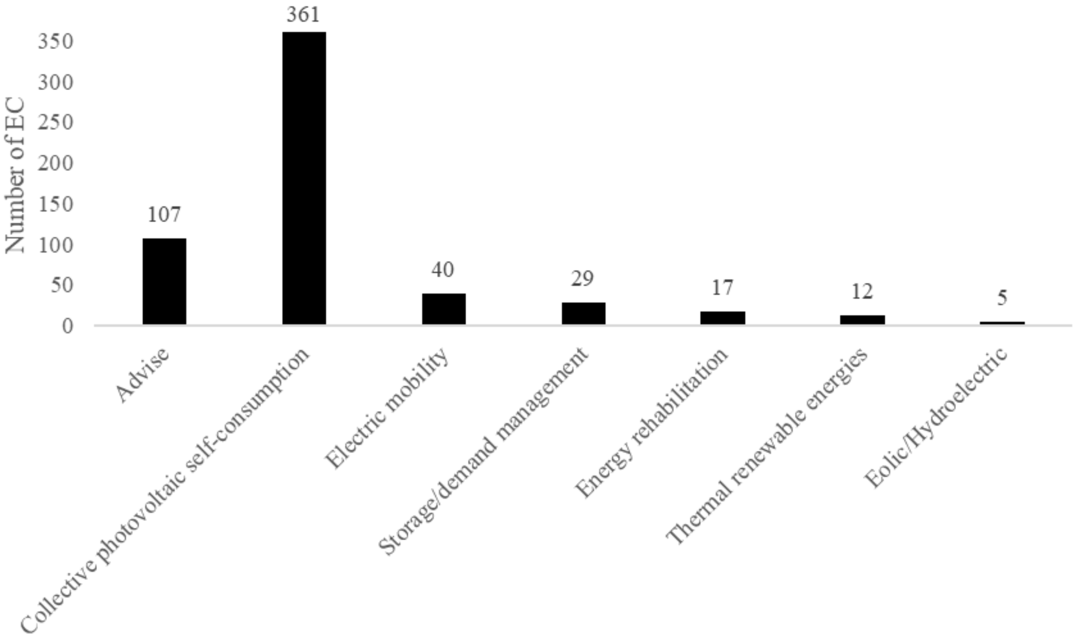


Figure 9: ECs per activity.

Key observations from the chart include:

Collective Photovoltaic Self-Consumption: This activity is the most prevalent among ECs, with 361 communities engaging in collective photovoltaic self-consumption. This highlights a strong focus on solar energy projects, where members collectively install and share photovoltaic systems to generate and consume electricity locally.

Advising: The second most common activity is advising, with 107 ECs offering advisory services. These services likely include guidance on energy efficiency, renewable energy technologies, and project development, helping communities and individuals make informed decisions about their energy use.

Electric Mobility: There are 40 ECs involved in electric mobility initiatives. These projects may include the installation of electric vehicle charging stations and promoting the use of electric vehicles within the community, contributing to sustainable transportation efforts.

Storage/demand management: Energy storage is an activity undertaken by 29 ECs. This involves the use of batteries or other storage technologies to manage energy supply and demand, enhancing the stability and reliability of local energy systems.

Energy Rehabilitation: A total of 17 ECs is engaged in energy rehabilitation activities, which likely involve improving the energy efficiency of buildings and infrastructure. This can include retrofitting older buildings with modern, energy-efficient systems to reduce overall energy consumption.

Thermal renewable energies: There are 12 ECs that focus on thermal renewable energies. These projects utilize organic materials or centralized heating systems to provide sustainable heating solutions to community members.

Wind/Hydroelectric Projects: The least common activities are wind and hydroelectric projects, with only 5 ECs involved in these types of renewable energy generation. These projects require specific geographical and environmental conditions, which may limit their prevalence.

Social Aspects of EC

The Figure 10 illustrates the focus on various social aspects by EC in Spain. The social aspects are categorized into none, energy poverty, gender, third age, and other.

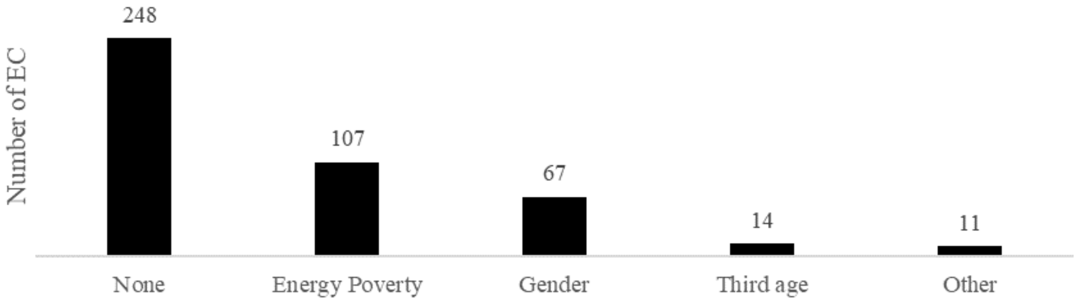


Figure 10: Number of ECs by social aspect.

Key observations from the chart include:

No Specific Social Focus: The majority of ECs, 248 in total, do not have a specific focus on social aspects. This suggests that many ECs are primarily concentrated on energy production and management without targeting specific social issues.

Energy Poverty: A significant number of ECs, 107 in total, are addressing energy poverty. These communities are working to ensure that all members have access to affordable and sustainable energy, thereby reducing the economic burden of energy costs on vulnerable populations.

Gender: There are 67 ECs with a focus on gender issues. These communities likely promote gender equality within their operations and decision-making processes, ensuring that both men and women have equal opportunities to participate and benefit from energy projects.

Third Age: A smaller number of ECs, 14 in total, focus on the third age, or elderly population. These initiatives might include efforts to improve energy accessibility and affordability for older adults, who may have fixed incomes and specific energy needs.

Other Social Aspects: There are 11 ECs addressing various other social aspects not specifically categorized above. These could include issues like disability inclusion, youth engagement, or broader community development goals.

Financing of EC

The Figure 11 above illustrates the various sources of financing utilized by EC in Spain. The financing sources are categorized into own funds, public aid, financial entities or investment funds, energy services, crowdfunding, and city hall support. Key observations from the chart include:

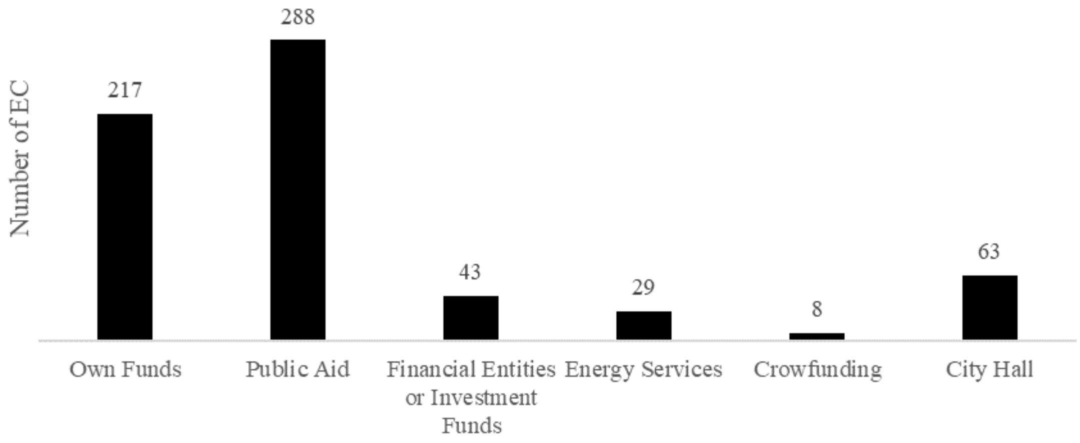


Figure 11: Number of ECs per type of financing.

Public Aid: The most common source of financing for ECs is public aid, with 288 communities receiving support from government grants and subsidies. This indicates strong governmental backing for renewable energy projects and community initiatives.

Own Funds: The second most prevalent source of financing is own funds, with 217 ECs relying on self-financing. This shows significant commitment and investment from the communities themselves, highlighting their dedication to sustainable energy projects.

City Hall Support: City halls provide financial support to 63 ECs. This reflects the active involvement of local governments in promoting and sustaining community energy projects, often providing critical funding and resources.

Financial Entities or Investment Funds: A total of 43 ECs secured financing from financial entities or investment funds. This suggests that private investors are growing interested in community energy projects, recognizing their potential for stable returns and social impact.

Energy Services: Energy services companies finance 29 ECs, indicating a partnership model where service providers invest in community energy projects, possibly in exchange for future service contracts or energy savings.

Crowdfunding: The least utilized source of financing is crowdfunding, with only 8 ECs using this method. While crowdfunding can be an effective way to raise funds from a large number of small contributors, it appears less common in the context of EC financing in Spain.

Development Phase of EC

The Figure 12 above illustrates the various development phases of EC in Spain. The development phases are categorized into four stages: in study, in installation process, installed and processing the connection point, and operational. Key observations from the chart include:

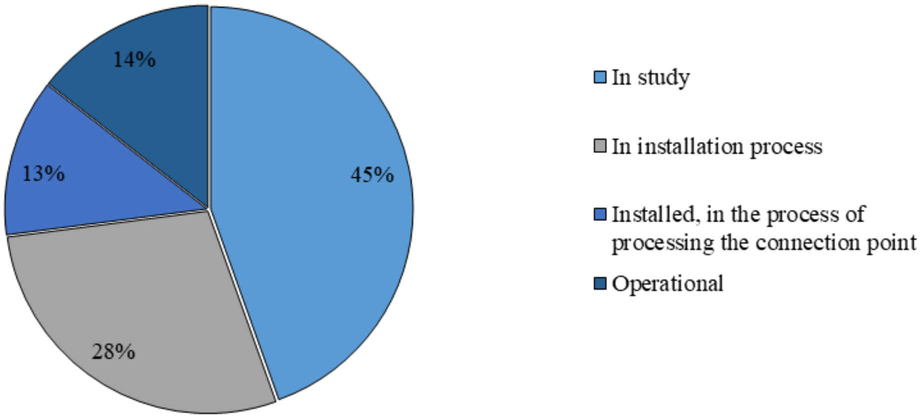


Figure 12: Development phase of the ECs.

In Study: The largest segment, comprising 45% of ECs, is in the study phase. This indicates a substantial number of communities are in the initial planning and feasibility assessment stage, exploring the potential for establishing an EC.

In Installation Process: The second largest segment, accounting for 28% of ECs, is in the installation process. These communities have moved beyond planning and are actively working on installing the necessary infrastructure and systems for their energy projects.

Installed, Processing the Connection Point: 13% of ECs have completed installation and are in the process of securing connection points. This stage involves finalizing the technical and regulatory requirements to connect their systems to the grid or local energy network.

Operational: 14% of ECs are fully operational, meaning they have successfully completed all stages of development and are now generating, consuming, or managing energy. These communities actively contribute to the local energy supply and demonstrate community-based energy solutions' viability.

Legal Figures of EC

The Figure 13 illustrates the distribution of EC in Spain based on their legal structure. The legal figures are categorized into five types: no legal figure is created, association, cooperative, SL (Sociedad Limitada) Non-Profit, and other. Key observations from the chart include:

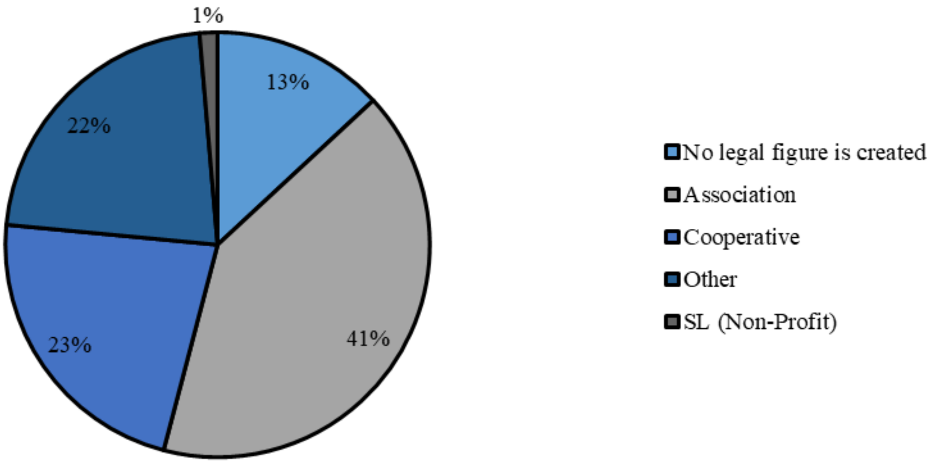


Figure 13: Legal Figure of the ECs

No Legal Figure Created: The largest segment, comprising 41% of ECs, operates without creating a formal legal figure. These communities may rely on private agreement or are in the early stages of organizing their legal structure.

Association: The second largest segment, accounting for 23% of ECs, is organized as associations. This legal structure allows for formalized collective action and decision-making, often suitable for smaller or less complex projects.

Cooperative: Cooperatives make up 22% of ECs. This legal figure is commonly used for community energy projects as it emphasizes democratic governance, member participation, and shared benefits, aligning well with the principles of ECs.

SL (Non-Profit): A total of 13% of ECs are registered as SL (Sociedad Limitada) non-profit entities. This structure provides a formal legal framework for managing the community's activities while ensuring that profits are reinvested into the community or project.

Other: The remaining 1% of ECs operate under other legal figures, which may include various forms of partnerships, trusts, or bespoke legal arrangements tailored to specific needs and contexts.

Conclusions

The analysis of EC in Spain, based on various parameters such as geographical distribution, participant types, installed capacity, activities, social aspects, financing, development phases, and legal figures, reveals several key insights and conclusions about the state and potential of ECs in the country.

Geographical Distribution

The geographical distribution of ECs shows significant variability across Spain, with regions like the Basque Country and Catalonia leading in the number of established communities. Areas with fewer ECs present opportunities for targeted interventions to promote community energy projects and enhance regional energy independence.

Participant Diversity

Participants in ECs primarily include citizens, commercial premises, and city halls, highlighting strong grassroots engagement and municipal support. The involvement of various stakeholders, including businesses and civil society entities, underscores the inclusive and collaborative nature of ECs. This diverse participation is vital for the resilience and adaptability of community energy projects.

Installed Capacity

The analysis of installed capacity reveals that most ECs start with small-scale installations, which are easier to manage and finance. However, there is potential for growth, as evidenced by the presence of larger projects. Supporting the scale-up of smaller ECs through financial and technical assistance can help maximize their impact on the energy transition.

Activities

Collective photovoltaic self-consumption is the most common activity among ECs, reflecting the widespread adoption of solar energy solutions. Other activities, such as advising, electric mobility, and energy storage, indicate a move towards integrated and sustainable energy systems. Promoting a diverse range of activities within ECs can enhance their overall effectiveness and contribution to sustainability goals.

Social Aspects

A significant number of ECs address social issues like energy poverty and gender equality, demonstrating their potential to drive social change alongside environmental benefits. However, many ECs do not focus on specific social aspects, indicating room for greater integration of social objectives. Encouraging ECs to incorporate social sustainability into their missions can amplify their positive impact on communities.

Financing

Public aid and own funds are the primary sources of financing for ECs, highlighting the importance of governmental support and community investment. The involvement of financial entities, energy services, and city halls also suggests a growing interest from various stakeholders in supporting community energy projects. Diversifying financing sources, including exploring crowdfunding and private investment, can enhance the financial sustainability of ECs.

Development Phases

A substantial number of ECs are in the study or installation phases, indicating robust interest and ongoing development. However, the transition from planning to operational status can be challenging due to regulatory and technical hurdles. Providing targeted support at different development stages can help ECs overcome these barriers and achieve operational success.

Legal Figures

ECs utilize various legal structures, with a significant number operating without formal legal figures. Associations and cooperatives are popular choices, reflecting the community-oriented nature of these projects. Formalizing ECs through suitable legal frameworks can provide stability and access to resources, facilitating their growth and long-term sustainability.

4.1.2 Case Study of the Survey to Know the ECs Situation in Spain

This section focusses on the findings from the survey conducted with EC in Spain. A total of 13 ECs participated in the survey, providing valuable insights into their current activities, challenges, and opportunities. The survey responses cover a range of topics, including organizational structure, market participation, technological implementation, and socio-economic impacts.

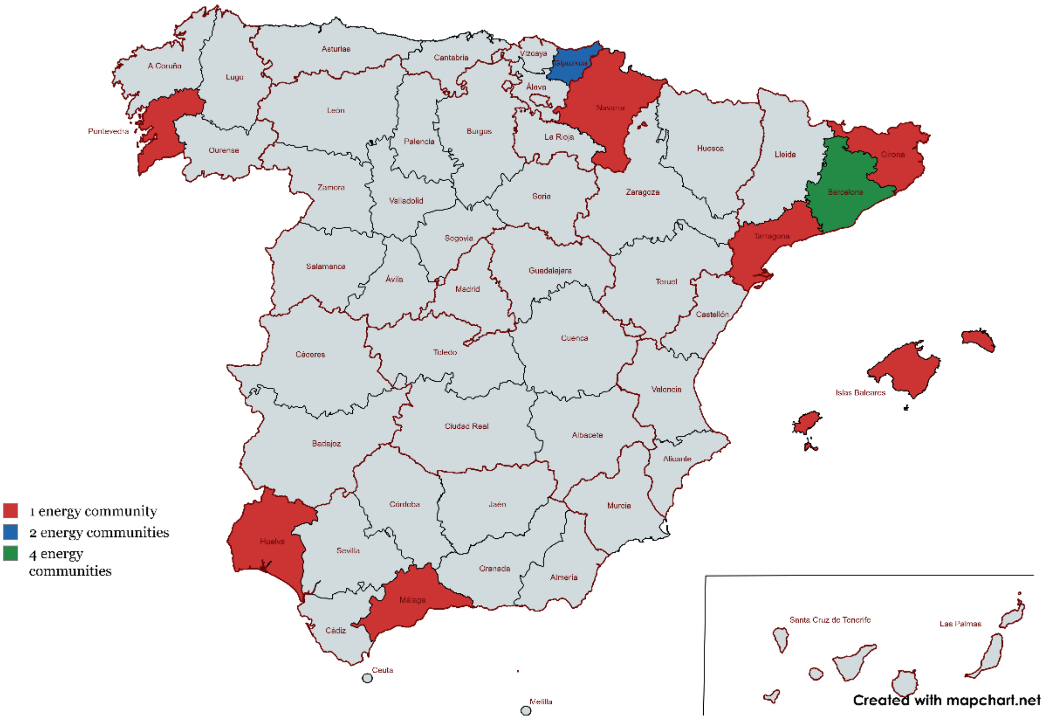


Figure 14: ECs survey distribution.

- 1 EC: Huelva, Málaga, Pontevedra, Navarra, Tarragona, Girona and Islas Baleares.
- 2 EC: Gipuzkoa.
- 4 EC: Barcelona.

In this study, a series of key questions were formulated to assess various aspects of EC in Spain. These questions were designed to gather detailed information on resource sharing, the implementation of automation systems, the use of technologies, battery storage capacity, and operational and measurement challenges, among others.

4.1.3 Case Study of Spanish Electricity Markets

This section focuses on the EC participation on some Spanish electricity markets. The analysis involves a study of various design features that define the structure and operation of these markets. The goal is to identify the key elements impacting the participation of ECs and understand the specific barriers they may face. The markets studied include:

- **Day-ahead Market**
- **Intraday Auction Market**
- **Intraday Continuous Market**
- **DSO Congestion Management**

The features studied in this characterization include [27]:

- **Operator:** Identifies the entity responsible for managing the market or market segment, providing insights into the governance and operational oversight.
- **Allowed Technology:** Specifies the types of generation and storage technologies permitted to participate in the market.
- **Aggregation Conditions:** Refers to the rules governing the aggregation of generation and consumption within bids, crucial for ECs aiming to pool resources.
- **Market Time Unit:** Defines the smallest time interval for market operations, affecting the frequency of bids and adjustments.
- **Local Granularity:** Indicates the geographical scope of market operations, determining the localization of market interactions.
- **Gate Closure Time:** The deadline for submitting bids before the market period begins, influencing real-time bid adjustments.
- **Type of Product:** Identifies what is being traded, such as energy, capacity, or ancillary services.
- **Full Activation Time (FAT):** Specifies the time required to fully activate a bid or service, critical for response times.
- **Ramping Period:** Defines the allowed period for ramping up or down generation or load, impacting operational flexibility.
- **Delivery Period:** Indicates the minimum duration for service or energy delivery, affecting planning and operations.
- **Bid Structure:** Refers to the complexity and types of bids allowed, influencing participation strategies.
- **Maximum Price and Minimum Price:** Set boundaries for bid prices, reflecting market tolerance for price fluctuations.
- **Maximum Bid Size and Minimum Bid Size:** Define the range of bid sizes that can be submitted, impacting participation scale.

4.2 Case Study of the Quantitative Analysis

This section focuses on the development and analysis of models aimed at optimizing the participation of EC in the Spanish electricity markets. The selected ECs for this analysis are 33 communities that are currently operational and have photovoltaic (PV) solar panels as their primary generation source. The geographical distribution of the ECs is showed in the Figure 15:

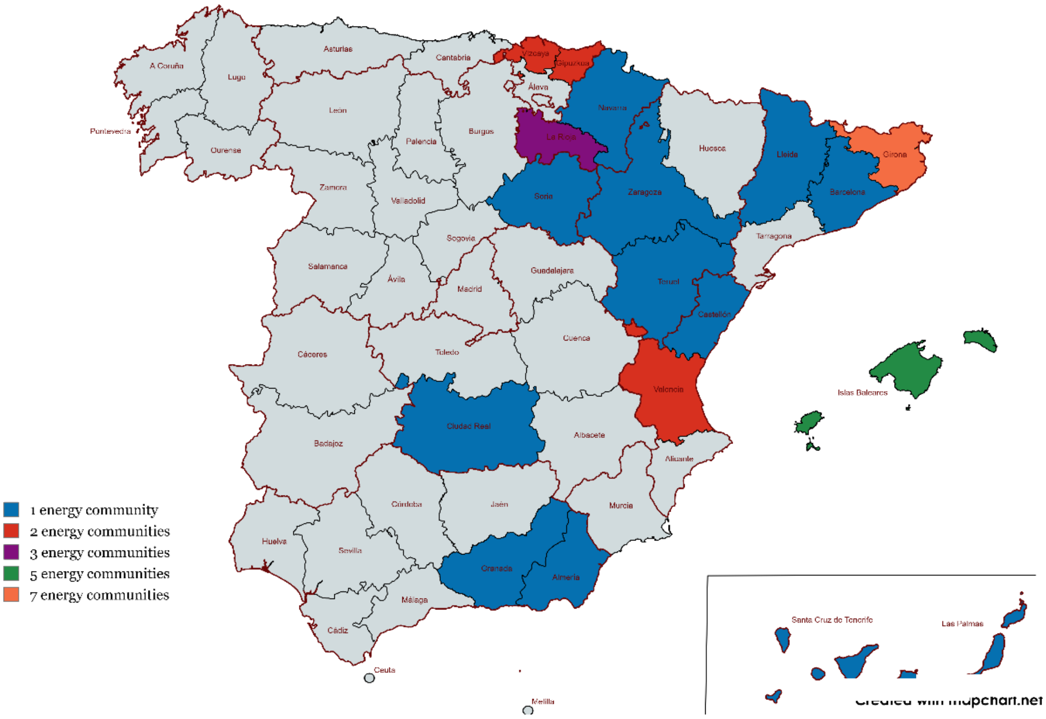


Figure 15: ECs EC whose batteries are sized.

The Figure 15 indicates the locations of the EC whose batteries will be sized. Battery sizing is crucial to ensure optimal energy storage and management, as it helps balance the generation and consumption within the community. Properly sized batteries can mitigate the intermittency of renewable energy sources, enhance grid stability, and enable ECs to participate more effectively in various electricity markets by providing reliable and flexible energy supply. Here is the distribution. Here is the distribution:

- 1 EC: Granada, Almería, Ciudad Real, Castellón, Teruel, Soria, Zaragoza, Navarra, Lleida, Santa Cruz de Tenerife, Las Palmas y Barcelona
- 2 EC: Valencia, Vizcaya y Gipuzkoa.
- 3 EC: La Rioja.
- 5 EC: Islas Baleares.
- 7 EC: Girona.

The model development involves defining relevant parameters, collecting data on energy generation, consumption, and market prices from these ECs, and using software tools to simulate energy storage and consumption scenarios. Optimization algorithms are applied to determine the optimal battery size and power configurations, followed by scenario analysis to evaluate the models' robustness under varying market conditions. Validation is performed using real-world data to ensure the reliability and accuracy of the models.

The final goal is to assess the feasibility of EC participation in the day-ahead market, intraday market, and local congestion management market. The results provide insights into necessary market rule modifications and regulatory framework adjustments to facilitate EC participation, ultimately contributing to a more decentralized and sustainable energy system.

Assumptions, Profiles, Prices, and Other Technical Parameters Definitions

Assumptions:

- The only energy source for all ECs is solar PV.
- Battery efficiency is considered to be 100%.
- There is not degradation of battery capacity over time.
- Energy consumption patterns follow historical data averages from each EC.
- Market prices are assumed to follow historical trends without significant unexpected fluctuations.

Profiles:

- Energy Generation Profiles: Based on solar irradiance data specific to each location, based on Renewables Ninja [28].
- Energy Consumption Profiles: Derived from historical consumption data, taking into account peak and off-peak usage patterns for each EC based on the location where they are located. The data is extracted from [29].

Prices:

- Day-Ahead Market Prices: Historical market prices of 2023 are used [30].
- PVPC: Historical market prices of 2023 are used [31].

By clearly defining these assumptions, profiles, prices, and technical parameters, the study ensures that the methodology is replicable, and the results are reliable and applicable to other similar contexts. This structured approach allows for the assessment and optimization of battery systems within ECs, providing a pathway for enhanced market participation.

5. Results and discussion

This chapter presents the results from the research: the survey results, the qualitative analysis and the quantitative analysis conducted on the optimization of battery storage systems and their market participation within Spanish EC. The findings are categorized into three main sections: survey results, market characterization, and model development and optimization outcomes.

5.1 Qualitative Analysis: On the one hand, this section details the responses collected from various ECs across Spain. The survey aimed to gather insights into the current state of ECs, their operational challenges, technological adoption, and community engagement levels. Key metrics analyzed include the number of participants, types of activities, geographical distribution, and the socio-economic impact of these communities.

On the other hand, we provide an in-depth analysis of the Spanish electricity markets and the participation capacity of 33 ECs. The analysis covers several market segments, including the Day-ahead market, Intraday auction, Intraday continuous market, and DSO Congestion Management. This section highlights the critical role of aggregation strategies for smaller ECs and identifies the main barriers to market entry, such as minimum bid sizes and restrictions on aggregating generation and consumption.

5.2 Quantitative Analysis: This section discusses the development of an optimization model that aims to analyse the capability the EC to participate in Spanish electricity markets. A model is evaluated in two ways: one focusing on optimizing battery size and power, and the other on optimizing energy profiles within fixed parameters. The results reveal significant variations in battery size and power requirements among ECs, correlated with installed power capacities. The outcomes of these models provide insights to know the capability of the EC to participate in the Spanish electricity markets.

Through this detailed analysis, the chapter synthesizes key findings, discusses their implications for the development of ECs, and proposes recommendations to overcome identified challenges to participate in the Spanish electricity markets. The results underscore the potential of optimized battery storage systems to enhance the participation of the EC in the Spanish electricity markets, supporting the broader transition to a decentralized and renewable energy future.

5.1 Qualitative Analysis

5.1.1 Survey Results

The survey conducted among various EC in Spain aimed to gather detailed information on their current status, operational challenges, and technological adoption. The findings from the survey provide critical insights into how these communities function

One of the primary areas of interest was identifying the types of resources shared among community members. This question is essential to understand how these resources could help to allow the EC to participate in the electricity markets.

The responses reveal a diverse range of shared resources, indicating the varied approaches and capabilities of different ECs. Commonly shared resources include photovoltaic systems, battery storage units, and advanced energy management tools.

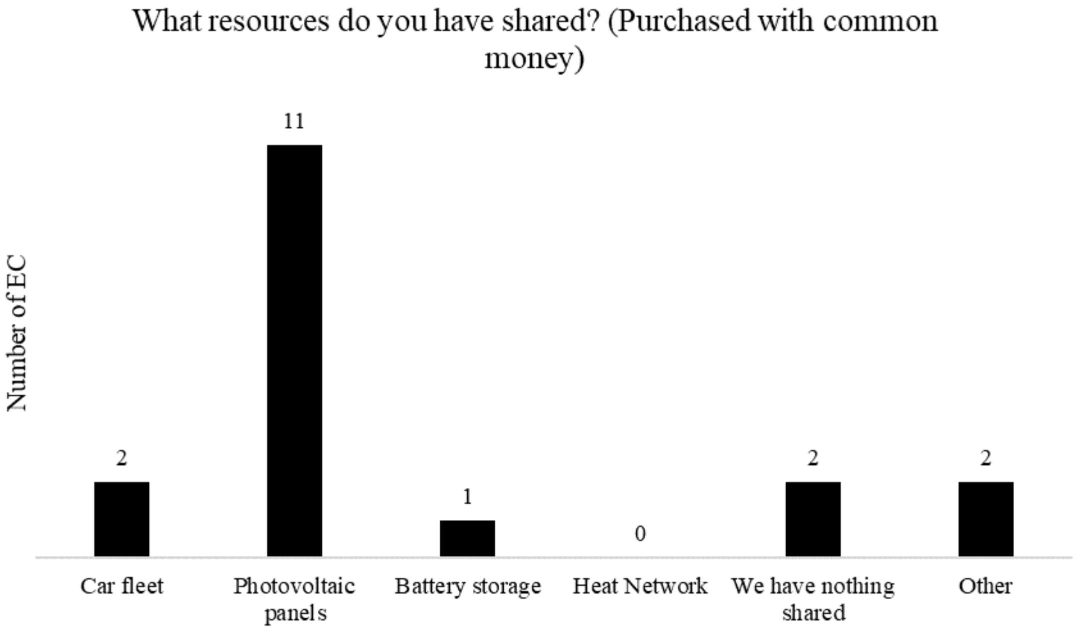


Figure 16: What resources do you have shared? (Purchased with common money) – Question 1.

The Figure 16 provides an overview of the types of resources shared within the surveyed EC and purchased collectively. The graph presents six categories of resources: Car Fleet, Photovoltaic Panels, Battery Storage, Heat Network, We have nothing shared, and Other. The distribution of responses is depicted by the number of communities sharing each type of resource.

Photovoltaic Panels:

The majority of the ECs, a total of 10, share photovoltaic panels. This indicates a strong emphasis on renewable energy generation within the communities, highlighting the importance and popularity of solar energy as a shared resource.

Car Fleet:

Two communities reported sharing a car fleet. Although this number is relatively low compared to photovoltaic panels, it shows that some communities are investing in shared transportation solutions, possibly aiming to reduce carbon footprints and promote sustainable mobility.

Battery Storage:

Only one community reported sharing battery storage. This low number might suggest that the adoption of battery storage systems is still in its early stages, possibly due to high costs, technological barriers, or a lack of awareness of the benefits.

Heat Network:

No communities reported sharing a heat network. This absence could indicate either a lack of demand or significant barriers to implementing shared heating solutions, such as high initial costs or technical challenges.

We Have Nothing Shared:

Two communities reported not sharing any resources. This could reflect various issues such as organizational challenges, financial constraints, or insufficient membership to support shared resource initiatives.

Other:

Two communities reported sharing other types of resources not specified in the given categories. This indicates some diversity in the resources that ECs might prioritize based on specific local needs or innovative community initiatives.

Implications

The data suggests that photovoltaic panels are the most commonly shared resource, underscoring the widespread adoption of solar energy solutions. The limited sharing of other resources such as car fleets, battery storage, and the complete absence of shared heat networks highlight potential areas for growth.

Conclusion

The graph provides a clear indication of the current priorities of ECs in terms of shared resources. The dominance of photovoltaic panels highlights successful integration of solar energy, while the limited sharing of other resources and the absence of shared heat networks suggest areas for potential development. Understanding the reasons behind the lack of shared resources in some communities can provide valuable insights for targeted support for the EC in Spain.

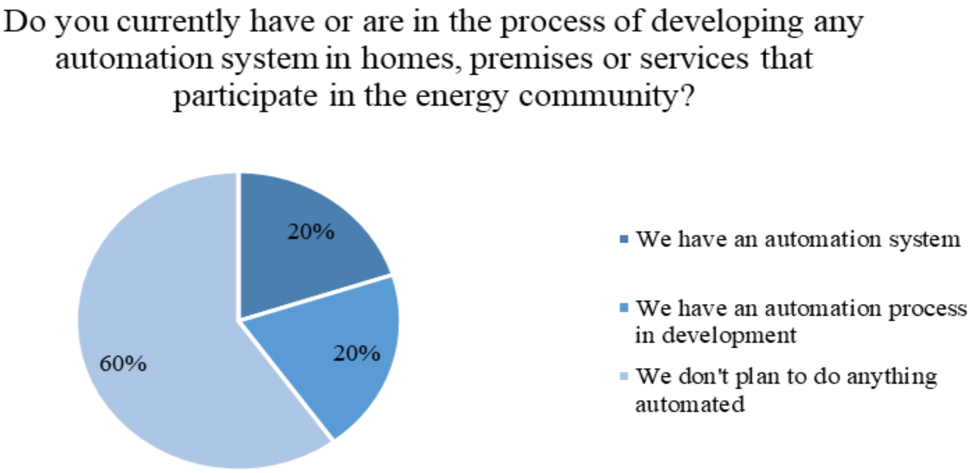


Figure 17: Do you currently have or are in the process of developing any automation system in homes, premises or services that participate in the EC? - Question 2.

The Figure 17 illustrates the adoption and development of automation systems within the surveyed EC. The chart is divided into three segments: communities with existing automation systems, those with automation processes in development, and those with no plans for automation.

We Have an Automation System:

Represented by the blue segment, this category shows that a portion of the ECs (20%) have already implemented automation systems in their homes, premises, or services. This indicates a level of advancement and readiness to integrate modern technological solutions to enhance energy management and efficiency.

We Have an Automation Process in Development:

The orange segment indicates that another portion of the ECs (20%) are currently in the process of developing automation systems. This suggests an ongoing effort to adopt advanced technologies, which could soon increase the number of communities with fully operational automation systems.

We Don’t Plan to Do Anything Automated:

The grey segment, making up the majority (60%), shows that most ECs do not plan to implement any automation systems. This could be due to various barriers such as financial constraints, lack of technical expertise, or limited awareness of the benefits of automation.

Implications

The data indicates that while there is a growing interest in automation, with 40% of ECs either having or developing automation systems, a significant portion (60%) of communities have no plans for such advancements. This highlights a potential area for policy intervention and support to encourage more widespread adoption of automation technologies, which can improve energy efficiency and operational efficiency within ECs.

Conclusion

The pie chart provides valuable insights into the current state and future prospects of automation system adoption among EC in Spain. While a notable segment of ECs is either utilizing or developing automation systems, the majority's lack of plans for automation underscores the need for targeted support and initiatives to overcome barriers and promote the benefits of automation. These findings can inform policy recommendations and strategic planning to enhance the technological capabilities of EC, ultimately contributing to their sustainability and efficiency.

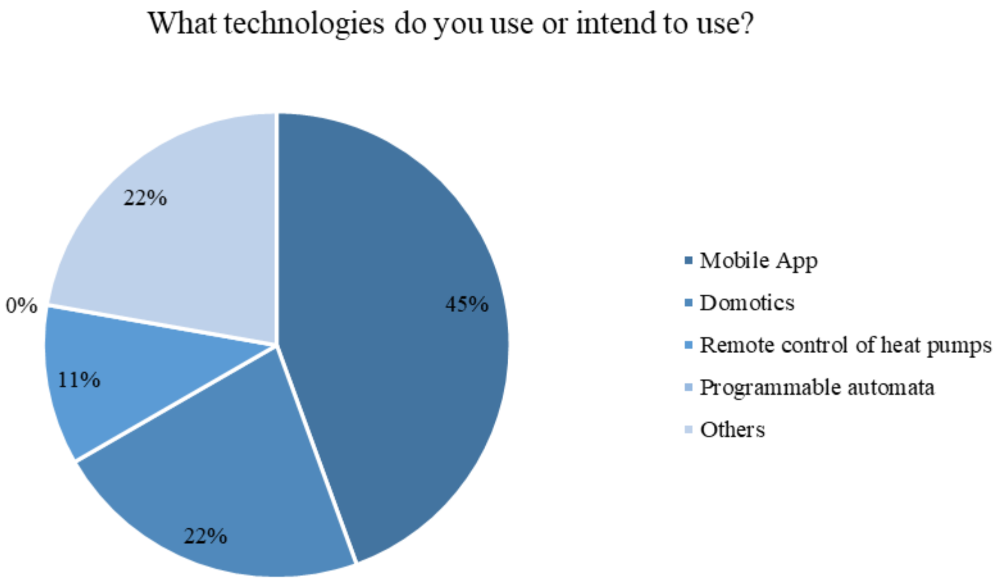


Figure 18: What technologies do you use or intend to use? - Question 3.

The Figure 18 presents the distribution of various technologies that EC currently utilize or plan to implement. The chart is divided into five segments: Mobile App, Domotics, Remote Control of Heat Pumps, Programmable Automata, and Others.

General Description of the Graph

Mobile App:

Represented by the largest segment (blue), 45% of the respondents use or intend to use mobile apps. This significant percentage indicates a high adoption rate of mobile technology, likely due to its ease of use and accessibility for managing and monitoring energy systems.

Domotics:

The orange segment shows that 22% of the respondents are using or planning to use domotics (home automation). This indicates a substantial interest in integrating smart home technologies to enhance energy efficiency and user convenience.

Remote Control of Heat Pumps:

Represented by the grey segment, 11% of the respondents are utilizing or intend to use remote control of heat pumps. This suggests a growing trend towards remote management of heating systems, which can optimize energy use and improve comfort.

Programmable Automata:

The yellow segment, accounting for 22%, indicates that programmable automata are also a key technology for ECs. This shows a focus on automation and programmable logic controllers to streamline energy management processes.

Others:

The blue segment represents 22% of respondents, suggesting that there are additional technologies being adopted that do not fall into the specified categories. This diversity indicates that ECs are exploring a wide range of technological solutions to meet their specific needs.

Implications

The data highlights a clear preference for mobile apps and domotics among ECs, suggesting that these technologies are viewed as essential tools for modern energy management. The significant use of programmable automata and remote control of heat pumps further underscores the trend towards automation and remote management. The presence of other technologies indicates a willingness to explore and adopt innovative solutions tailored to the unique requirements of each community.

Conclusion

The pie chart provides valuable insights into the technological landscape within EC in Spain. The dominance of mobile apps and domotics reflects a strong inclination towards user-friendly and efficient energy management tools. The adoption of programmable automata and remote control of heat pumps highlights the importance of automation and remote capabilities. Additionally, the variety of other technologies being utilized points to a diverse and adaptive approach to energy management within ECs. These findings can guide future technological investments and policy recommendations to support the continued advancement and sustainability of EC.

The question 4, **"What amount of controllable loads do you have in the EC [kW] in a day?"** aims to understand the load management capacity within the surveyed EC. The responses provide insights into the variability in the capacity to manage controllable loads in terms of kilowatts (kW) handled daily.

Overview of the Results

The responses vary significantly, indicating a wide range of controllable load capacities among the ECs. The values reported are:

34 kW 200 kW 0 kW 31 kW 1 kW 0 kW

Interpretation of the Data:

High Capacity: One community reported a controllable load capacity of 200 kW, which is the highest among the responses. This suggests a well-developed infrastructure and significant investment in load management technologies.

Moderate Capacity: Two communities reported capacities of 34 kW and 31 kW. These values indicate a moderate level of load management capabilities.

Low Capacity: One community reported a capacity of 1 kW, suggesting minimal load management capabilities.

No Capacity: Two communities reported 0 kW, indicating that they do not currently manage any controllable loads.

Implications

The wide range of responses highlights the diversity in the development and implementation of load management systems across different ECs. Communities with higher capacities likely benefit from better resources, infrastructure, and possibly more advanced technological adoption. Conversely, communities with low or no capacity might face barriers such as lack of funding, technical expertise, or necessary infrastructure.

Conclusion

The results from this question illustrate the varying levels of load management capabilities within EC in Spain. While some communities have substantial capacities for managing controllable loads, others are either at the early stages of development or face significant challenges. Understanding these disparities can help in tailoring support and resources to enhance load management capabilities across all ECs, thereby promoting more efficient and sustainable energy use. This data can also inform policy recommendations aimed at reducing these gaps and fostering more equitable development of load management systems within the energy sector.

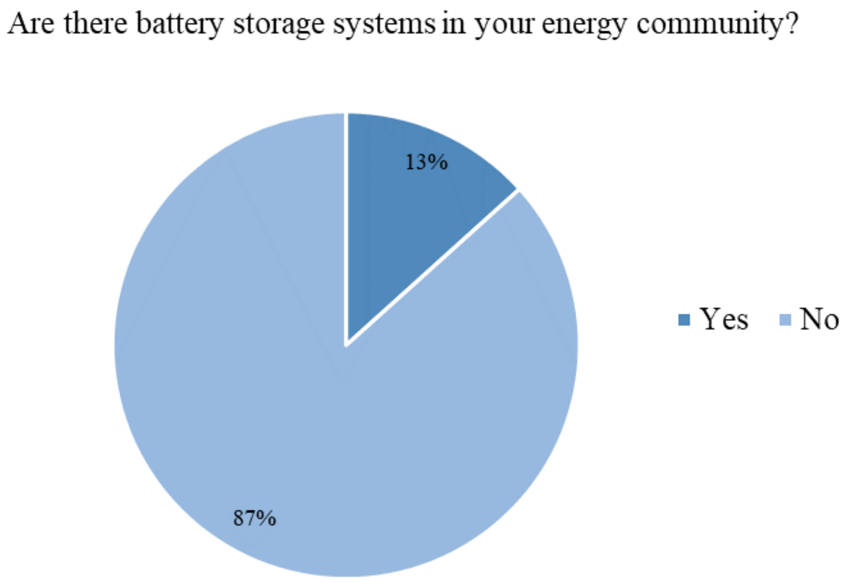


Figure 19: Are there battery storage systems in your EC? - Question 5

The Figure 19 illustrates the presence of battery storage systems within the surveyed EC. The chart is divided into two segments: "Yes" (indicating the presence of battery storage systems) and "No" (indicating the absence of battery storage systems).

General Description of the Graph

Yes:

Represented by the blue segment, 13% of the respondents have battery storage systems in their ECs. This minority indicates that only a few communities have implemented battery storage solutions.

No:

The orange segment shows that 87% of the respondents do not have battery storage systems. This significant majority suggests that most ECs have not yet adopted battery storage technology.

Question 6: Total Storage Capacity [kW]

The responses to the question about the total storage capacity in kilowatts (kW) are as follows: 10 kW and 20 kW.

These results indicate that the ECs with battery storage systems have relatively small capacities. The presence of 10 kW and 20 kW storage capacities suggests that while battery storage is being implemented, it is on a modest scale.

Question 7: Estimated Maximum Energy Injection to the Grid per Hour [kWh]

The responses to the question about the maximum amount of energy that could be injected into the grid per hour are: 10 kWh and 45 kWh.

These values indicate the potential contribution of ECs to the grid if they utilize their battery storage systems. The ability to inject 10 kWh and 45 kWh into the grid per hour shows that these communities can provide a significant amount of energy back to the grid, contributing to grid stability and efficiency.

Integrated Analysis

Presence of Battery Storage Systems

The presence of battery storage systems in only 13% of the ECs highlights a significant area for potential growth. The modest storage capacities (10 kW and 20 kW) and the ability to inject up to 45 kWh into the grid suggest that these communities are in the early stages of adopting battery storage technology.

Energy Injection Potential

Despite the low adoption rate, the potential to inject up to 45 kWh into the grid per hour is notable. This capability indicates that even small-scale battery storage systems can make a substantial contribution to energy distribution and grid support.

Conclusion

The data suggests that while the adoption of battery storage systems among ECs is currently limited, the existing systems have a meaningful impact on energy management and grid stability. Encouraging more ECs to implement battery storage technology could significantly enhance their ability to manage energy more efficiently and contribute to the overall energy network. These insights underscore the need for targeted policies and support mechanisms to promote the adoption of battery storage systems, thereby improving the sustainability and operational efficiency of EC in Spain.

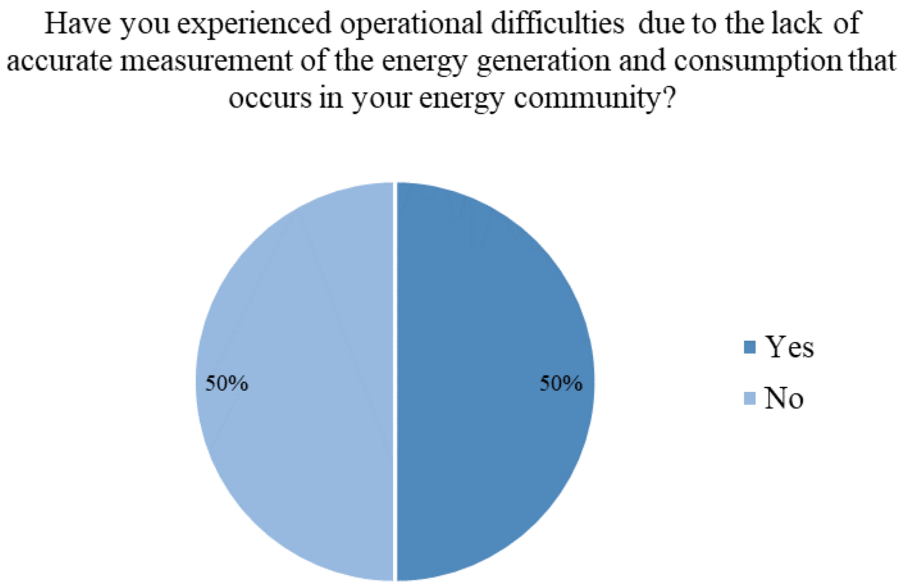


Figure 20: Have you experienced operational difficulties due to the lack of accurate measurement of the energy generation and consumption that occurs in your EC? - Question 8

The Figure 20 displays the distribution of responses from EC regarding their operational challenges caused by measurement inaccuracies. The chart is evenly split into two segments: "Yes" and "No."

General Description of the Graph

Yes:

Represented by the blue segment, 50% of respondents indicated that they have experienced operational difficulties due to the lack of accurate measurement of energy generation and consumption. This highlights a significant issue for half of the surveyed ECs, suggesting that measurement inaccuracies are a common problem affecting their efficiency and management.

No:

The orange segment shows that the remaining 50% of respondents have not faced operational difficulties due to measurement inaccuracies. This suggests that these ECs either have accurate measurement systems in place or have not been significantly impacted by any existing measurement issues.

Implications

The equal distribution of responses indicates that while a considerable number of ECs are managing well with their current measurement systems, an equally significant portion is struggling due to inaccuracies. This division underscores the need for improved measurement technologies and practices to ensure that all ECs can optimize their energy management and operations effectively.

Conclusion

The pie chart reveals that 50% of EC experience operational difficulties due to inaccurate measurement of energy generation and consumption, while the other 50% do not face such issues. This data highlights a critical area for improvement, emphasizing the importance of reliable and precise measurement systems to enhance the operational efficiency of ECs in Spain.

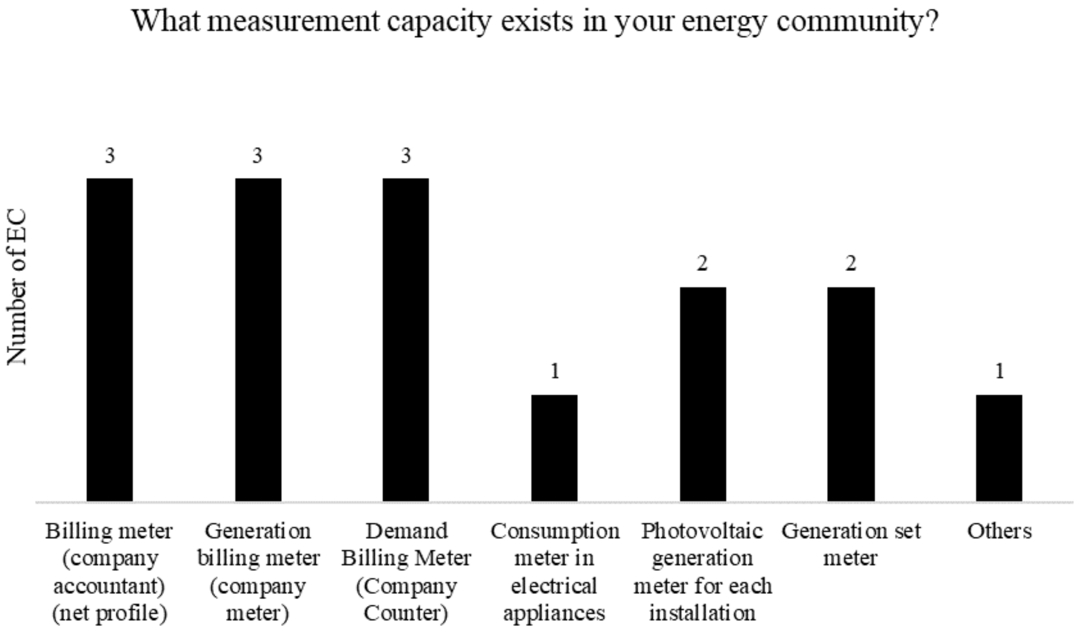


Figure 21: What measurement capacity exists in your EC? - Question 9.

The Figure 21 presents the different types of measurement systems implemented within the surveyed EC. The chart includes several categories of measurement capacity and shows the number of communities that use each type.

General Description of the Graph

Billing Meter (Company Accountant) (Net Profile):

3 communities reported having a billing meter used by the company accountant for net profiling. This indicates that this type of meter is fairly common, used to track and manage overall billing and net energy consumption.

Generation Billing Meter (Company Meter):

Similarly, 3 communities use a generation billing meter, which is employed to measure the billing of generated energy. This highlights the importance of tracking generated energy for accurate billing and accounting purposes.

Demand Billing Meter (Company Counter):

Another 3 communities use a demand billing meter, which is likely used to measure and bill energy demand accurately. This shows the significance of understanding demand patterns for efficient energy management.

Photovoltaic Generation Meter for Each Installation:

3 communities reported having photovoltaic generation meters for each installation. This suggests that these communities prioritize monitoring solar energy production at a granular level to ensure efficient use and management of photovoltaic systems.

Consumption Meter in Electrical Appliances:

1 community uses consumption meters in electrical appliances. This relatively low number indicates that appliance-level monitoring is less common, potentially due to higher costs or complexity.

Generation Set Meter:

3 communities have a generation set meter, indicating that they monitor energy generation from specific sets or sources. This is crucial for managing different energy sources effectively within the community.

Others:

1 community reported using other types of measurement systems. This category reflects the diversity of measurement approaches that might be tailored to specific needs or innovative practices within the community.

Implications

The data suggests that certain types of measurement systems, such as billing meters, generation billing meters, demand billing meters, photovoltaic generation meters, and generation set meters, are widely adopted among ECs. These systems are essential for accurate billing, monitoring, and management of energy production and consumption. The lower adoption of consumption meters in electrical appliances indicates potential areas for growth in granular energy monitoring.

Conclusion

The bar chart reveals that EC in Spain employ a variety of measurement systems to manage their energy resources effectively. The widespread use of billing and generation meters underscores the importance of accurate measurement for efficient energy management. The adoption of photovoltaic generation meters highlights the focus on renewable energy monitoring. These insights can inform future efforts to enhance measurement capacities within ECs, promoting more efficient and sustainable energy use.

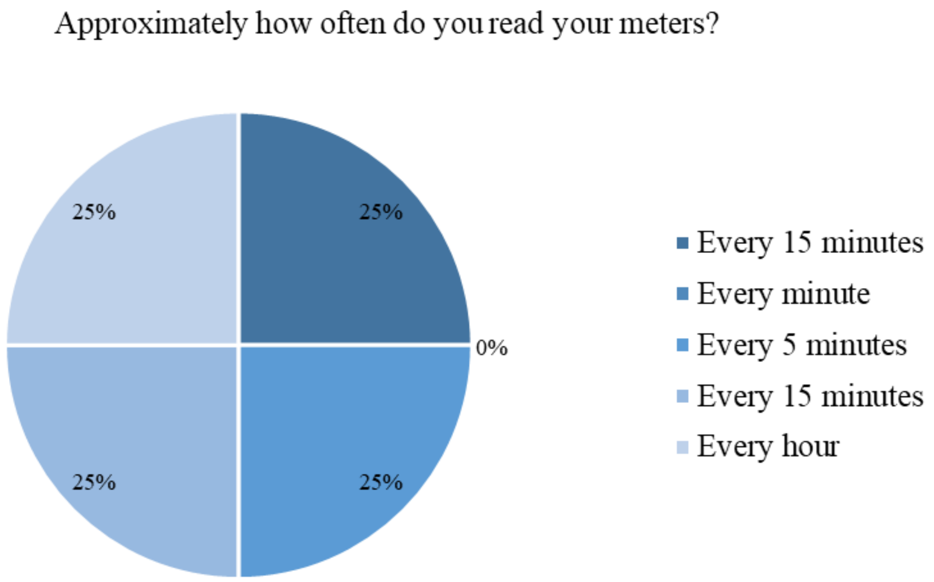


Figure 22: Approximately how often do you read your meters? - Question 10.

The Figure 22 titled "Approximately how often do you read your meters?" displays the frequency with which EC read their energy meters. The chart is divided into five segments, each representing a different meter reading frequency.

General Description of the Graph

Every 15 seconds:

Represented by the blue segment, 25% of the respondents read their meters every 15 seconds. This high-frequency reading indicates a real-time monitoring system that allows for very precise and immediate energy management.

Every minute:

The orange segment shows that 0% of the respondents read their meters every minute. This indicates that none of the ECs have opted for this specific frequency, possibly because it offers neither the granularity of real-time monitoring nor the simplicity of less frequent readings.

Every 5 minutes:

Represented by the gray segment, 25% of the respondents read their meters every 5 minutes. This frequent reading interval allows for detailed energy management and can quickly identify and respond to changes in energy consumption or generation.

Every 15 minutes:

The yellow segment indicates that 25% of the respondents read their meters every 15 minutes. This interval strikes a balance between detailed monitoring and data management efficiency, providing enough data points for effective energy management without overwhelming data systems.

Every 1 hour:

The blue segment shows that 25% of the respondents read their meters every hour. This less frequent reading is sufficient for general monitoring and can be easier to manage in terms of data storage and analysis.

Implications

The data suggests that ECs employ a variety of meter reading frequencies, with equal proportions using very high frequency (every 15 seconds), moderate frequency (every 5 and 15 minutes), and lower frequency (every hour). The absence of minute-level readings indicates a preference for either more granular real-time data or simpler, less frequent updates.

Conclusion

The pie chart reveals that EC in Spain use diverse strategies for reading their energy meters, with significant portions opting for high-frequency (every 15 seconds), moderate (every 5 and 15 minutes), and lower-frequency (every hour) readings. These varying approaches reflect different needs and capabilities within the communities, from real-time energy management to more straightforward monitoring. Understanding these preferences can help in designing tailored solutions and support for efficient energy management in ECs.

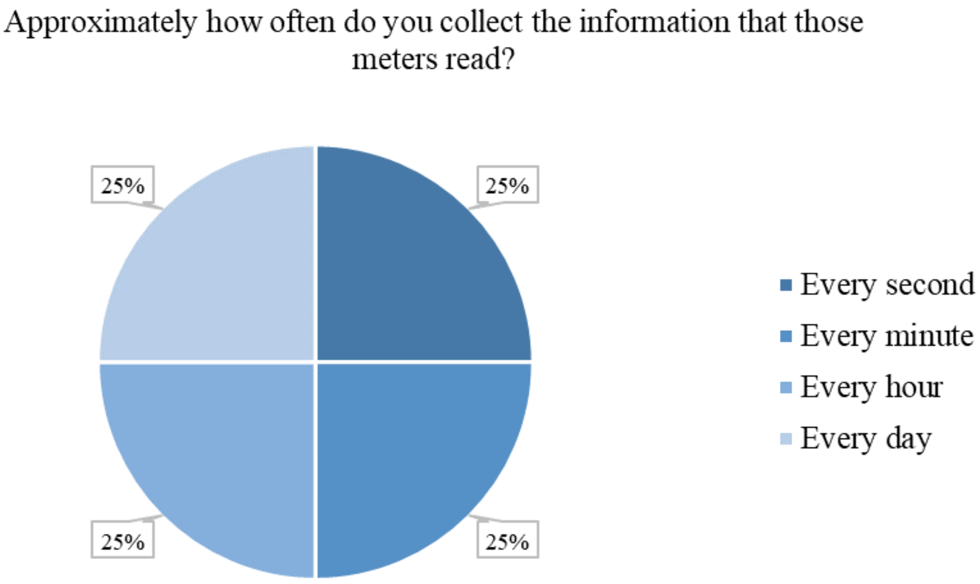


Figure 23: Approximately how often do you collect the information that those meters read? - Question 11.

The Figure 23 illustrates the frequency with which EC collect data from their energy meters. The chart is divided into four equal segments, each representing a different data collection frequency.

General Description of the Graph

Every second:

Represented by the blue segment, 25% of the respondents collect meter information every second. This extremely high-frequency data collection indicates real-time monitoring systems, allowing for the most immediate and detailed energy management.

Every minute:

The orange segment shows that 25% of the respondents collect meter data every minute. This frequent collection rate allows for near real-time monitoring, providing detailed insights while potentially reducing the data load compared to second-by-second monitoring.

Every hour:

Represented by the gray segment, 25% of the respondents collect meter data every hour. This less frequent data collection is sufficient for general monitoring and can be easier to manage in terms of data storage and analysis.

Every day:

The yellow segment indicates that 25% of the respondents collect meter data daily. This approach is the least frequent and might be used by ECs that require less granular data, focusing on broader trends and daily summaries.

Implications

The equal distribution among the four frequencies suggests that ECs employ diverse strategies for data collection based on their specific needs and capabilities. Real-time and near real-time data collection (every second and every minute) is used by half of the respondents, indicating a preference for detailed and immediate data. Conversely, collecting data every hour or every day reflects a more traditional approach, possibly due to lower resource availability or different operational needs.

Conclusion

The pie chart reveals that EC in Spain use a wide range of data collection frequencies for their energy meters, with equal proportions collecting data every second, minute, hour, and day. These varying frequencies reflect different operational requirements and capabilities within the communities. Understanding these preferences can help in designing tailored solutions and support for efficient energy management in ECs. This diversity also highlights the importance of flexible data management systems that can accommodate different data collection needs.

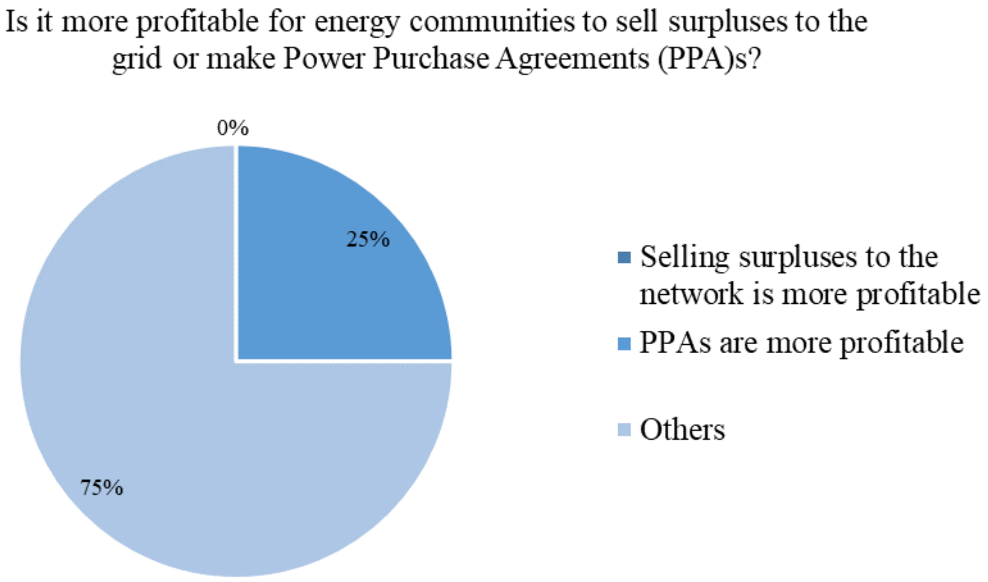


Figure 24: Is it more profitable for EC to sell surpluses to the grid or make Power Purchase Agreements (PPA)s? - Question 12.

The Figure 24 presents the preferences of EC regarding the profitability of selling energy surpluses to the grid versus entering into PPAs. The chart is divided into three segments: selling surpluses to the network is more profitable, PPAs are more profitable, and others.

General Description of the Graph

Selling surpluses to the network is more profitable:

Represented by the blue segment, 0% of the respondents indicated that selling surpluses to the network is more profitable. This absence suggests that none of the surveyed ECs consider this option as the most profitable.

PPAs are more profitable:

The orange segment shows that 25% of the respondents believe that entering into Power Purchase Agreements (PPAs) is more profitable. This indicates that a quarter of the ECs see PPAs as a better financial strategy compared to selling directly to the grid.

Others:

The gray segment, making up 75% of the respondents, suggests alternative views or approaches to profitability that were not specifically addressed by the other two options. This significant majority indicates that many ECs might have unique or varied perspectives on the best financial strategies for managing energy surpluses.

Implications

The data reveals a clear lack of preference for selling surpluses to the grid, with no respondents considering it the most profitable option. The moderate preference for PPAs suggests that while some ECs find this option financially advantageous, the majority are exploring or adopting different strategies. The large "others" category indicates a diverse range of views and approaches, highlighting the complexity of financial decision-making within ECs.

Conclusion

The pie chart indicates that EC in Spain generally do not find selling surpluses to the grid to be the most profitable option. Instead, a minority prefers Power Purchase Agreements, while the majority considers other unspecified strategies. This diversity in preferences underscores the need for tailored financial strategies and support mechanisms to meet the unique needs and contexts of different ECs. Understanding these varied approaches can help in designing more effective policies and support systems to enhance the financial sustainability of EC.

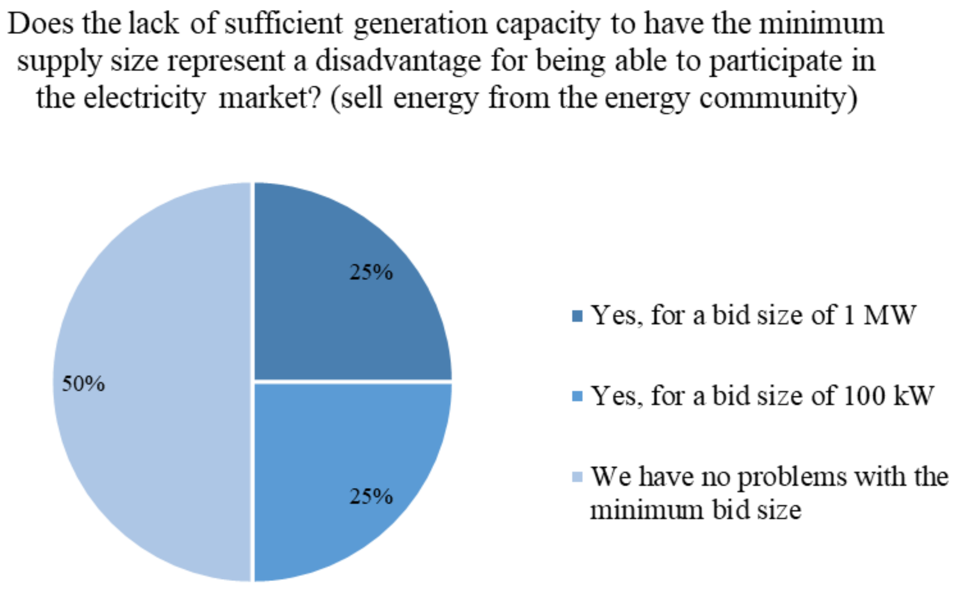


Figure 25: Does the lack of sufficient generation capacity to have the minimum supply size represent a disadvantage for being able to participate in the electricity market? (sell energy from the EC) - Question 13.

The Figure 25 illustrates the challenges faced by EC in meeting the minimum supply size required for participation in the electricity market. The chart is divided into three segments: "Yes, for a bid size of 1 MW," "Yes, for a bid size of 100 kW," and "We have no problems with the minimum bid size."

General Description of the Graph

Yes, for a bid size of 1 MW:

Represented by the blue segment, 25% of respondents indicated that the lack of sufficient generation capacity is a disadvantage for participating in the electricity market when the minimum bid size is 1 MW. This suggests that a quarter of the ECs find it challenging to meet this higher threshold.

Yes, for a bid size of 100 kW:

The orange segment shows that 25% of respondents face disadvantages for a minimum bid size of 100 kW. This indicates that even smaller bid sizes present significant challenges for some ECs.

We have no problems with the minimum bid size:

The gray segment represents 50% of respondents, indicating that half of the ECs do not have issues meeting the minimum bid size requirements. This suggests these communities either have sufficient generation capacity or have developed strategies to manage their energy production effectively.

Implications

The data reveals that half of the ECs struggle with meeting minimum bid sizes, whether the requirement is 1 MW or 100 kW. This highlights a barrier to market participation for many ECs, potentially limiting their ability to sell surplus energy and optimize their financial returns. The other half of respondents, who do not face such problems, may serve as models or sources of best practices for overcoming these challenges.

Conclusion

The pie chart demonstrates that the lack of sufficient generation capacity to meet minimum bid sizes is a significant issue for 50% of EC in Spain. This challenge is evident for both larger (1 MW) and smaller (100 kW) bid sizes. Addressing these capacity constraints is crucial for enhancing the participation of ECs in the electricity market, supporting their financial sustainability and contribution to the energy sector. Solutions may include increasing generation capacity, aggregating resources, or implementing policy measures to lower entry barriers for smaller ECs.

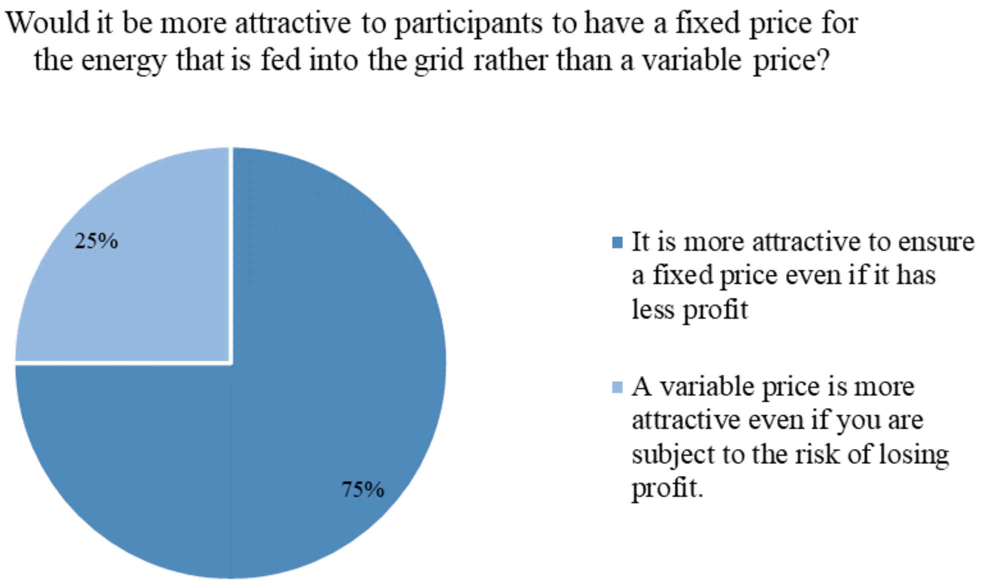


Figure 26: Would it be more attractive to participants to have a fixed price for the energy that is fed into the grid rather than a variable price? - Question 14.

The Figure 26 illustrates the preferences of ECparticipants regarding fixed versus variable pricing for energy sold to the grid. The chart is divided into two segments: a fixed price and a variable price.

General Description of the Graph

Fixed Price:

Represented by the blue segment, 67% of respondents find it more attractive to ensure a fixed price for the energy fed into the grid, even if it results in less profit. This indicates a preference for stability and predictability in income over the potential for higher, but variable, profits.

Variable Price:

The orange segment shows that 33% of respondents prefer a variable price, even if it means being subject to the risk of losing profit. This suggests that a significant minority is willing to accept the uncertainty associated with variable pricing in hopes of achieving higher returns.

Implications

The data indicates that the majority of EC participants prefer the security of a fixed price, likely due to the reduced financial risk and greater predictability it offers. The preference for a fixed price could be driven by the desire to stabilize income streams and make more accurate financial planning. On the other hand, the preference for variable pricing among a third of the respondents suggests that some communities are more risk-tolerant and willing to potentially benefit from market fluctuations.

Conclusion

The pie chart reveals that two-thirds of EC participants in Spain favor a fixed price for the energy fed into the grid, prioritizing income stability over potential profit variability. In contrast, a third of the participants prefer the possibility of higher profits through variable pricing, despite the associated risks. These preferences highlight the need for flexible policy options that can cater to both risk-averse and risk-tolerant ECs, ensuring that all communities can choose the pricing model that best suits their financial strategies and risk management preferences.

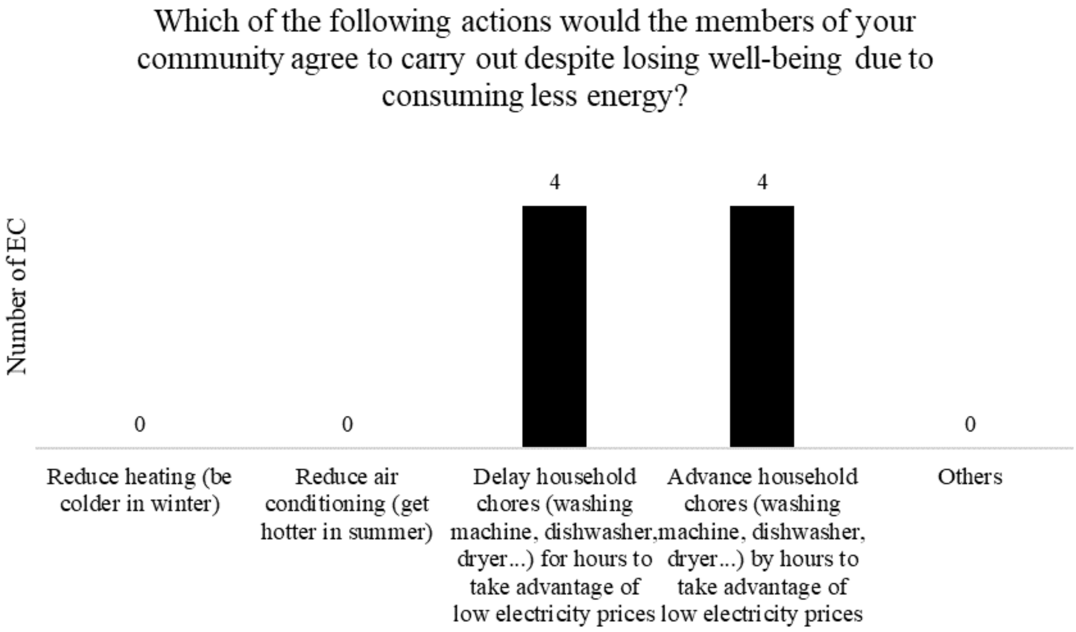


Figure 27: Which of the following actions would the members of your community agree to carry out despite losing well-being due to consuming less energy? - Question 15.

The Figure 27 illustrates the willingness of community members to adopt specific energy-saving actions, even if it impacts their well-being. The chart includes five categories: reducing heating, reducing air conditioning, delaying household chores, advancing household chores, and others.

General Description of the Graph

Reduce Heating (be colder in winter):

No community members agreed to reduce heating in winter. This indicates that maintaining a comfortable temperature during colder months is a priority, and members are not willing to compromise on heating.

Reduce Air Conditioning (get hotter in summer):

Similarly, no community members agreed to reduce air conditioning in summer. This suggests that staying cool during hot months is also a high priority, and members are not willing to sacrifice their comfort by reducing air conditioning.

Delay Household Chores:

Four community members agreed to delay household chores, such as using the washing machine, dishwasher, or dryer, to take advantage of lower electricity prices. This shows a willingness to adjust daily routines to achieve energy savings and reduce costs.

Advance Household Chores:

Four community members also agreed to advance household chores for the same purpose of taking advantage of lower electricity prices. This further emphasizes the flexibility of community members in altering their schedules to save energy and money.

Others:

No community members selected the "Others" category, indicating that the provided options covered the main actions they were willing to consider.

Implications

The data reveals that community members are most willing to adjust the timing of their household chores to save on energy costs. Both delaying and advancing chores to take advantage of lower electricity prices are equally popular choices. However, there is a clear reluctance to reduce heating in winter or air conditioning in summer, highlighting the importance of maintaining thermal comfort.

Conclusion

The bar chart shows that while community members are willing to modify the timing of their household chores to save energy and reduce costs, they are not willing to compromise on their heating and air conditioning needs. These insights suggest that energy-saving initiatives in these communities should focus on promoting and facilitating schedule adjustments for energy-intensive activities, rather than expecting reductions in heating or cooling usage. This approach can help achieve energy savings while maintaining the well-being and comfort of community members.

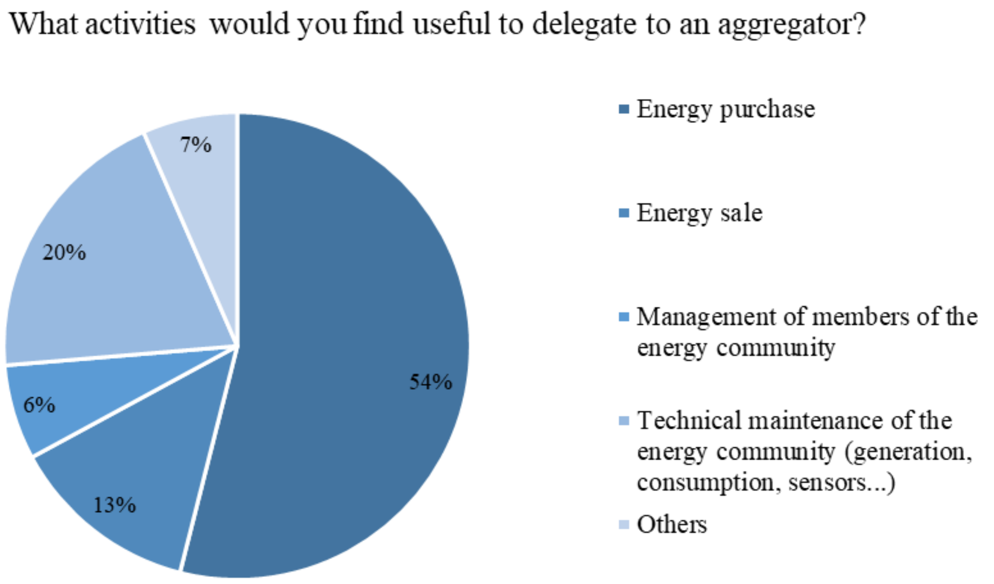


Figure 28: What activities would you find useful to delegate to an aggregator? - Question 16.

The Figure 28 illustrates the preferences of EC members regarding which activities they consider beneficial to delegate to an aggregator. The chart is divided into five segments: energy purchase, energy sale, management of members of the EC, technical maintenance of the EC, and others.

General Description of the Graph

Energy Purchase:

Represented by the blue segment, this is the largest portion of the chart, indicating that energy purchase is considered the most useful activity to delegate to an aggregator. This preference highlights the complexity and importance of energy procurement, suggesting that ECs see significant value in outsourcing this task to professionals.

Energy Sale:

The orange segment shows that energy sale is also considered an important activity to delegate. This indicates that managing the sale of energy, possibly due to its regulatory and market complexities, is a key area where ECs would benefit from external expertise.

Management of Members of the EC:

Represented by the gray segment, this category is smaller, indicating that fewer ECs see the management of community members as a priority for delegation. This could suggest that internal management of member relations is seen as more manageable or less complex.

Technical Maintenance of the EC:

The yellow segment represents a significant portion, indicating that technical maintenance (including generation, consumption monitoring, and sensors) is also a key area where ECs see value in delegation. This preference likely reflects the technical expertise required to maintain and optimize energy systems effectively.

Others:

The smallest segment, indicating that other activities are less frequently considered for delegation. This suggests that the main areas of focus for delegation are well covered by the other categories.

Implications

The data indicates that ECs primarily value the delegation of activities related to energy transactions (both purchase and sale) and technical maintenance. These areas likely require specialized knowledge and resources, which can be more effectively managed by aggregators. The relatively lower emphasis on member management suggests that ECs feel more confident handling these tasks internally.

Conclusion

The pie chart reveals that EC in Spain see significant benefits in delegating energy purchase, energy sale, and technical maintenance activities to aggregators. These tasks require specialized skills and resources that aggregators can provide, allowing ECs to focus on other aspects of their operations. The lower preference for delegating member management indicates that this is an area where ECs feel more self-sufficient. Understanding these preferences can help in designing support services and policies that align with the needs and priorities of ECs.

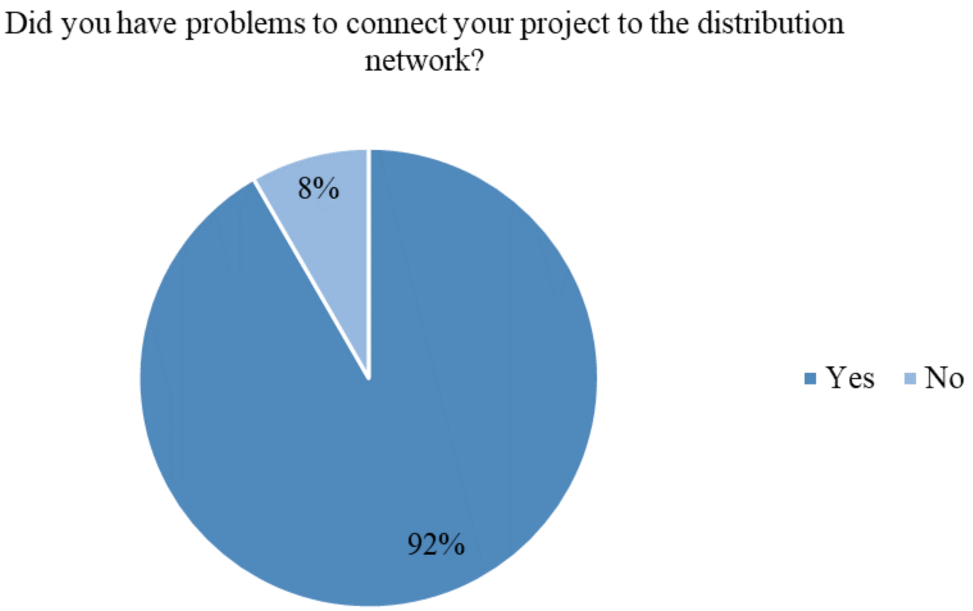


Figure 29: Did you have problems to connect your project to the distribution network? - Question 17.

The Figure 29 illustrates the challenges faced by EC in connecting their projects to the distribution network. The chart is divided into two segments: Yes (indicating problems) and No (indicating no problems).

General Description of the Graph

Yes:

Represented by the blue segment, 92% of the respondents reported having problems connecting their projects to the distribution network. This overwhelming majority suggests that connectivity issues are a significant and widespread challenge for ECs.

No:

The orange segment shows that only 8% of the respondents did not face any problems connecting to the distribution network. This small percentage indicates that only a few ECs manage to connect their projects without encountering difficulties.

Implications

The data highlights a critical barrier to the development and integration of ECs into the Spanish electricity market. The high percentage of communities perceiving connectivity problems suggests that there may be regulatory, technical, or/and bureaucratic obstacles that need to be addressed.

Conclusion

The pie chart clearly demonstrates that the majority of EC in Spain perceived significant problems when attempting to connect their projects to the distribution network.

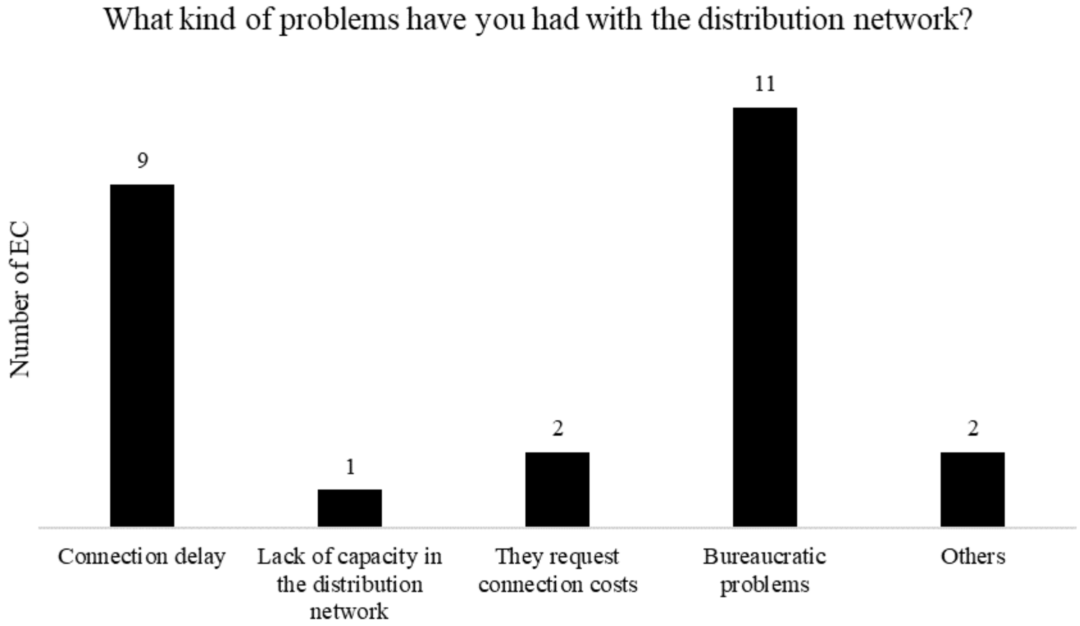


Figure 30: What kind of problems have you had with the distribution network? - Question 18.

The Figure 30 identifies various issues faced by EC in their interactions with the distribution network. The chart presents five categories of problems and shows the number of communities experiencing each type. It is important to note that these insights report the perceptions of the surveyed communities and further in-depth analysis would be necessary in future studies.

General Description of the Graph

Connection Delay:

Represented by the first bar, 9 communities reported experiencing connection delays. This indicates that a significant number of ECs face delays in getting their projects connected to the distribution network, which can hinder their operations and development.

Lack of Capacity in the Distribution Network:

The second bar shows that 1 community reported issues related to a lack of capacity in the distribution network. This suggests that this particular problem, while present, is less common among the surveyed ECs.

They Request Connection Costs:

The third bar represents 2 communities that have encountered issues with connection costs. This indicates that the financial burden of connection fees is a concern for some ECs, potentially affecting their financial viability.

Bureaucratic Problems:

The fourth bar, with 10 communities reporting bureaucratic problems, is the most frequently cited issue. This suggests that administrative and regulatory hurdles are a major challenge for ECs, possibly causing significant delays and complications in their operations.

Others:

The fifth bar shows that 2 communities reported other unspecified problems. This indicates that there are additional issues not covered by the main categories but still impacting the operations of some ECs.

Implications

The data highlights that the most common issues perceived by ECs are bureaucratic problems and connection delays. These challenges can significantly hinder the development and efficient operation of ECs, potentially leading to increased costs and delays in project implementation.

Conclusion

The bar chart reveals that ECs in Spain encounter a variety of perceived problems with the distribution network, with bureaucratic issues and connection delays being the most prevalent. Addressing these challenges is crucial for facilitating the smooth operation and growth of ECs. Streamlining administrative processes, improving network capacity, and reducing financial barriers could significantly enhance the efficiency and effectiveness of ECs, supporting their contribution to the renewable energy transition. Understanding and addressing these issues can help policymakers and stakeholders develop targeted solutions to support the sustainable development of EC. Future studies should aim to analyze these problems in depth to provide more comprehensive insights and solutions.

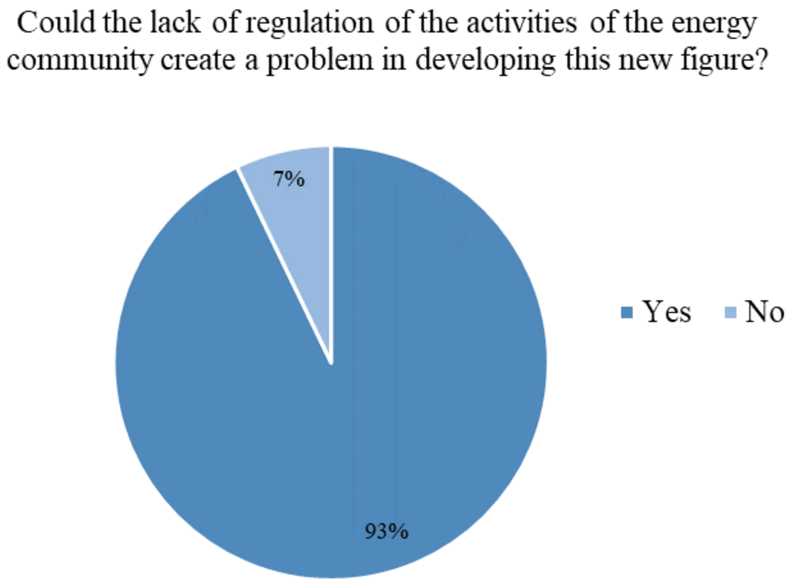


Figure 31: Could the lack of regulation of the activities of the EC create a problem in developing this new figure? - Question 19.

The Figure 31 illustrates the opinions of EC members regarding the impact of regulatory deficiencies on the development of EC. The chart is divided into two segments: Yes and No.

General Description of the Graph

Yes:

Represented by the blue segment, 90% of respondents believe that the lack of regulation of the activities of the EC could create a problem in developing this new figure. This overwhelming majority indicates a strong concern among EC members about the potential negative impact of regulatory gaps on their development and operations.

No:

The orange segment shows that 10% of respondents do not think that the lack of regulation would create a problem. This minority suggests that some members feel confident in managing their activities despite regulatory uncertainties or believe that existing frameworks are sufficient.

Implications

The data clearly indicates a significant concern among EC members about the impact of regulatory deficiencies. The lack of proper regulation is seen as a major obstacle that could hinder the growth and effective functioning of EC. This concern highlights the need for clear, comprehensive, and supportive regulatory frameworks to ensure the sustainable development of ECs.

Conclusion

The pie chart reveals that a large majority of EC members in Spain are worried about the lack of regulation affecting their development. This concern underscores the importance of establishing robust regulatory frameworks to support the growth and operational efficiency of ECs. Addressing these regulatory gaps could enhance confidence, streamline operations, and foster the overall success of EC. These insights should inform policymakers and stakeholders to prioritize regulatory reforms that align with the needs and challenges faced by ECs.

The responses from EC members reveal a range of additional barriers not previously mentioned, highlighting significant challenges across various areas:

Process Delays:

The overall process is very slow, causing frustration and delays in project implementation.

Lack of Legal Framework:

The absence of a specific legal framework for EC. Current structures, like cooperatives, are not always effective and may not meet the founders' requirements.

Cooperativism and Bureaucracy:

The system relies heavily on cooperativism and volunteer work. There is extensive bureaucracy for grants, loans, and grid connections, with subsidies delayed by over 18 months and connection waiting times of 6-12 months. During this period, full financing is needed upfront, with installers demanding payment before benefits are generated. There is a lack of subsidies, public credit, and high-interest rates on available loans (6.2-

6.5%). Additionally, there are shortages in membership, information, education, and environmental awareness among the general population.

Lack of Technical Expertise:

Many EC members are not technically proficient. They are environmentally committed individuals eager to participate in the energy transition but lack the necessary technical and legal knowledge, which presents a significant obstacle.

Data Transmission Issues:

There are incomprehensible errors in data transmission files, causing further complications.

Communication Challenges:

Difficulty in contacting different distributors and commercializers, hindering smooth communication and coordination.

Financing Difficulties:

Despite existing subsidies for collective installations, obtaining the necessary loans for the remaining implementation costs is very difficult. There is a lack of suitable public or private financing lines for such collective installations.

Mistrust and Lack of Knowledge:

Mistrust in the electrical sector, combined with a lack of basic knowledge among the population and poorly developed and standardized procedures, creates barriers.

Social Barriers:

Social barriers prevent putting users at the center of the system. There is a need to promote a system where citizens actively participate in the energy transition, as mandated by applicable European directives.

Legal and Bureaucratic Hurdles:

Legal, administrative, and bureaucratic challenges make it very difficult to integrate public entities like municipalities. Distributors often create many obstacles, leading to prolonged timelines for permits and licenses.

These responses emphasize the multifaceted nature of the challenges faced by ECs, including regulatory, financial, technical, and social barriers. Addressing these issues requires comprehensive and coordinated efforts to streamline processes, provide adequate legal frameworks, improve technical support, enhance financial mechanisms, and foster community engagement and education.

5.1.2 Spanish Electricity Market characterisation

The characterization of Spanish electricity markets and products involves a detailed analysis of various design features that define the structure and operation of these markets. This analysis aims to identify the key elements that impact the participation of EC and to understand the specific barriers they may face based on the paper [27]. By examining these features, we can develop targeted solutions to enhance ECs' integration into the electricity markets, thereby promoting a more decentralized and sustainable energy system.

This detailed analysis of each market and its design features provides a comprehensive understanding of the operational frameworks, participation conditions, and potential barriers faced by EC in the Spanish electricity markets. This characterization is essential for identifying areas where market design can be improved to facilitate greater participation of ECs.

Day Ahead Market

Table 3: Day Ahead Market characterization.

Operator	The Day Ahead Market is operated by OMIE.
Allowed Technology	There are no restrictions by technology type, meaning any type of generation technology can participate.
Aggregation Conditions	Generation and consumption should not be aggregated in a single bid. This separation ensures clarity and efficiency in bid evaluation and market operations.
Market Time Unit:	The current market time unit is 1 hour, which is transitioning to 15 minutes in the near future. This shift aims to provide greater granularity and flexibility in market operations.
Local Granularity	The market operates on a zonal basis, which means bids and operations are segmented by geographical zones, aligning with grid management and operational constraints.
Gate Closure Time	The gate closure time is D-1: 12:00. This means that bids must be submitted by noon on the day before the delivery period, allowing sufficient time for market clearing and scheduling.
Type of Product	The primary product traded in this market is energy.
FAT (Full Activation Time)	There are no specific technical requirements for FAT in the Day Ahead Market, allowing for a wide range of participants.
Ramping Period	No specific ramping period is defined, providing flexibility in ramping up or down generation as needed.
Delivery Period	There are no specific delivery period requirements, which allows participants to operate flexibly within the market's time frames.
Bid Structure	Bids can be simple or complex, including conditions like maximum income and load gradient constraints, offering flexibility in bid submission.
Maximum Price and Minimum Price	The maximum bid price is set at 4000 €/MWh. The minimum bid price is set at -500 €/MWh,

	accommodating a wide range of market conditions and bid strategies.
Maximum Bid Size and Minimum Bid Size	There is no defined maximum bid size, allowing for large-scale generation units to participate without restriction. The minimum bid size is 1 MW, ensuring that even relatively small generation units can participate in the market.

Intraday Auction Market [27]

Table 4: Intraday Auction Market characterization.

Operator	OMIE operates the Intraday Auction Market.
Allowed Technology	There are no restrictions by technology type, allowing a diverse range of generation technologies to participate.
Aggregation Conditions	Like the Day Ahead Market, generation and consumption should not be aggregated in a single bid, ensuring clear and effective market operations.
Market Time Unit:	The market time unit is currently 1 hour, transitioning to 15 minutes in the near future, which enhance market responsiveness and operational precision.
Local Granularity	This market operates on a zonal basis, aligning with grid management practices.
Gate Closure Time	The gate closure times vary, with D-1 closure at 15:00, 17:50, 21:50, and intraday closures at 01:50, 04:50, 09:50. These multiple closure times provide opportunities for market participants to adjust their bids closer to the delivery period.
Type of Product	Energy is the primary product traded.
FAT (Full Activation Time)	No specific technical requirements for FAT are defined, allowing broad participation.
Ramping Period	There is no defined ramping period, providing flexibility for participants to ramp generation as needed.
Delivery Period	There are no specific delivery period requirements, enabling flexible participation within the market’s time frames.

Bid Structure	Complex conditions are allowed, including maximum income conditions and load gradients, offering flexibility in bid strategies.
Maximum Price and Minimum Price	The maximum bid price is set at 9999 €/MWh. The minimum bid price is -9999 €/MWh, accommodating a wide range of market conditions and bid strategies.
Maximum Bid Size and Minimum Bid Size	There is no defined maximum bid size, allowing large generation units to participate without restriction. The minimum bid size is 0.1 MW, which allows smaller generation units to participate.

Intraday Continuous Market [23]

Table 5: Intraday Continuous Market characterization.

Operator	OMIE operates the Intraday Continuous Market.
Allowed Technology	There are no restrictions by technology type, enabling a diverse range of generation technologies to participate.
Aggregation Conditions	Generation and consumption should not be aggregated in a single bid, maintaining clear market operations.
Market Time Unit:	The market time unit is 1 hour, transitioning to 15 minutes in the near future, which enhance market responsiveness.
Local Granularity	The market operates on a zonal basis, aligning with grid management practices.
Gate Closure Time	Trading is allowed up to 2 hours before the delivery period, providing flexibility for market participants to adjust their bids close to real-time.
Type of Product	Energy is the primary product traded.
FAT (Full Activation Time)	No specific technical requirements for FAT are defined, allowing broad participation.
Ramping Period	There is no defined ramping period, providing flexibility for participants to ramp generation as needed.
Delivery Period	There are no specific delivery period requirements, enabling flexible participation within the market’s time frames.

Bid Structure	Certain types of complexity can be expressed through execution conditions, offering flexibility in bid strategies.
Maximum Price and Minimum Price	The maximum bid price is set at 9999 €/MWh. The minimum bid price is -9999 €/MWh, accommodating a wide range of market conditions and bid strategies.
Maximum Bid Size and Minimum Bid Size	There is no defined maximum bid size, allowing large generation units to participate without restriction. The minimum bid size is 0.1 MW, allowing smaller generation units to participate.

Frequency Containment Reserves [32]

Table 6: Frequency Containment Reserves characterization.

Operator	Operated by REE.
Allowed Technology	There are no restrictions by technology type, enabling a broad range of generation technologies to participate.
Aggregation Conditions	Bids in the auction are symmetric, requiring providers to procure equal volumes of positive and negative primary reserves.
Market Time Unit:	The auction takes place daily with six four-hour products, with procurement applying for the following delivery day.
Local Granularity	The market operates on an Area LFC basis.
Gate Closure Time	Real-time gate closure, allowing immediate adjustments to market conditions.
Type of Product	Capacity is the primary product traded.
FAT (Full Activation Time)	FAT is less than 30 seconds, requiring rapid response capabilities from participants.
Ramping Period	There is no defined ramping period, providing flexibility for rapid adjustments.
Delivery Period	Minimum duration of 15 minutes, ensuring short-term balancing capabilities.
Bid Structure	Bids are symmetric and can be divisible or indivisible, offering flexibility in participation.

Maximum Price and Minimum Price	Not defined
Maximum Bid Size and Minimum Bid Size	25 MW, allowing large generation units to participate. 1 MW, enabling smaller generation units to participate.

Automatic Frequency Restoration Reserve [33]

Table 7: Automatic Frequency Restoration Reserve characterization.

Operator	Operated by REE.
Allowed Technology	There are no restrictions by technology type.
Aggregation Conditions	No specific conditions for aggregation.
Market Time Unit:	Real-time operations.
Local Granularity	Operates on an Area LFC basis.
Gate Closure Time	25 minutes before the validity period.
Type of Product	Capacity and energy are the primary products traded.
FAT (Full Activation Time)	FAT is less than 5 minutes, requiring quick response times.
Ramping Period	No defined ramping period.
Delivery Period	Minimum duration of 15 minutes.
Bid Structure	Bids are divisible and the activation request can be lower than the minimum granularity.
Maximum Price and Minimum Price	Not defined
Maximum Bid Size and Minimum Bid Size	Minimum Bid Size of 1 MW.

Manual Frequency Restoration Reserve [34]

Table 8: Manual Frequency Restoration Reserve characterization.

Operator	Operated by REE.
Allowed Technology	There are no restrictions by technology type.
Aggregation Conditions	No specific conditions for aggregation.

Market Time Unit:	Real-time operations.
Local Granularity	Operates on an Area LFC basis.
Gate Closure Time	Real-time or scheduled.
Type of Prodçuct	Capacity and energy are the primary products traded.
FAT (Full Activation Time)	FAT is less than 12.5 minutes
Ramping Period	Maximum ramping period is 12.5 minutes.
Delivery Period	Minimum duration of 5 minutes.
Bid Structure	Bids are divisible and indivisible, offering flexibility.
Maximum Price and Minimum Price	Only minimum price of 0.01 €/MWh.
Maximum Bid Size and Minimum Bid Size	9,999 MW and 1 MW.

Replacement Reserve [27]

Table 9: Replacement Reserve characterization.

Operator	Operated by REE.
Allowed Technology	Generation units, aggregators, demand response, and energy storage are allowed.
Aggregation Conditions	Generation and consumption should not be aggregated in the same bid.
Market Time Unit:	15-minute intervals.
Local Granularity	Operates on an LFC area or bidding zone basis, whichever is the smallest.
Gate Closure Time	Capacity closure at 23:00 D-1 and energy closure in real-time minus 40 minutes.
Type of Product	Capacity and energy are the primary products traded.
FAT (Full Activation Time)	Prequalification is necessary, and FAT is less than 30 minutes.
Ramping Period	Preparation time is less than 30 minutes.
Delivery Period	No specific requirements

Bid Structure	Bids can be simple or complex, including conditions like exclusivity, multipart, or time linkage.
Maximum Price and Minimum Price	Not defined.
Maximum Bid Size and Minimum Bid Size	Only minimum bid size of 1 MW.

Voltage Control [35]

Table 10: Voltage Control characterization.

Operator	Operated by REE.
Allowed Technology	There are no restrictions by technology type.
Aggregation Conditions	No specific conditions for aggregation.
Market Time Unit:	Real-time operations.
Local Granularity	Operates on an LFC area basis.
Gate Closure Time	Real-time closure.
Type of Product	Energy is the primary product traded.
FAT (Full Activation Time)	FAT is less than 15 minutes.
Ramping Period	No specific ramping period.
Delivery Period	Minimum duration of 2 hours.
Bid Structure	Mandatory participation.
Maximum Price and Minimum Price	Not defined.
Maximum Bid Size and Minimum Bid Size	Not defined.

Service Replacement [27]

Table 11: Service Replacement characterization.

Operator	Operated by REE.
Allowed Technology	There are no restrictions by technology type.

Aggregation Conditions	No specific conditions for aggregation.
Market Time Unit:	Real-time operations.
Local Granularity	Operates on an LFC area basis.
Gate Closure Time	Real-time closure.
Type of Product	Energy is the primary product traded.
FAT (Full Activation Time)	FAT is less than 15 minutes.
Ramping Period	No specific ramping period.
Delivery Period	Minimum duration of 2 hours.
Bid Structure	Mandatory participation.
Maximum Price and Minimum Price	Not defined.
Maximum Bid Size and Minimum Bid Size	Not defined.

Capacity Market [36]

Table 12: Capacity Market characterization.

Operator	Operated by REE.
Allowed Technology	Generation, storage, and demand response are allowed.
Aggregation Conditions	Aggregation of demand is allowed.
Market Time Unit:	Short-term and mid-term operations
Local Granularity	Operates on a nodal basis.
Gate Closure Time	Not defined.
Type of Product	Capacity is the primary product traded.
FAT (Full Activation Time)	FAT is less than 15 minutes or real-time.
Ramping Period	No specific ramping period.
Delivery Period	Minimum duration of 2 hours
Bid Structure	Mandatory participation

Maximum Price and Minimum Price	Not defined
Maximum Bid Size and Minimum Bid Size	Not defined

Interruptibility [37]

Table 13: Interruptibility characterization.

Operator	Operated by REE.
Allowed Technology	Involves power reduction from the consumer.
Aggregation Conditions	No specific conditions for aggregation
Market Time Unit:	Real-time operations
Local Granularity	Operates on a nodal basis
Gate Closure Time	Instantaneous execution (without minimum notice) or with a minimum advance notice of 15 minutes.
Type of Product	Capacity is the primary product traded.
FAT (Full Activation Time)	FAT is less than 15 minutes or real-time.
Ramping Period	No specific ramping period.
Delivery Period	No specific requirements
Bid Structure	Not defined
Maximum Price and Minimum Price	Not defined.
Maximum Bid Size and Minimum Bid Size	Minimum of 1 MW.

DSO Congestion Management (Local) [27]

Table 14: DSO Congestion Management (Local) characterization.

Operator	Managed by DSO.
Allowed Technology	There are no restrictions by technology type
Aggregation Conditions	Upward and downward flexibility cannot be aggregated in a single bid.

Market Time Unit:	1 hour.
Local Granularity	Operates on a nodal basis
Gate Closure Time	D-1: 14:45.
Type of Product	Energy is the primary product traded
FAT (Full Activation Time)	FAT is less than 1 hour
Ramping Period	No specific ramping period
Delivery Period	No specific requirements
Bid Structure	Simple bids only
Maximum Price and Minimum Price	Not defined
Maximum Bid Size and Minimum Bid Size	Minimum Bid Size: 0.01 MW.

5.1.3 Barriers for each feature and solutions

The electrical markets and products to be studied include Intraday, Day Ahead, Replacement Reserve, TSO Congestion Management, DSO Congestion Management, Active Demand Response Service (SRAD), Manual Frequency Restoration Reserve, and Automatic Frequency Restoration Reserve. These markets were selected due to two main reasons: firstly, FCR and aFRR markets are excluded because of their high technical requirements [38], and secondly, the capacity market is excluded as it has not been defined yet [39].

By addressing these areas, the Active Demand Response Service can become more inclusive and accessible, enabling broader participation from EC and smaller consumers. This, in turn, enhance grid stability, optimize energy use, and contribute to a more sustainable energy system.

Allowed Technology

Market:

The Active Demand Response Service, operational since 2022, is designed to engage consumers in adjusting their electricity usage in response to market signals. This service aims to enhance grid stability and efficiency by leveraging demand-side flexibility.

Problem:

The primary challenge identified in this market is the large capacity requirement for reducing consumption. Specifically, the reduction capacity needed is greater than 1 MW over 5745 hours. This high threshold makes it difficult for smaller consumers and EC to participate effectively [40].

Type of Solution:

1. Technology and Infrastructure:

Solution: Utilize automation in houses to synchronize the electricity exchange according to market requirements. Implementing advanced home automation systems can help households adjust their energy consumption in real-time, meeting the market requirements more effectively. These systems can be integrated with smart meters and IoT devices to optimize energy use automatically based on market signals [41].

2. Regulatory Framework:

Solution: Allow aggregation of demand, generation, and storage. Changing regulations to permit the aggregation of smaller loads, generation units, and storage systems can enable EC to collectively meet the capacity requirements. This aggregation can create a more significant and manageable block of flexible demand, enhancing participation in the demand response market [42].

3. Community Engagement:

Solution: Engage customers. Active participation from community members is crucial for the success of demand response programs. Educating and involving consumers about the benefits and mechanisms of demand response can increase their willingness to participate. Community engagement initiatives can include workshops, information campaigns, and incentive programs to motivate consumer involvement [43], [44].

4. Business Models:

Solution: Develop business models analysis. Comprehensive analysis and development of new business models are necessary to support the financial viability and operational success of demand response initiatives. These business models should consider the economic incentives for participants, cost-sharing mechanisms, and revenue streams that can make demand response participation attractive for EC [43], [44].

FAT(Full Activation Time)

Market

mFRR and RR (Manual Frequency Restoration Reserve and Replacement Reserve)

Problem

The primary issue in the mFRR and RR markets is the requirement for a Full Activation Time (FAT) of less than 30 minutes. This short activation period is challenging for many participants, particularly smaller EC and those with limited automation capabilities [45].

Market

SRAD (System Response and Demand Management)

Problem

The SRAD market specifically requires a FAT of less than 15 minutes. This extremely rapid response time is a significant barrier for many participants, especially those without advanced real-time control systems [37].

Market

aFRR (automatic Frequency Restoration Reserve)

Problem

The aFRR market specifically requires a FAT of less than 5 minutes. This extremely rapid response time is a significant barrier for many participants, especially those without advanced real-time control systems [37].

Type of Solution

1. Technology and Infrastructure

Solution: Use automation to synchronize. Implementing advanced automation technologies can help synchronize the demand and supply adjustments needed to meet the FAT requirements. Automated systems can respond quickly and efficiently to market signals, ensuring compliance with the tight activation times [41].

Aggregation Conditions

Problem

A significant barrier across all markets is the restriction on aggregation. Specifically, two primary issues have been identified:

1. Generation and Consumption Cannot be Aggregated in a Single Bid: This restriction prevents participants from combining generation and consumption resources into a single bid, limiting the flexibility and efficiency of their market participation [27].

2. Upward and Downward Bids Cannot be Aggregated in a Single Bid: This rule restricts the ability to submit a combined bid for increasing and decreasing energy supply or demand, which can complicate the bidding process and reduce operational efficiency [27].

Type of Solution

1. Business Models

Solution: Favor the creation of business models that integrate customers with different units. Developing innovative business models that allow the integration of various types of customers and resources can help overcome the aggregation barriers. These models should facilitate the pooling of generation, consumption, and storage resources, enabling a more effective and unified market participation strategy [43].

2. Regulatory Framework

Solution: Define aggregation rules that allow the aggregation of diverse technologies. Regulatory reforms are needed to permit the aggregation of different technologies and resource types within a single bid. By allowing diverse units to be combined, market participants can achieve greater flexibility and efficiency, making it easier to meet market requirements and respond to market signals [42].

3. Community Engagement

Solution: Engage customers. Active engagement and education of community members about the benefits of aggregation and collaborative market participation are essential. Encouraging community members to participate in aggregated bids can enhance collective market power and operational efficiency. Engagement initiatives can include informational campaigns, workshops, and incentive programs to motivate and educate participants about the advantages of aggregation [43], [44].

Ramping Period

Problem

For markets such as RR and mFRR, a significant issue is the prequalification requirement, which necessitates a preparation time of less than 30 minutes. This stringent requirement can limit participation and flexibility, particularly for smaller or less automated units [46].

Type of Solution

1. Technology and Infrastructure

Solution: Automate residential systems to provide faster response times. By integrating automation technologies into residential systems, it is possible to achieve quicker response times, thereby meeting the prequalification requirements. This approach can facilitate more effective participation in these markets by enabling faster and more reliable service provision [41].

Bid Structure

Problem

The lack of flexibility in the bid structure can hinder the effective inclusion of demand response resources in various markets [47].

Type of Solution

1.Regulatory Framework

Solution: Encourage ECs to learn to make simple and complex offers. Implementing educational and training programs can help ECs understand and adapt to the bid structure.

This could include creating incentives that support flexible and varied demand response, allowing ECs to participate more effectively with diverse capacities and needs [47].

Type of Product

Problem

In the aFRR market, the requirement to aggregate upward and downward flexibility into a single bid restricts operational flexibility. This constraint can complicate market participation and reduce overall efficiency [27].

Type of Solution

1. Regulatory Framework

Solution: Separate products for upward and downward flexibility. By allowing distinct bids for upward and downward flexibility, market participants can optimize their operations and bid more effectively. This regulatory adjustment can enhance market dynamics and improve the integration of flexible resources [27].

Additional Consideration

The aFRR is a technically complex product due to TSO requirements. ECs should focus on developing their technical capabilities to meet the aFRR demands, rather than expecting market design to conform to their current capabilities.

Market Time Unit

Problem

The transition from 1-hour to 15-minute market products presents a significant challenge across several market segments, including Day-ahead, Intraday, RR (Replacement Reserve), mFRR (Manual Frequency Restoration Reserve), and DSO Congestion Management. This shift requires enhanced forecasting, monitoring, and control capabilities to manage the increased granularity and responsiveness needed [48].

Type of Solution

1. Technology and Infrastructure

Solution: Implement metering and submetering (if required), and advanced control infrastructure.

Metering and Submetering: Accurate metering and submetering are essential for capturing detailed consumption and generation data at shorter intervals. This data is critical for precise forecasting and market participation [49].

Gate Closure Time

Problem

In all markets, Gate Closure Times (GCTs) that are closer to real-time require more effort to participate in trading. This increased complexity and the need for rapid response can be challenging for market participants, particularly for smaller EC and those without advanced decision-making systems [50].

Type of Solution

1. Technology and Infrastructure

Solution: Automatic decision-making systems.

Automatic Systems: Implementing automatic and AI-driven systems can significantly enhance the ability to respond to market signals promptly. These systems can analyze market data, optimize bids, and execute trades in real-time, reducing the effort and time required for manual decision-making [51].

Minimum Bid Size

Problem

In all markets, a significant barrier is the minimum bid size requirement, which can be problematic for ECs due to their typically smaller scale. This requirement can prevent smaller ECs from participating effectively in the market, limiting their ability to contribute to and benefit from market activities [52].

Type of Solution

1. Regulatory Framework

Solution: Reduce the minimum bid size. Adjusting regulations to lower the minimum bid size requirement can enable smaller ECs to participate in the market. This change would make it easier for these communities to contribute their available resources without needing to meet a prohibitively high threshold [53]. It is important to note that this can be done when possible. Some products, due to SO requirements, must have a high minimum bid size.

2. Aggregation

Solution: Aggregate more ECs in a single bid. Encouraging and facilitating the aggregation of multiple ECs into a single bid can help meet the minimum bid size requirement. By pooling their resources, smaller ECs can collectively participate in the market, thereby overcoming the size barrier and enhancing their market presence and influence [42].

Locational Granularity

Problem

In markets such as TSO Congestion Management and DSO Congestion Management, only resources that are well-located can effectively provide congestion management. This locational constraint can limit the participation of EC that are not ideally situated. Additionally, if the resources are not called upon, value stacking can become an issue, where resources are unable to derive multiple value streams from their participation [27].

Type of Solution

1. Regulatory Framework

Solution: Allow bid forwarding between markets, e.g., from local to central markets (e.g., energy and system services). By enabling bid forwarding, resources that might not be optimally located for one market can still participate in another, enhancing their value and market participation opportunities. This approach can mitigate the locational constraints by allowing flexibility in how and where bids are submitted and utilized [27].

5.2 Quantitative Analysis

This section presents the development and optimization of models designed to enhance the efficiency and market participation of battery storage systems within EC. The goal is to quantify the potential for participation in electricity markets by tailoring battery capacities to each community's specific needs and constraints.

The outcomes of these models provide valuable insights into the variability of battery storage needs across different ECs, influenced by factors such as installed renewable energy capacity and consumption patterns. The following sections detail the methodologies used, the results obtained, and the implications for developing more effective energy management strategies within ECs.

By integrating these optimized models, ECs can significantly enhance their participation in various electricity markets, improve their operational efficiency, and contribute more effectively to a sustainable and resilient energy system.

Two distinct models were created and evaluated:

Optimization Model for Battery Size and Power:

This model focuses on determining battery storage systems' optimal size and power capacity. By analyzing the specific energy consumption and production profiles of each EC, the model aims to customize battery configurations that maximize efficiency and meet the community's unique requirements. Factors such as peak demand, renewable energy generation, and grid interaction are considered to ensure that the battery systems are both effective and economically viable.

Optimization Model for Energy Profiles:

In contrast to the first model, this approach fixes the parameters for battery size and power and instead focuses on optimizing the energy profiles within these constraints. The model seeks to enhance the operational efficiency of the existing battery systems by refining charge and discharge cycles, improving energy distribution, and ensuring better alignment with market participation opportunities. This model is particularly relevant for ECs with established battery systems looking to optimize their performance without significant infrastructure changes.

5.2.1 Calculation of the Net Profile and Visualizations of the report.

Calculation of the Net Profile

The net profile is a crucial parameter to optimize EC's battery size and usage. It is calculated by subtracting the total demand from the total energy generation. The following steps outline the process used to calculate the net profile:

Data Sources:

Generation Data: Energy generation data is sourced from Renewables Ninja [28] for the year 2019.

Demand Data: Demand data is sourced from Datadis for the year 2023 [29].

Calculation Method:

Net Generation: For each hour of each day in 2023, the net generation is calculated as:

$$Net\ Generation\ =\ Total\ Generation\ -\ Total\ Demand$$

The total energy demand is approximated using disaggregated data provided by Datadis [29], which includes residential consumption, service consumption, and industrial consumption. These consumption categories are linked to the EC as follows:

Residential Consumption (α): This represents the municipality's residential energy consumption proportion. It is calculated by multiplying the total residential consumption by the factor K, which is the ratio of the number of participants in the ECto the total population of the municipality. This corresponds to citizens and social entities of the our study based on the website EnergiaComun [26].

Service Consumption (β): This represents the energy consumption of commercial and service establishments. It is calculated by multiplying the total service consumption by the factor K. This represents the local commerce and majors of EnergiaComun [26].

Industrial Consumption (γ): This corresponds to the energy consumption of companies and industrial parks. It is calculated by multiplying the total industrial consumption by the factor K. This represents the industrial businesses of EnergiaComun [26].

The factor K is defined as:

$$K = \frac{Number\ of\ EC\ participants}{Total\ population\ of\ the\ municipality}$$

At the end the total demand is:

$$Total\ Demand =\ \alpha + \beta + \gamma$$

In this way, each type of consumption is weighted according to the relative participation of the EC within the municipality, allowing for a detailed and accurate approximation of the total energy demand. This approach ensures that the demand modeling appropriately reflects the different consumption characteristics in each EC.

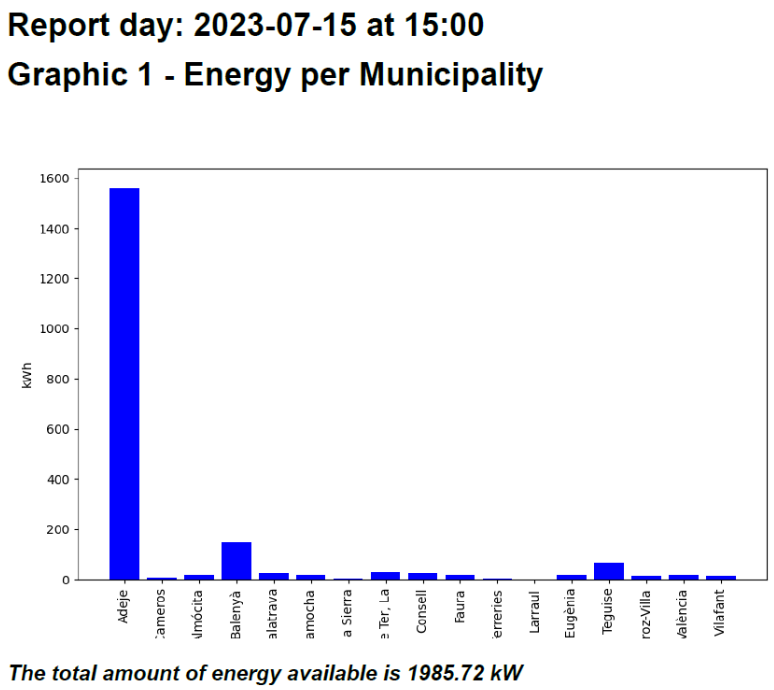
Python Code and Report Generation:

A Python script is used to automate the calculation of net generation and to generate detailed reports. The script produces visualizations and tables that provide insights into the energy availability and market participation potential for each community.

Example Visualizations and Tables

1. Graphic 1: Energy per Municipality

Figure *32* shows the amount of energy available to each of the 33 EC at a specific hour and day in 2023. It helps in understanding the distribution of available energy across different municipalities.



Report day: 2023-07-15 at 15:00

Graphic 1 - Energy per Municipality

The total amount of energy available is 1985.72 kW

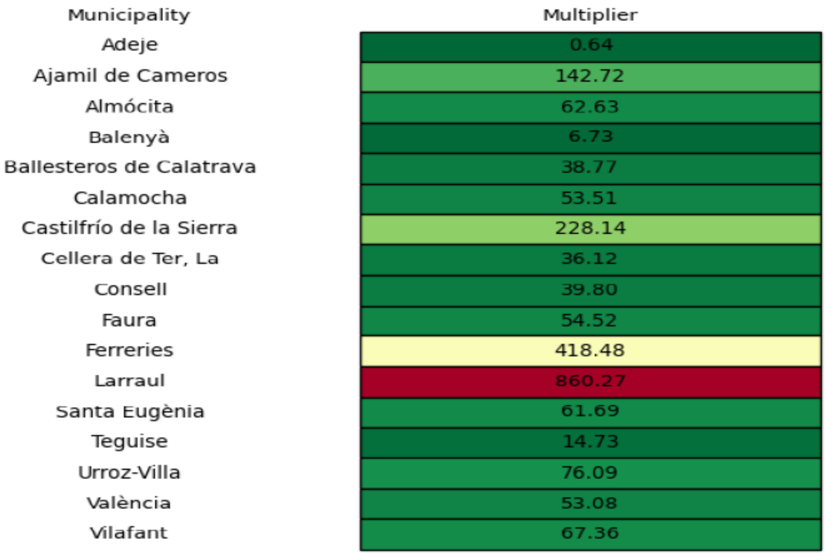
Figure 32: Graphic 1 of the report - Energy per Municipality.

Commentary:

From Figure 32, it is evident that Adeje has the highest available energy at 1500 kWh, significantly more than any other municipality. This indicates that Adeje has a substantial surplus of generated energy compared to its demand. In contrast, other municipalities like Ajameno and Almenara show minimal energy availability, indicating a closer balance between their energy generation and consumption. This disparity highlights the potential for energy sharing and aggregation to balance out the energy availability across different municipalities.

2. Table 1: EC Equals Necessary to Participate in the Day-Ahead Market (1 MWh)

This table illustrates the number of EC of the same size required to meet the minimum bid size of the daily market (1 MW) for the same hour. It provides a clear view of how many communities need to aggregate their resources to participate in the market.



Municipality	Multiplier
Adeje	0.64
Ajamil de Cameros	142.72
Almócita	62.63
Balenyà	6.73
Ballesteros de Calatrava	38.77
Calamocha	53.51
Castilfrío de la Sierra	228.14
Cellera de Ter, La	36.12
Consell	39.80
Faura	54.52
Ferreries	418.48
Larraul	860.27
Santa Eugènia	61.69
Teguise	14.73
Urroz-Villa	76.09
València	53.08
Vilafant	67.36

Figure 33: Table 1 of the report - EC equals to be able to participate in the daily market (1MW)

Commentary:

The Figure 33 shows that Adeje requires only 0.64 EC to meet the minimum bid size, indicating that its available energy is well above the threshold. In stark contrast, municipalities like Larraul and Ferreries require 860.27 and 418.48 EC respectively, demonstrating their very low energy availability relative to the market requirement. This highlights the critical need for aggregation and optimization strategies to enable smaller communities to participate in the market effectively.

3. Graphic 2: Total kWh per Province - Congestion Management

These graphic aggregates the net generation by province for the specified hour and day, analyzing the potential for provincial-level aggregation in the congestion management market. It highlights the possibilities and limitations for each province to contribute to congestion management.

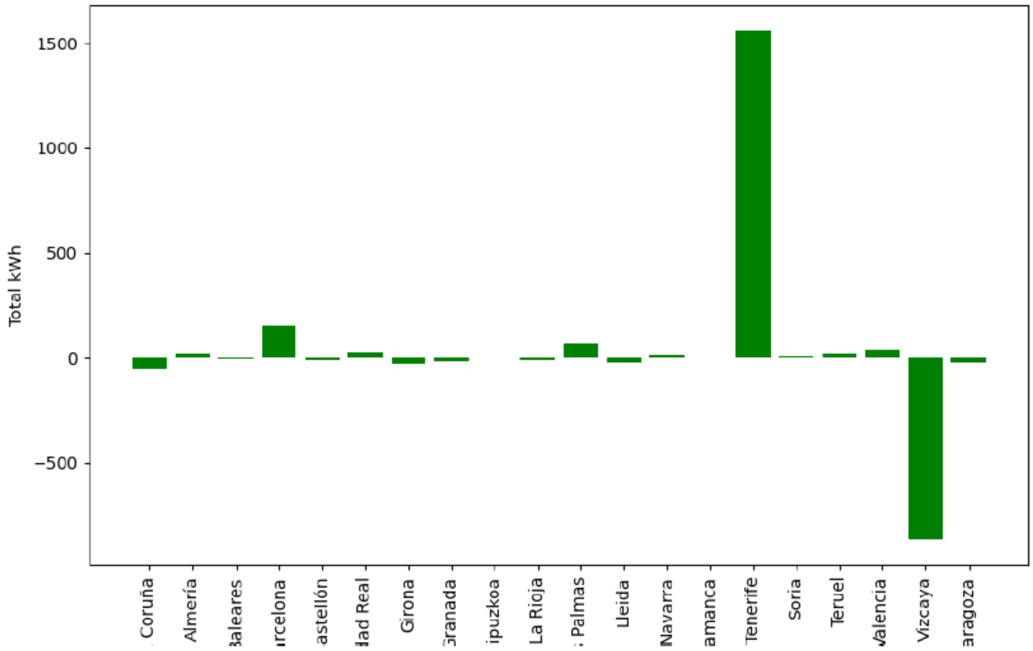


Figure 34: Graphic 2 of the report - Total kWh per province - Congestion Management

Commentary:

The Figure 34 reveals significant variations in net generation across different provinces. Tenerife shows a substantial positive net generation, making it a strong candidate for contributing to congestion management. On the other hand, provinces like Vizcaya exhibit a negative net generation, indicating higher demand than generation and a potential need for external energy support. These insights can guide strategic decisions for provincial-level energy management and congestion mitigation efforts.

By following this comprehensive methodology and analyzing the detailed visualizations and tables, the model ensures that EC can effectively assess their energy profiles and participation potential in the Spanish electricity market.

5.2.2 Objective function, parameters, variables and constraints of the battery size optimization model

Objective function

$$\min \quad p_b \cdot \left(P_{Battery} + Size_{Battery}\right) + \sum_{t=0}^{n} \left(PVPC(t) \cdot Grid_{INJ}(t) + DAP(t) \cdot Grid_{W}(t)\right)$$

Parameters

The following parameters are used in the optimization model:

$Energy_0$: Initial energy stored in the battery (kWh).

P_0: Initial power of the battery (kWh).

p_b: Price of battery storage capacity (€ per kWh).

η_c: Charging efficiency of the battery.

η_d: Discharging efficiency of the battery.

net: Net generation profile (generation minus consumption) of the EC (kWh).

$PVPC$: Time-series data of electricity market prices for buying (€/MWh).

DAP: Time-series data of electricity market prices for selling (€/MWh).

$SimWindow$: Number of hours in the optimization window (e.g., 24).

$SimSpan$: Number of days for sequential optimization (e.g., 1, 2, ... 30 or 365).

$OptimizationMode$: Mode for optimization (daily independent or daily sequence).

Variables

The following variables are used in the optimization model:

- $Grid_{INJ}$: Energy consumed from the grid in period t (kWh).
- $Grid_{W}$: Energy delivered to the grid in period t (kWh).
- $Energy_{Battery}$: Energy stored in the battery in period t (kWh).
- $Discharge_{Battery}$: Energy discharged from the battery in period t (kWh).
- $Charge_{Battery}$: Battery charging in period t (kWh).
- $Size_{Battery}$: Optimal battery size (kWh).
- $P_{Battery}$: Optimal battery power (kW).
- $Exchange_{Battery}$: Battery exchange in period t (kWh).
- aux_{Grid}: Auxiliary binary variable for grid delivery in period t.
- $aux_{Battery}$: Auxiliary binary variable for battery delivery in period t.
- $Exchange_{Grid}$: Energy exchange with the grid in period t (kWh).

Constraints

The following constraints are used in the optimization model, firsly the limits of the variables:

$$Grid_{INJ_t} \geq 0 \ \forall t \in \{0, 1, \dots, T\}$$

$$Grid_{W_t} \leq 0 \ \forall t \in \{0,1, \dots, T\}$$

$$Energy_{Battery_t} \geq 0 \ \forall t \in \{0,1, \dots, T\}$$

$$Discharge_{Battery_t} \geq 0 \ \forall t \in \{0,1, \dots, T\}$$

$$Charge_{Battery_t} \leq 0 \ \forall t \in \{0,1,\dots,T\}$$

$$Size_{Battery} \geq 0$$

$$P_{Battery} \geq 0$$

$$-\infty \ \leq Exchange_{Battery_t} \leq \infty \ \forall t \in \{0,1,\dots,T\}$$

$$\left|Exchange_{Battery_t}\right| \geq 0 \ \forall t \in \{0,1,\dots,T\}$$

$$aux_{Grid} \in \{0,1\} \ \forall t \in \{0,1,\dots,T\}$$

$$aux_{Battery} \in \{0,1\} \ \forall t \in \{0,1,\dots,T\}$$

$$-\infty \ \leq Exchange_{Grid_t} \leq \infty \ \forall t \in \{0,1,\dots,T\}$$

Now the relations between the variables:

$$Discharge_{Battery_t} + Charge_{Battery_t} = Exchange_{Battery_t} \ \forall t \in \{0,1,\dots,T\}$$

$$Exchange_{Battery_t} \geq Charge_{Battery_t} \cdot \left(1 - aux_{Battery_t}\right) \ \forall t \in \{0,1,\dots,T\}$$

$$Exchange_{Battery_t} \leq Charge_{Battery_t} \cdot aux_{Battery_t} \ \forall t \in \{0,1,\dots,T\}$$

$$aux_{battery_t} = 1 \rightarrow Charge_{Battery_t} = 0 \ \forall t \in \{0,1,\dots,T\}$$

$$aux_{battery_t} = 0 \rightarrow Discharge_{Battery_t} = 0 \ \forall t \in \{0,1,\dots,T\}$$

$$Energy_{Battery_t} \cdot 1{,}1 \leq Size_{Battery} \ \forall t \in \{1,\dots,T\}, t \neq 0$$

$$Size_{Battery} \geq E_0 \ if \ t = 0$$

$$\left|Exchange_{Battery_t}\right| \cdot 1{,}1 \leq P_{Battery} \forall t \in \{1,2,\dots,T\}, t \neq 0$$

$$P_{Battery} \geq P_0 \ if \ t = 0$$

$$Energy_{Battery_{t-1}} - \eta_c \cdot Charge_{Battery_t} \cdot \left(1 - aux_{Battery_t}\right) - \frac{1}{\eta_d} \cdot Discharge_{Battery_t} \cdot aux_{Battery_t} = Energy_{Battery_t} \ \forall t \in \{1,\dots,T\}, t \neq 0$$

$$Energy_0 - \eta_c \cdot Charge_{Battery_t} \cdot \left(1 - aux_{Battery_t}\right) - \frac{1}{\eta_d} \cdot Discharge_{Battery_t} \cdot aux_{Battery_t} = Energy_{Battery_t} \ if \ t = 0$$

$$-\frac{Size_{Battery} - Energy_{Battery_{t-1}}}{\eta_c} \leq Charge_{Battery_t} \ \forall t \in \{1,2,\dots,T\}, t \neq 0$$

$$-\frac{Size_{Battery} - Energy_0}{\eta_c} \leq Charge_{Battery_t} \ if \ t = 0$$

$$Energy_{Battery_{t-1}} \cdot \eta_d \geq Discharge_{Battery_t} \forall t \in \{1,2,\dots,T\}, t \neq 0$$

$$Discharge_{Battery_t} \leq Energy_0 \cdot \eta_d \ if \ t = 0$$

$$Grid_{INJ_t} + Grid_{W_t} = Exchange_{Grid_t} \ \forall t \in \{0,1,\dots,T\}$$

$$aux_{Grid_t} = 1 \rightarrow Grid_{W_t} = 0 \ \forall t \in \{0,1,\dots,T\}$$

$$aux_{Grid_t} = 0 \rightarrow Grid_{INJ_t} = 0 \ \forall t \in \{0,1,\dots,T\}$$

$$Exchange_{Grid_t} + Exchange_{Battery_t} + net_t = 0 \ \forall t \in \{0,1,\dots,T\}$$

$$Discharge_{Battery_t} \geq -Grid_{W_t} \ \forall t \in \{0,1,\dots,T\}$$

$$Charge_{Battery_t} \leq -Grid_{INJ_t} \ \forall t \in \{0,1,\dots,T\}$$

This optimization model gives the following results in the Table 15.

Table 15: Results in size and power of the battery for each EC

Municipality of the EC	Battery Size [kWh]	Battery Power [kW]
Adeje	18231,62	4810,01
Ajamil de Cameros	110,46	20,65
Alcalà de Xivert	144,04	36,01
Almócita	665,86	130,63
Amer	300,23	71,28
Balenyà	2265,62	446,81
Ballesteros de Calatrava	571,36	110,89
Bilbao	629,63	167,73
Calamocha	284,49	55,32
Campanet	193,11	50,95
Castelló de Farfanya	414,01	86,89
Castilfrío de la Sierra	103,50	19,13
Cellera de Ter, La	515,42	99,49
Consell	564,76	112,95
Faura	371,94	72,69
Ferreries	90,21	16,63
Larraul	102,83	19,89

Monachil	584,15	153,44
Rupià	85,30	21,33
Salines, Ses	232,20	59,87
Santa Engracia del Jubera	48,00	12,25
Santa Eugènia	284,81	55,02
Soto en Cameros	53,65	9,60
Teguise	871,25	221,99
Urroz-Villa	238,14	41,53
València	449,02	87,36
Vall d'en Bas, La	66,95	17,11
Viladamat	87,74	22,14
Vilafant	343,76	64,55
Vilanant	89,51	22,43
Zaragoza	308,80	77,20
Zierbena	7295,39	1823,85
Zumarraga	837,26	226,95

5.2.3 Changes to optimise the market buying and selling optimization

The new code modifies the original optimization script to include fixed parameters for battery size ($Size_{Battery}$) and battery power ($P_{Battery}$). This approach changes the focus from optimizing these parameters to optimizing the energy profile of the battery given fixed size and power constraints.

Key Changes and Their Impact

Function Renaming:

The function StorageSizeOptimizer has been renamed to StorageProfileOptimizer to reflect the new focus on optimizing the energy profile rather than the battery size and power.

Additional Parameters:

Two new parameters, Tamaño_Bateria and P_Bateria, are added to the StorageProfileOptimizer function to fix the battery size and power during optimization.

Modified Constraints:

The constraints for battery size and power are updated to use the fixed parameters $Size_{Battery}$ and $P_{Battery}$ instead of optimizing these values within the model.

Objective Function Adjustment:

The objective function now focuses solely on minimizing the energy costs, without including the cost of the battery size and power.

$$\min \sum_{t=0}^{n}\left(PVPC(t)\cdot Grid_{INJ}(t)+DAP(t)\cdot Grid_{ADS}(t)\right)$$

Initialization and Iteration Adjustments:

The main script is adjusted to pass the fixed battery size (TB) and power (PB) parameters to the optimization function.

Parameter Updates in the Loop:

The loop that iterates through the simulation window updates the initialization parameters and calls the StorageProfileOptimizer with the fixed battery size and power.

Output Management:

The output management part of the script remains largely unchanged, but the results now reflect the optimization given fixed battery size and power constraints.

By incorporating these changes, the new code focuses on optimizing the energy profile for fixed battery parameters, providing insights into how the EC can best manage its energy resources given the constraints of its existing battery system.

5.2.4 Analysis of the results

Variation in Battery Size and Power:

Battery Size:

- The battery sizes vary significantly across the ECs, ranging from as small as 48 kW (Santa Engracia del Jubera) to as large as 18,231.62 kW (Adeje Verde).

- Similarly, battery power also varies widely, from 9.60 kW (Treguajantes) to 4,810.01 kW (Adeje Verde).

Battery Power:

- The power of the batteries also shows significant variation, reflecting the diverse needs and capacities of the EC.

Correlation between Installed Power and Battery Size:

Installed Power Capacity:

- There is a noticeable correlation between the installed power capacity and the battery size. ECs with higher installed power capacities tend to have larger battery sizes.

- For instance, Adeje Verde, with an installed power capacity of 3000 kW, has the largest battery size (18,231.62 kW). Conversely, ECs with lower installed capacities, such as Iniciativa municipal de Rupiá (22 kW), have relatively smaller battery sizes (85.30 kW).

Optimization Results Interpretation:

First Model:

The first model's objective is to optimize both battery size and power, resulting in varied battery capacities tailored to each EC's needs and potential constraints.

This optimization approach considers each community's unique energy profiles and seeks to balance energy storage with consumption demands.

Second Model:

The second model, which fixes the battery size and power parameters, focuses on optimizing the energy profile within these fixed constraints. This approach might result in different energy management strategies but keeps battery size and power constant.

Economic and Technical Feasibility:

Larger Battery Sizes:

Larger battery sizes and power capacities, as seen in ECs like Adeje Verde and TEK ZIERBENA, suggest a more significant investment in energy storage infrastructure. These ECs likely aim to maximize self-consumption and energy independence.

The larger investment in storage infrastructure indicates a commitment to long-term sustainability and energy autonomy.

Smaller ECs:

Smaller ECs, such as those in La Rioja and Girona, with more modest battery sizes and power capacities, might be focusing on cost-effective solutions that balance investment and return on energy savings.

These ECs might prioritize immediate financial viability and incremental improvements in their energy systems.

Findings from the Second Model and Market Analysis:

Market Participation Capacity:

The second model and market analysis focus on the quantitative analysis of market participation capacity of the ECs in various Spanish electricity markets, including Day-ahead, Intraday auction, Intraday continuous, and DSO Congestion Management (Local).

Minimum Bid Size for Independent Participation:

- Market Daily:

The minimum bid size limits the participation capacity of ECs in the market, allowing only a few ECs to participate independently. For example, only Adeje can participate alone in the Day-ahead market with 1318 hours of participation.

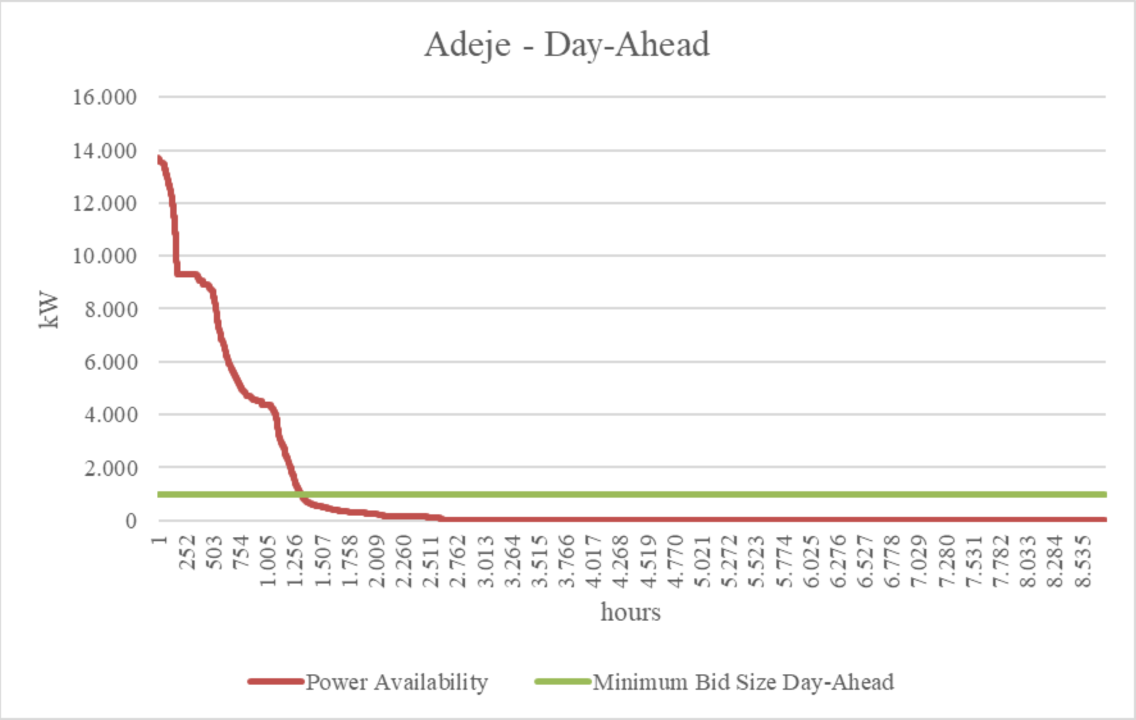


Figure 35: Adeje EC power availability fot he day-ahead market.

The aggregated participation of the ECs allows for 2,444 hours (28% of the year) of market participation per year, surpassing the independent participation hours of Adeje.

- Intraday Auction and Continuous Markets:
  - Upward Market Participation:

The minimum bid size allows for only 9 of the 33 ECs to participate independently. Adeje can participate for 2,603 hours (30% of the year).

Aggregated participation of the ECs allows for 5,717 hours (65% of the year) of market participation per year, surpassing the independent participation hours.

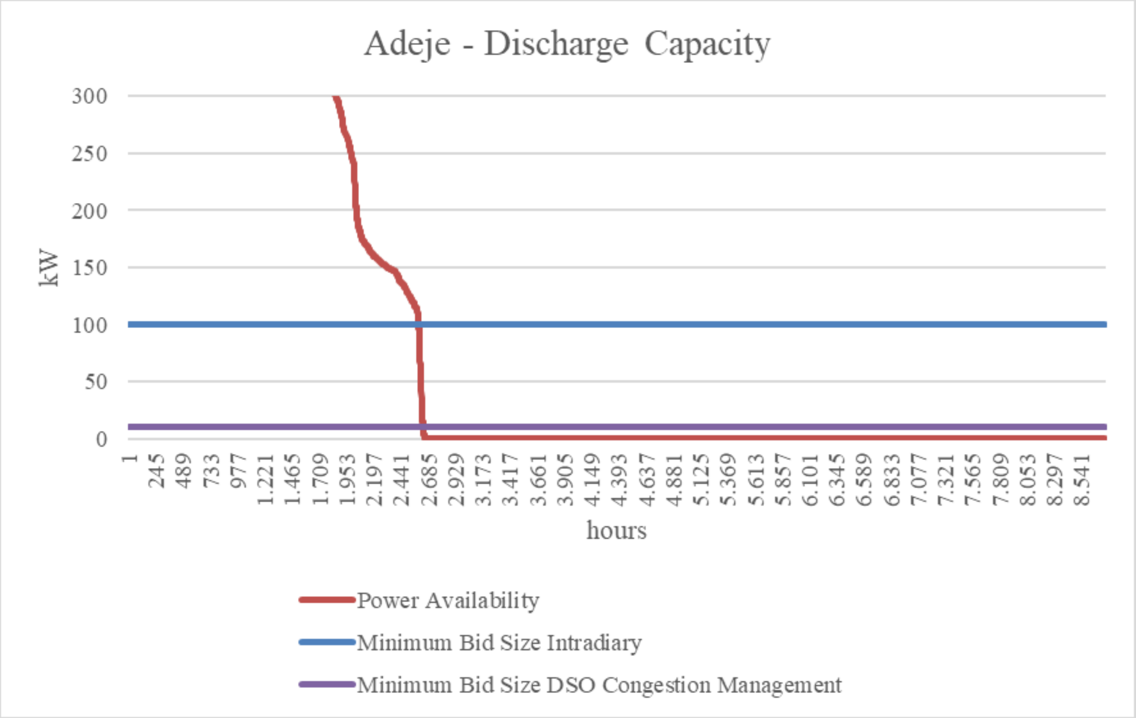


Figure 36: Adeje EC power availability for the upward market participation in the intraday market.

- Downward Market Participation:

The minimum bid size allows for only 9 of the 33 ECs to participate independently. Adeje can participate for 5,020 hours (57% of the year).

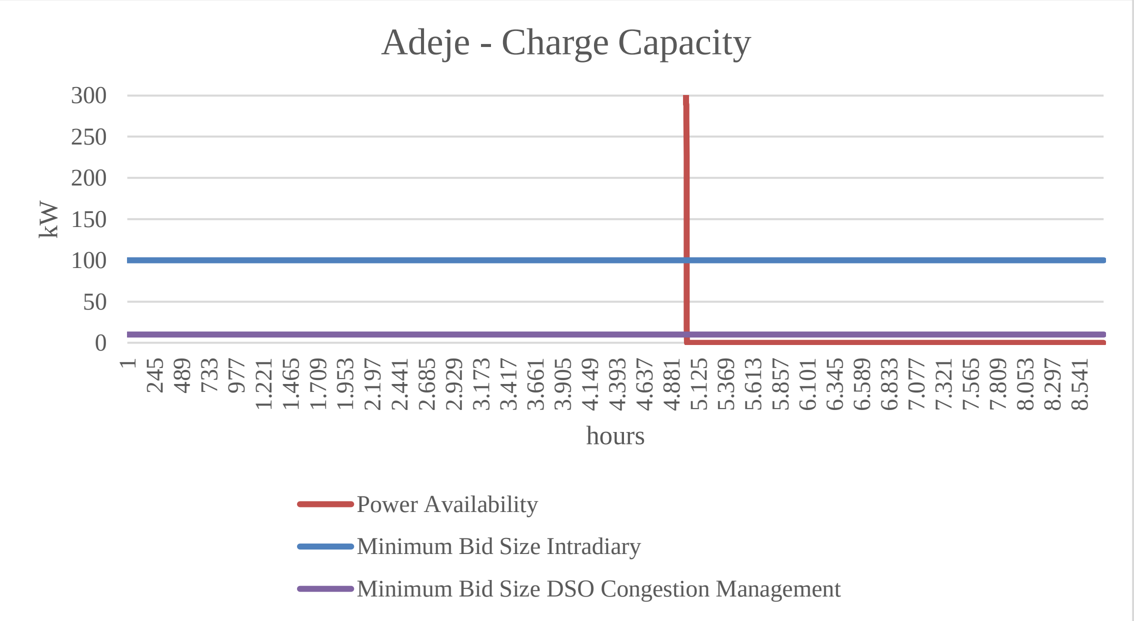


Figure 37: Adeje EC power availability for the downward market participation in the intraday market.

Aggregated participation of the ECs allows for 6,164 hours (70% of the year) of market participation per year.

- DSO Congestion Management:

- Upward Market Participation:

The minimum bid size does not limit the participation capacity of ECs in the market, allowing 31 out of the 33 ECs to participate independently. Zumárraga can participate for 4,172 hours.

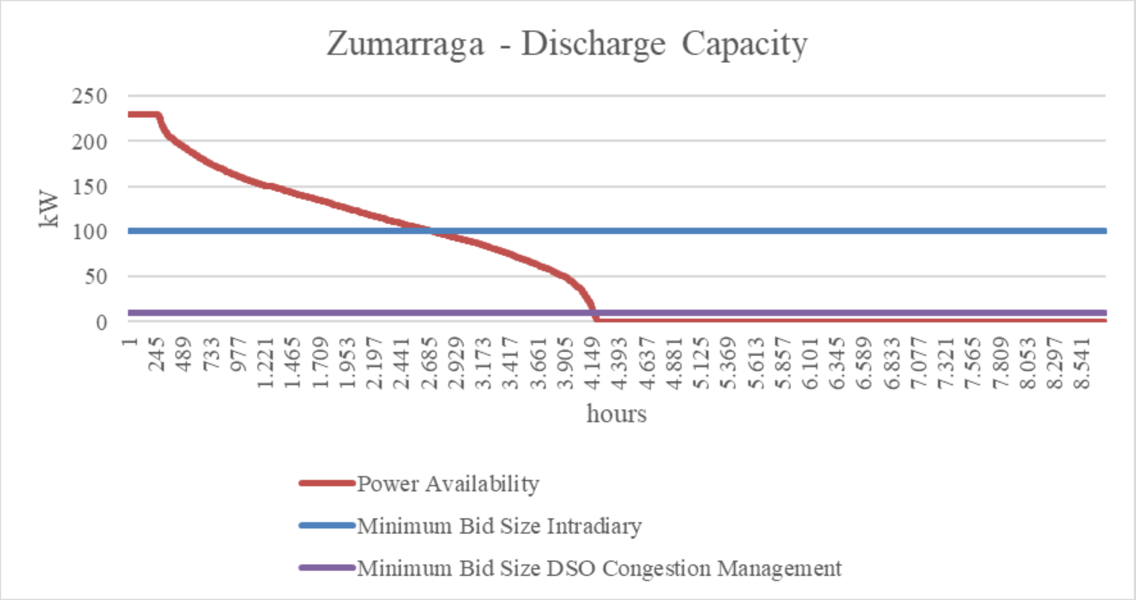


Figure 38: Zumarraga EC power availability for the upward market participation in the DSO congestion management.

Aggregated participation of the ECs allows for 5,874 hours (67% of the year) of market participation per year, surpassing the independent participation hours.

- Downward Market Participation:

The minimum bid size does not limit the participation capacity of ECs in the market, allowing 31 out of the 33 ECs to participate independently. Adeje can participate for 5,021 hours (57% of the year).

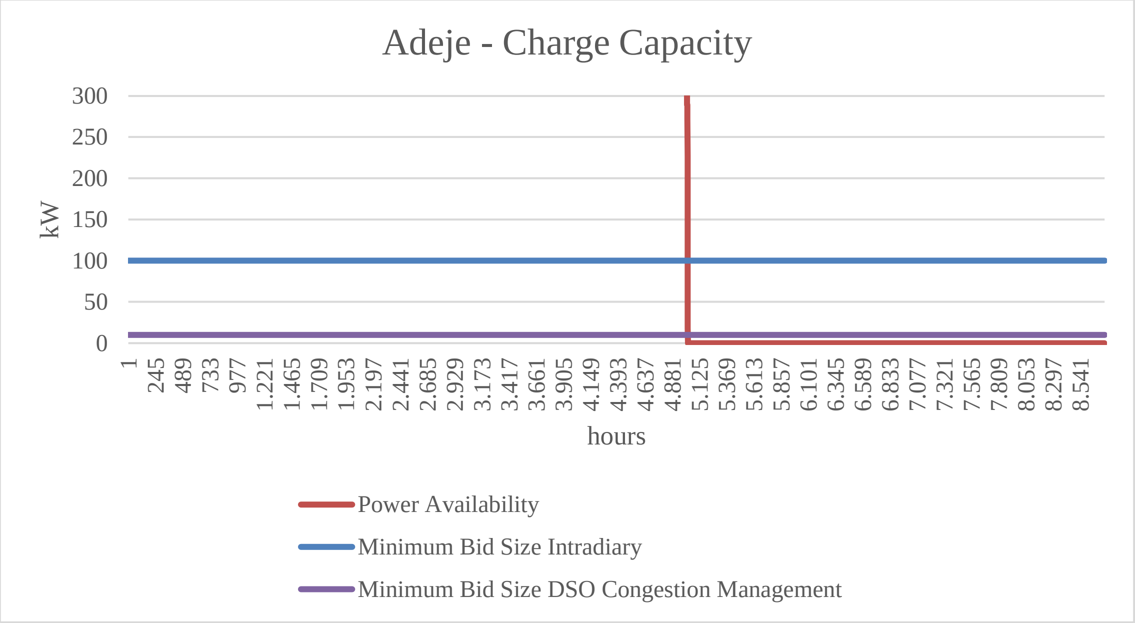


Figure 39: Adeje EC power availability for the downward market participation in the DSO congestion management.

Aggregated participation of the ECs allows for 6,753 hours (77% of the year) of market participation per year, surpassing the independent participation hours.

Key Findings:

The inability to aggregate generation and consumption in a single bid is a significant restriction for ECs that are prosumers.

The minimum bid size requirement limits the number of ECs participating independently in various markets.

Recommendations:

- Implement Aggregation Strategies:

Develop and implement aggregation strategies to meet market participation thresholds, enabling more ECs to participate effectively.

- End the Restriction on Aggregation:

Remove the restriction on the aggregation of generation and consumption to allow for more flexible and inclusive participation of ECs in the energy markets.

By addressing these key findings and implementing the recommended strategies, EC can enhance their market participation, optimize their energy management, and contribute more effectively to the overall energy system.

6. Conclusions

6.1 Main conclusions

This research has thoroughly explored the optimization of battery storage systems and their market participation within Spanish EC. Several key insights and recommendations have emerged through a combination of survey analysis, market characterization, and the development of optimization models.

Survey Analysis: The survey results highlighted the diverse nature of ECs in Spain, revealing variations in their size, resource sharing practices, and technological adoption. Most ECs are relatively small, with fewer than 100 participants, indicating a grassroots approach to energy management. The predominant activities within these communities include collective photovoltaic self-consumption and advisory services, emphasizing a strong focus on solar energy and community education.

Qualitative Analysis: The detailed market analysis underscored the importance of aggregation strategies for smaller ECs to participate effectively in the Spanish electricity markets. Key barriers identified include minimum bid sizes, aggregating generation and consumption restrictions, and technological requirements. Addressing these barriers through policy changes and market reforms is crucial for enabling broader participation of ECs in various market segments, such as the Day-ahead market, Intraday auction, Intraday continuous market, and DSO Congestion Management. Additionally, even if regulation allows aggregation, communities must invest in automation to meet the technical requirements of the products necessary for SOs to operate effectively.

Quantitative Analysis of Market Participation: The development of two optimization models provided actionable insights into the market participation potential of battery storage systems within ECs. The first model, which focuses on optimizing battery size and power, highlighted the significant variations in storage needs across different communities. By tailoring battery capacities to the specific requirements of each EC, the model demonstrated potential improvements in energy management cost-effectiveness.

The second model, which optimizes energy profiles within fixed battery parameters, emphasized the importance of advanced charge and discharge logics and better alignment with market participation opportunities.

6.2 Recommendations

Based on the findings, several key recommendations have been proposed:

- Implement aggregation strategies to enable smaller ECs to meet market participation thresholds where technically possible.
- Revise minimum bid size requirements and remove restrictions on the aggregation of generation and consumption where technically possible.
- Offer financial guarantees for installing renewable energy systems and battery storage solutions that allow EC to participate with a bigger market bid.

- Provide technical support programs to facilitate the adoption of advanced grid integration technologies and smart energy management systems within ECs, helping them scale their operations more efficiently.
- Encourage future research to validate business models through power system simulations, explore advanced energy management techniques, and assess the impact of external competitors on aggregator revenues.

6.3 Future Research

Investigate Business Dynamics of Flexibility Aggregators:

Future research should delve deeper into the business dynamics of flexibility aggregators, particularly in different countries with varied market regulations and prices. This helps to gather more nuanced knowledge of their business dynamics under different market settings and improve the understanding of market size effects.

Cross-Validation with Power System Simulations:

Cross-validation of the business models with power system simulations can enhance understanding how these models impact the grid. This approach helps in refining the models and ensuring their practical applicability.

Explore Advanced Charge and Discharge Degradation:

Updating the optimization models to include advanced charge and discharge strategies for storage systems can improve their efficiency and effectiveness. This research can focus on developing more sophisticated algorithms to enhance energy management strategies.

Expand Battery Swarm Business Models:

Expanding the battery swarm business models to include other flexibility sources on the demand side, such as electric heating, heat pumps, and electric vehicles, can provide a more comprehensive understanding of the resulting business dynamics and their impact on the energy market.

Analyze the Impact of External Competitors:

Investigating the effects of external competitors on the revenues of flexibility aggregators can provide valuable insights into market dynamics. This research can help develop strategies to mitigate competition and enhance market positioning.

7. Annexes

7.1 Participation capacity of each EC in each market of study

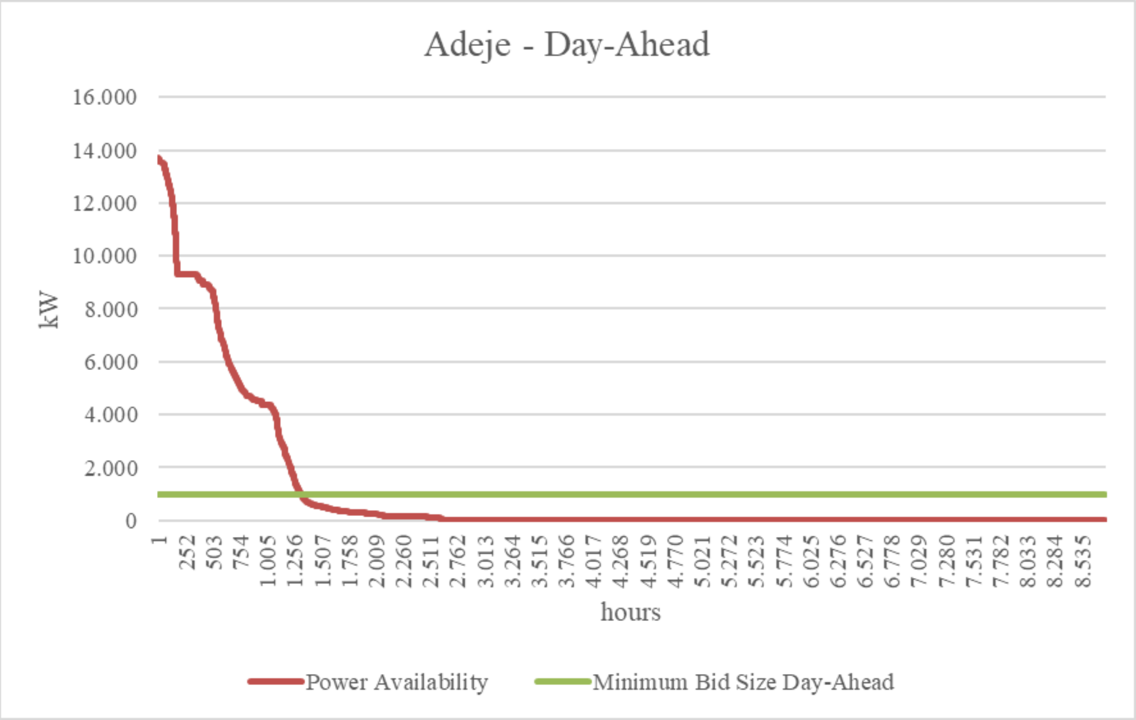


Figure 40: Adeje Day-Ahead participation capacity.

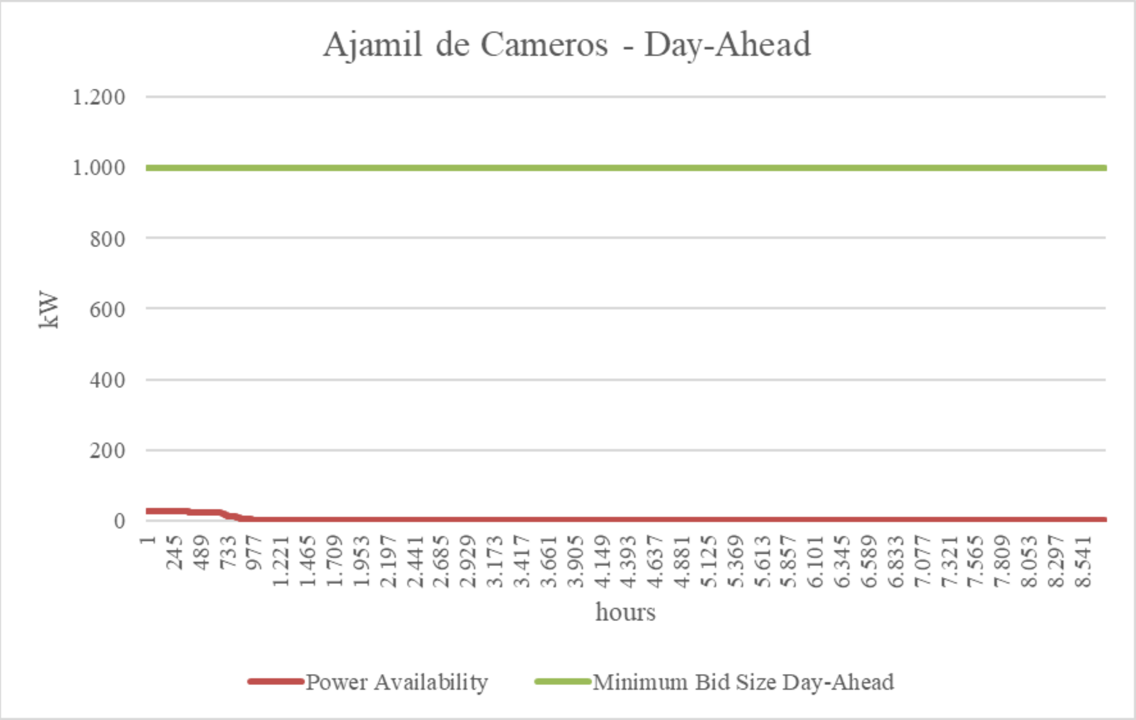


Figure 41: Ajamil de Cameros Day-Ahead participation capacity.

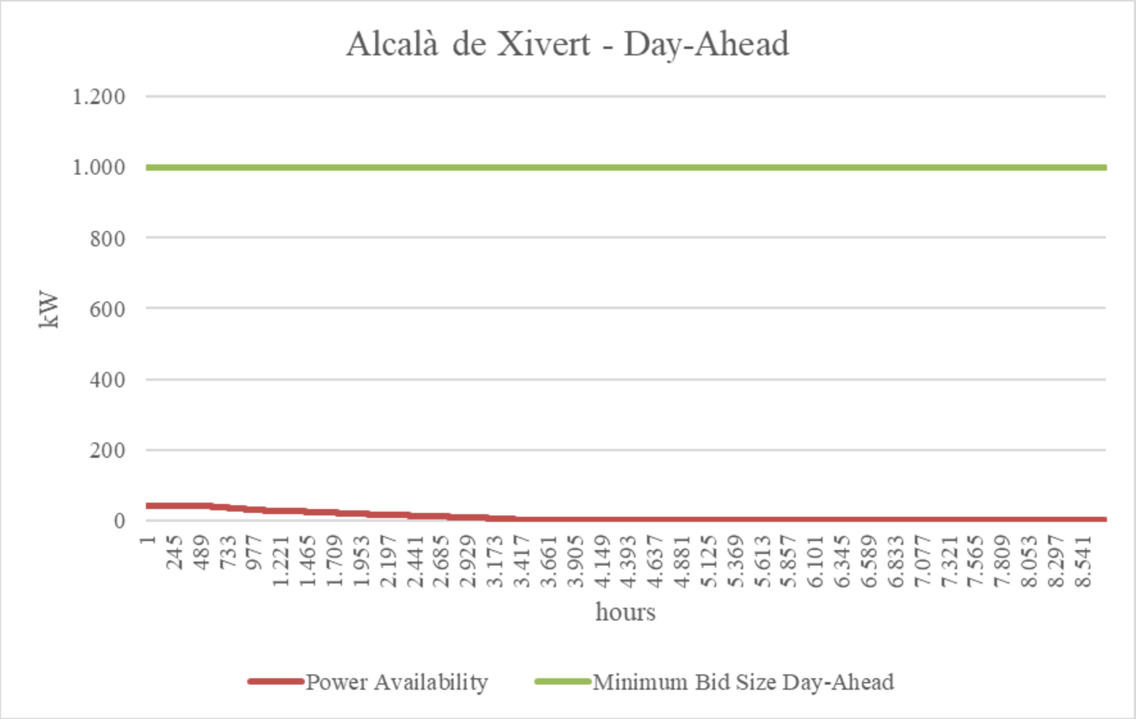


Figure 42: Alcalà de Xivert Day-Ahead participation capacity.

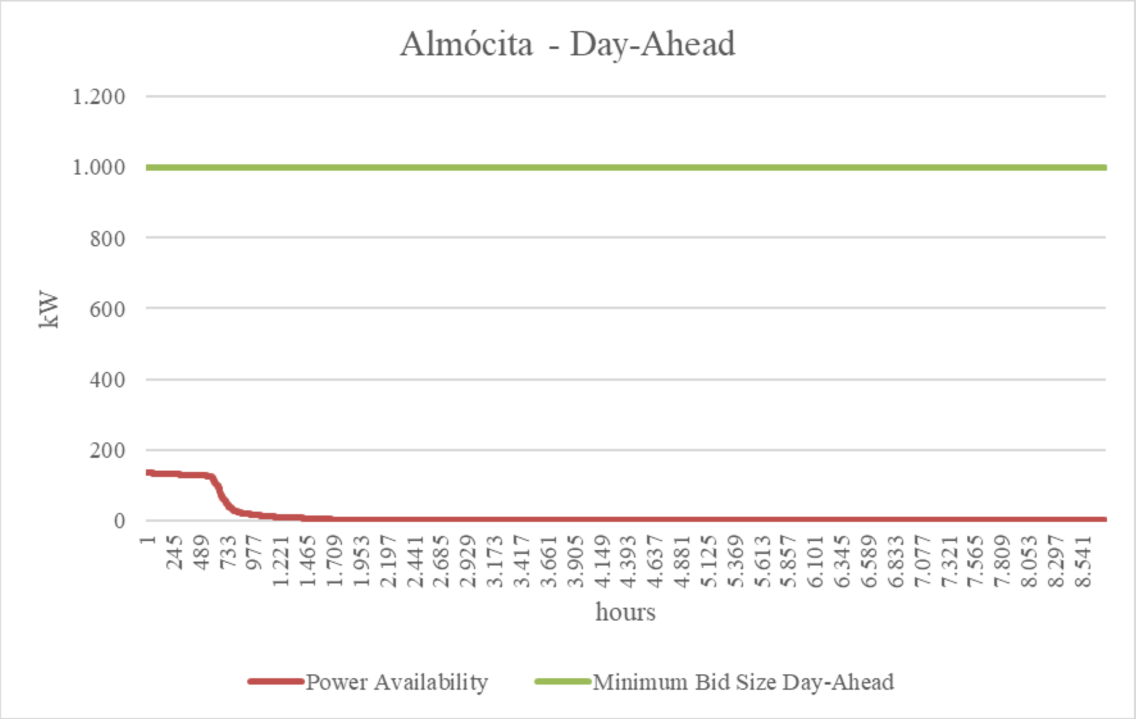


Figure 43: Almócita Day-Ahead participation capacity.

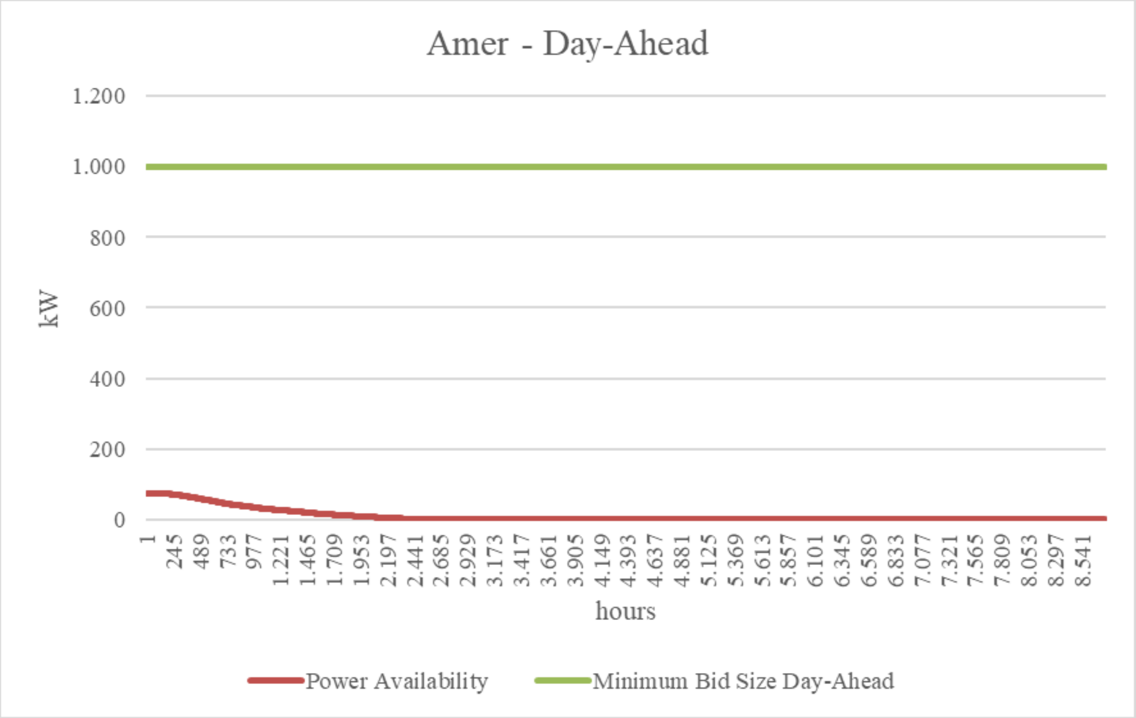


Figure 44: Amer Day-Ahead participation capacity.

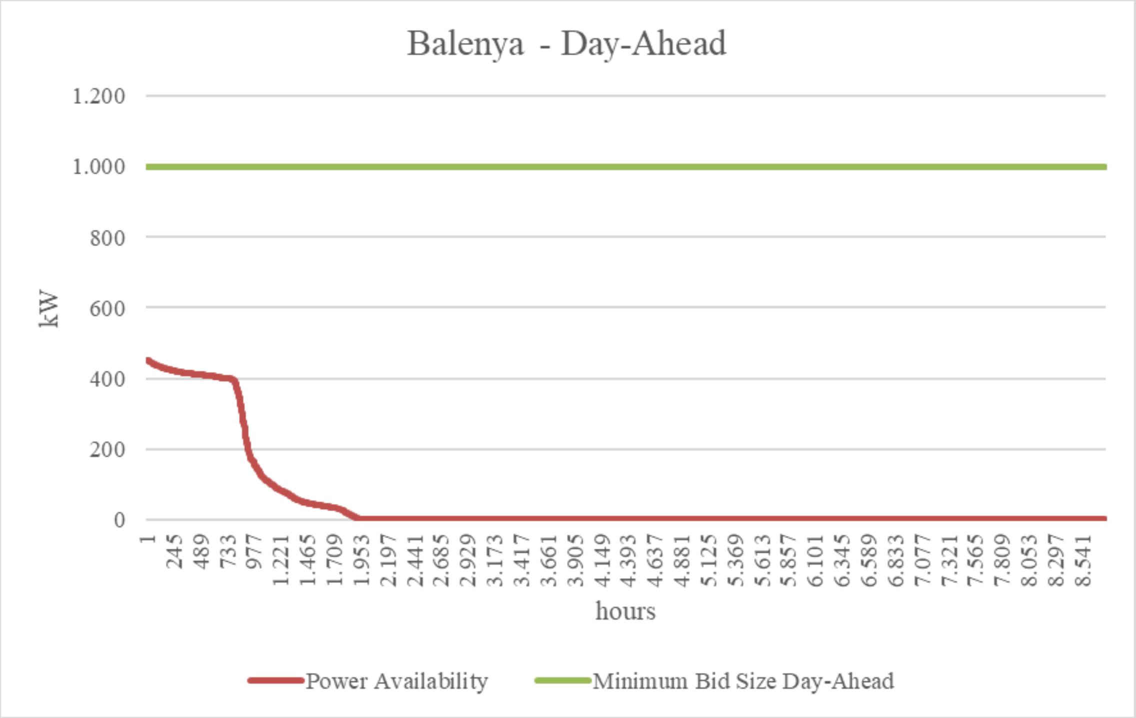


Figure 45: Balenya Day-Ahead participation capacity.

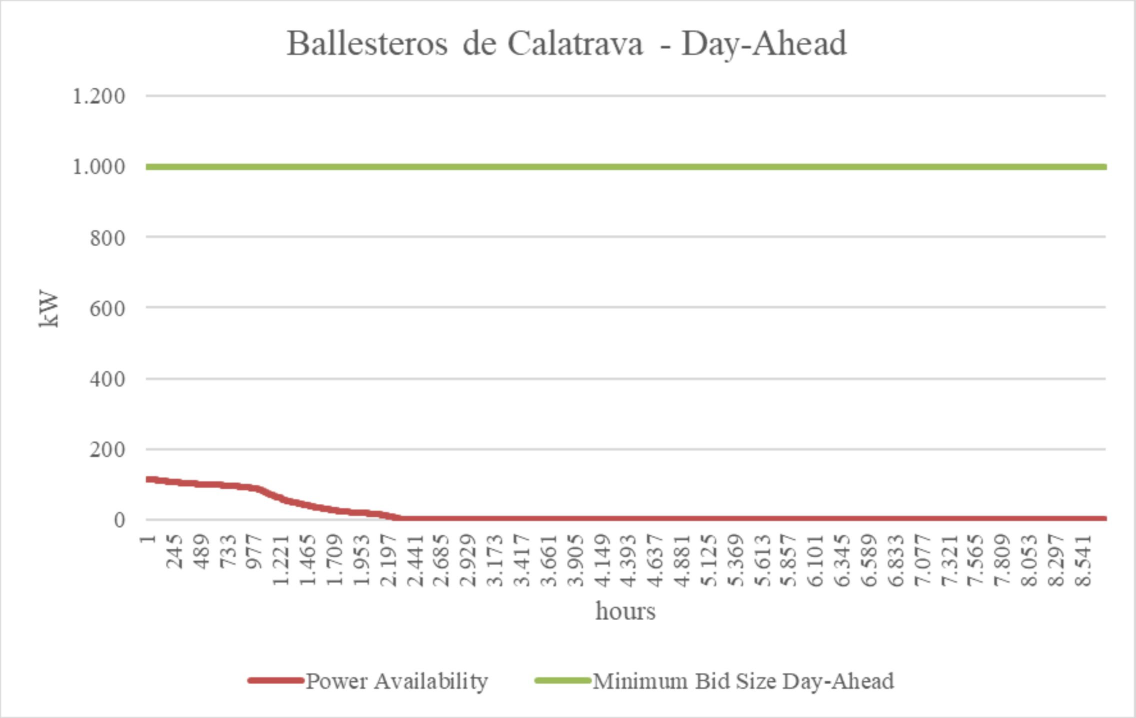


Figure 46: Ballesteros de Calatrava Day-Ahead participation capacity.

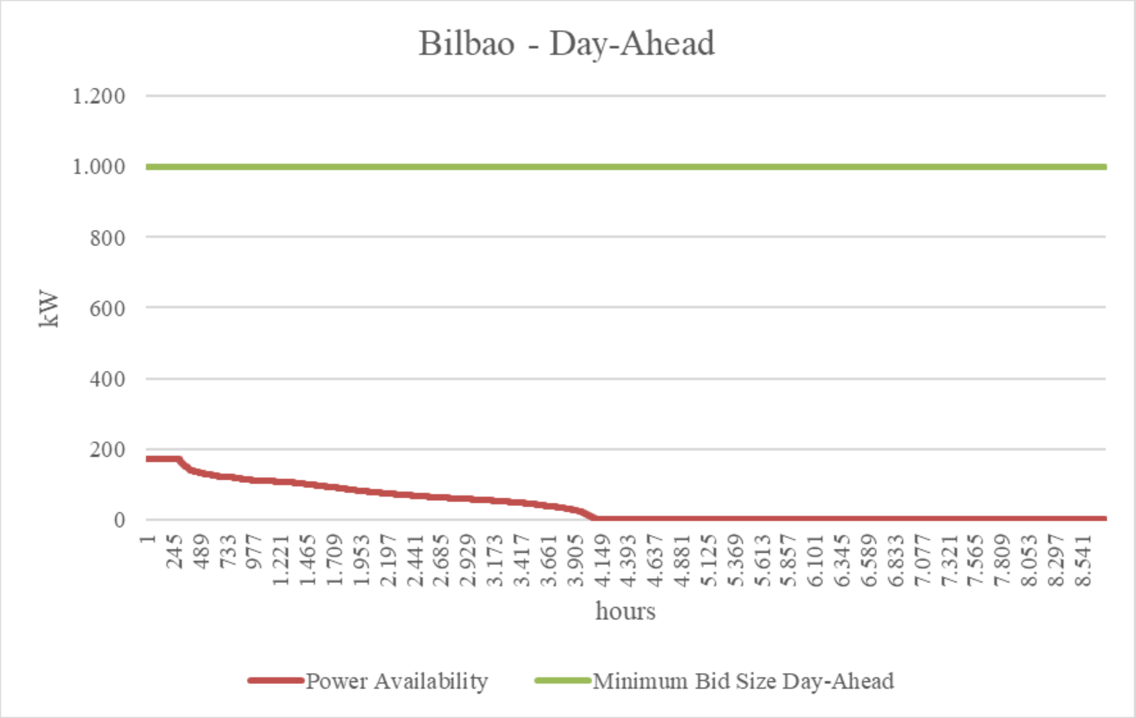


Figure 47: Bilbao Day-Ahead participation capacity.

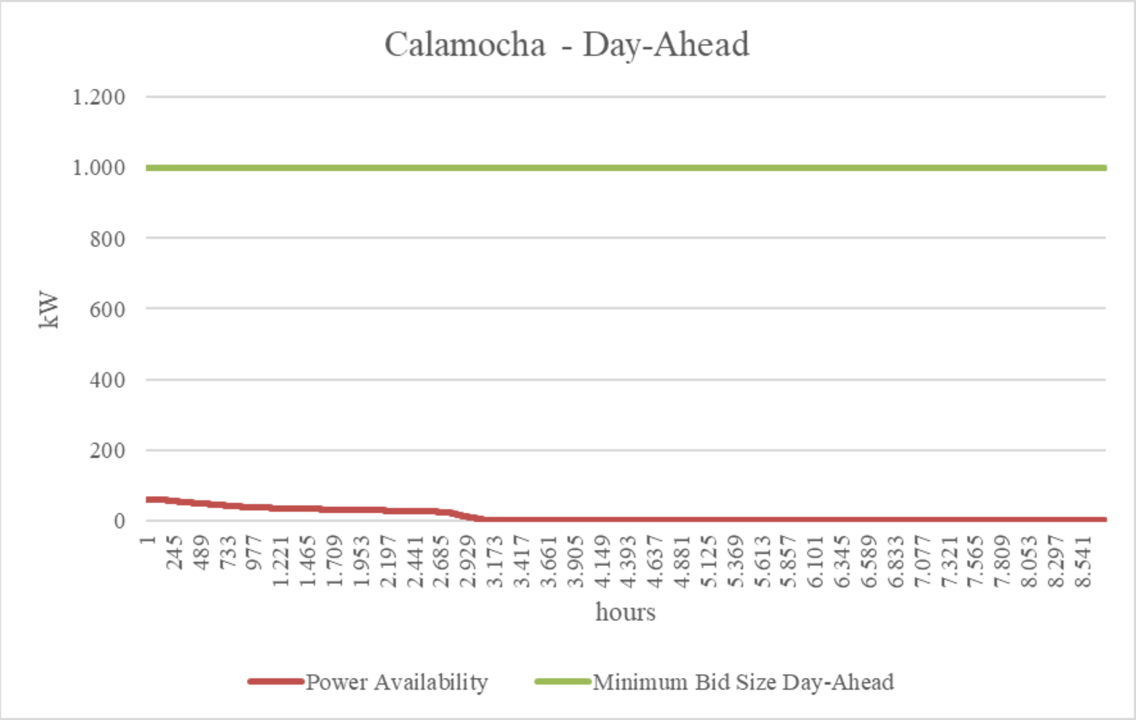


Figure 48: Calamocha Day-Ahead participation capacity.

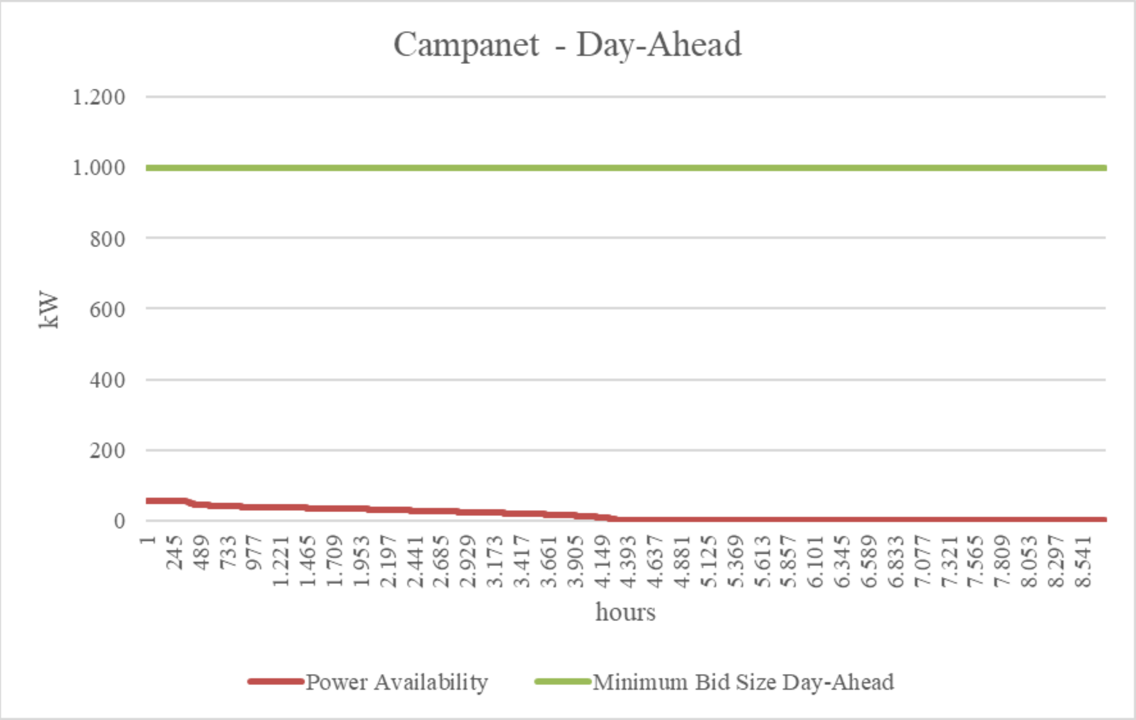


Figure 49:Camapanet Day-Ahead participation capacity.

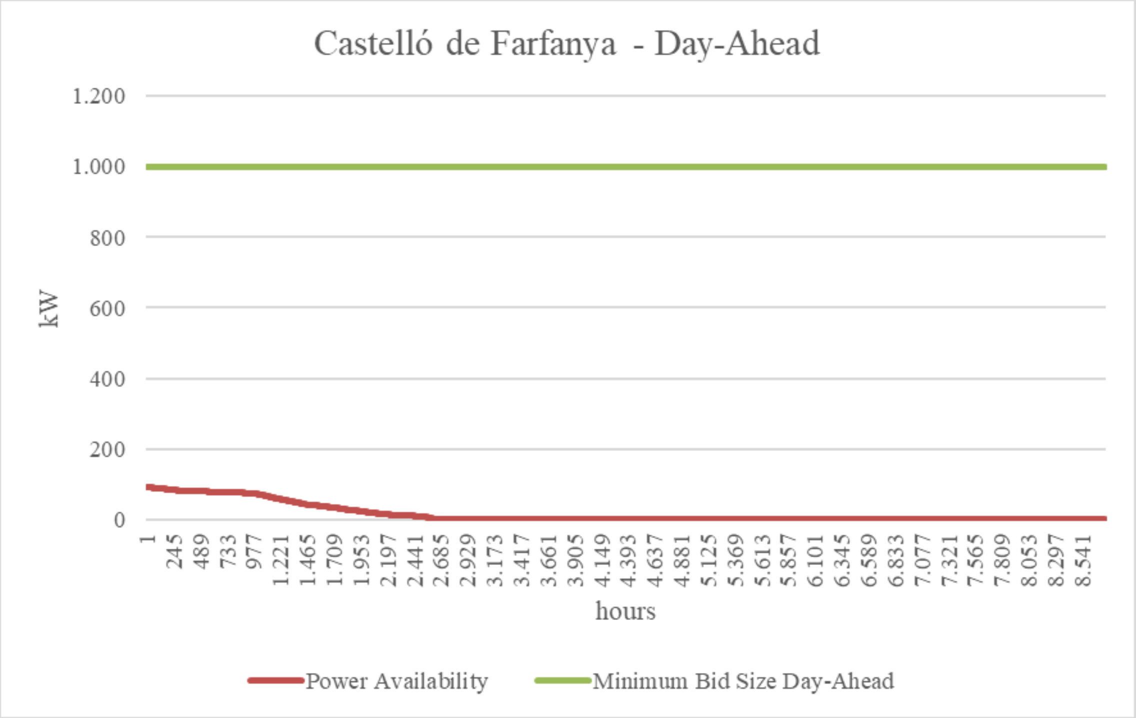


Figure 50: Castelló de Farfanya Day-Ahead participation capacity.

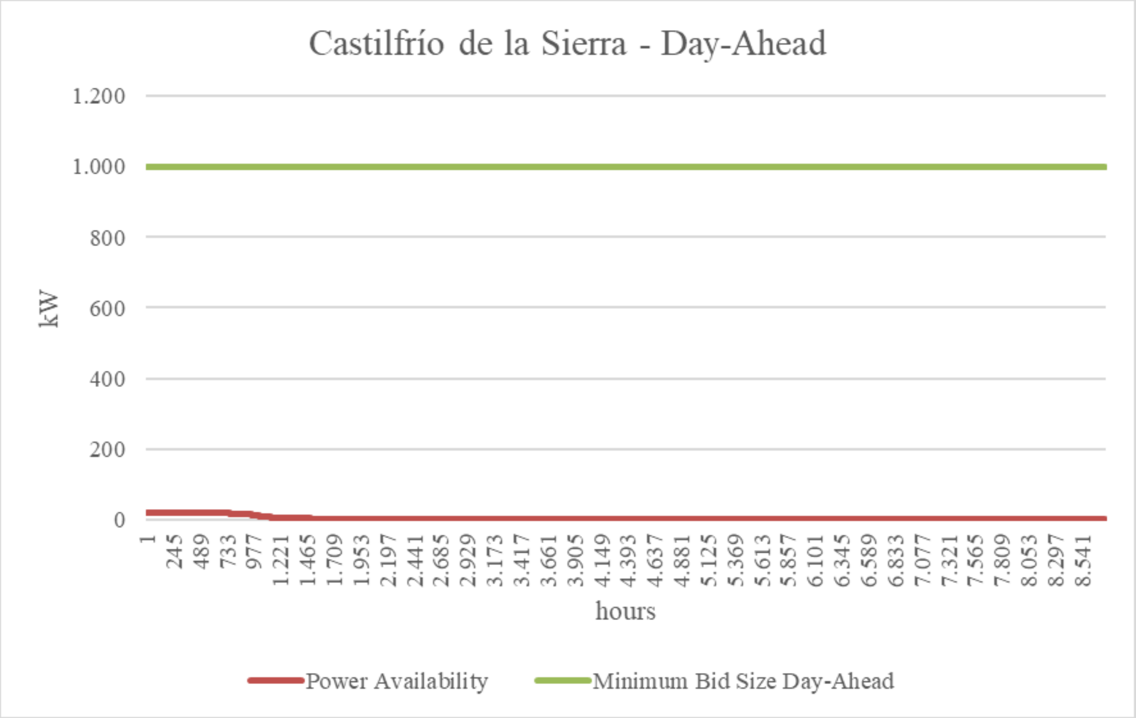


Figure 51; Castilfrío de la Sierra Day-Ahead participation capacity.

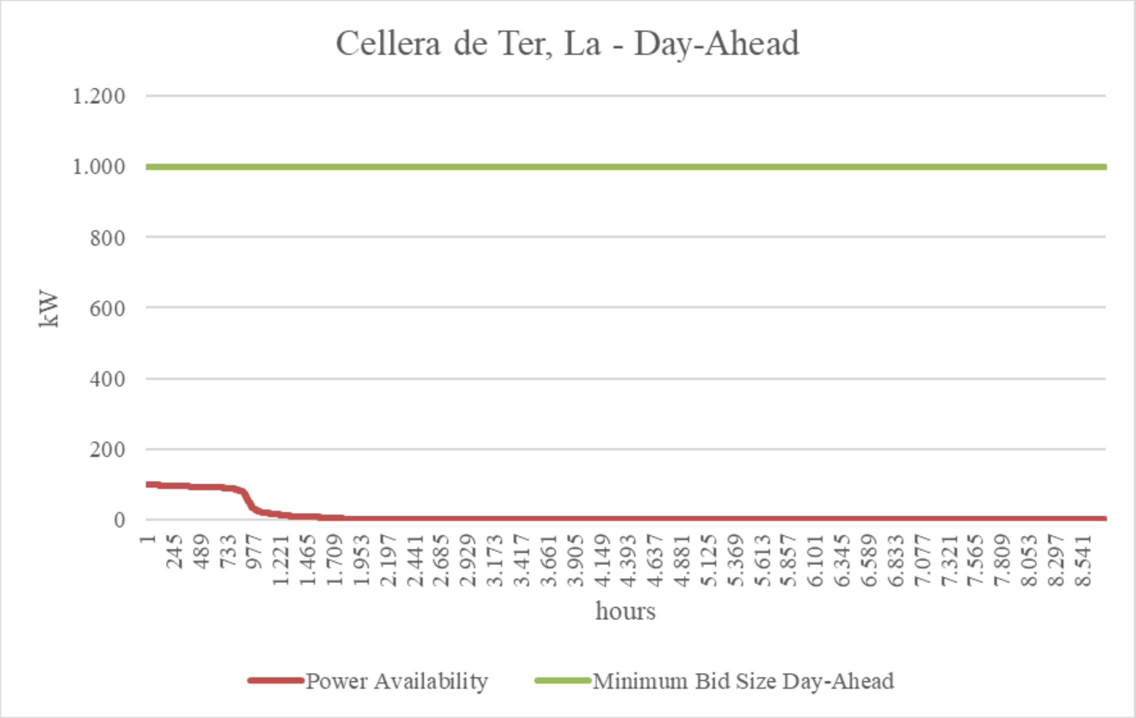


Figure 52: Cellera de Ter, La Day-Ahead participation capacity.

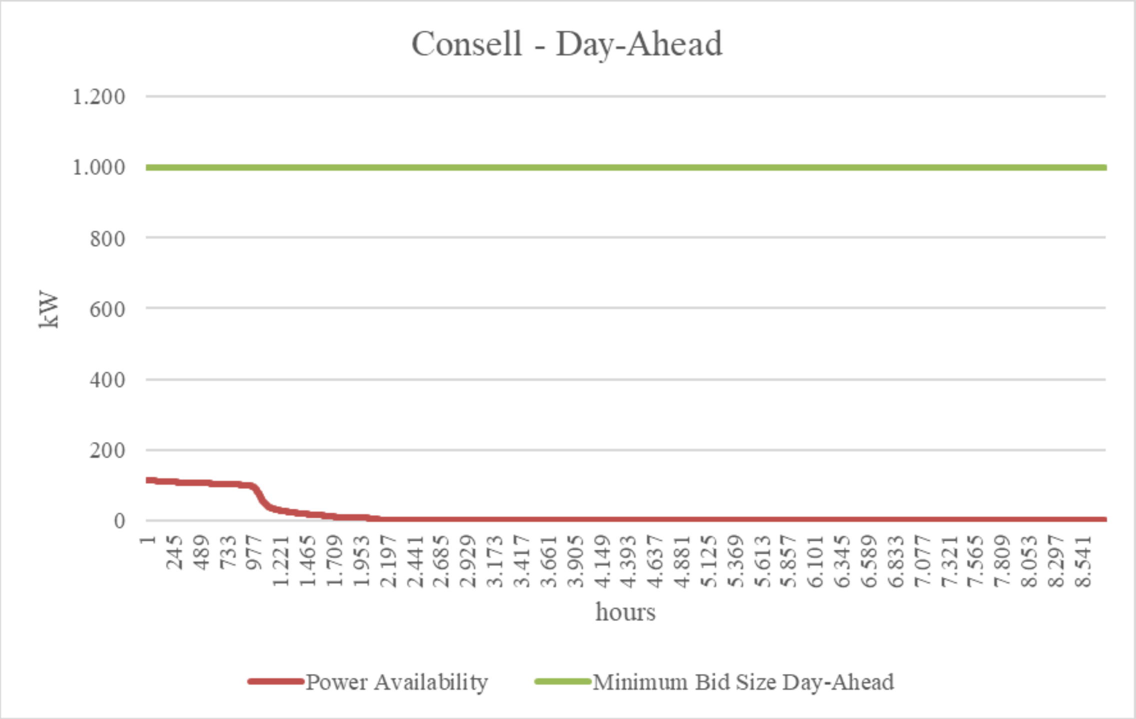


Figure 53: Consell Day-Ahead participation capacity.

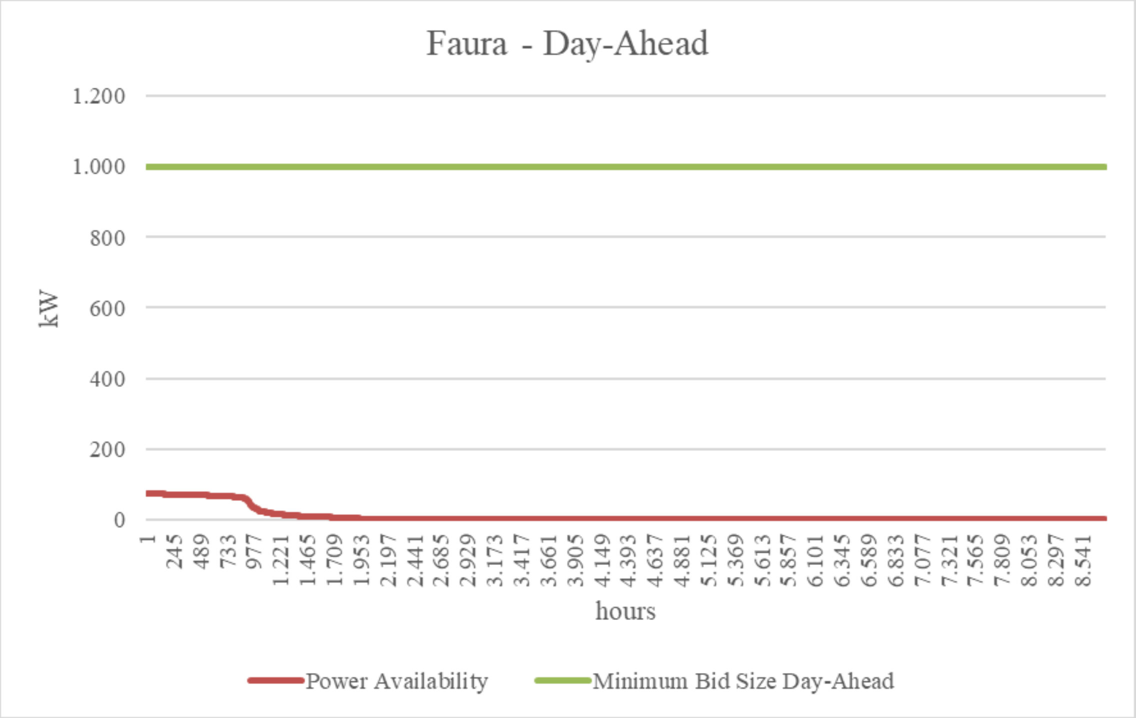


Figure 54: Faura Day-Ahead participation capacity.

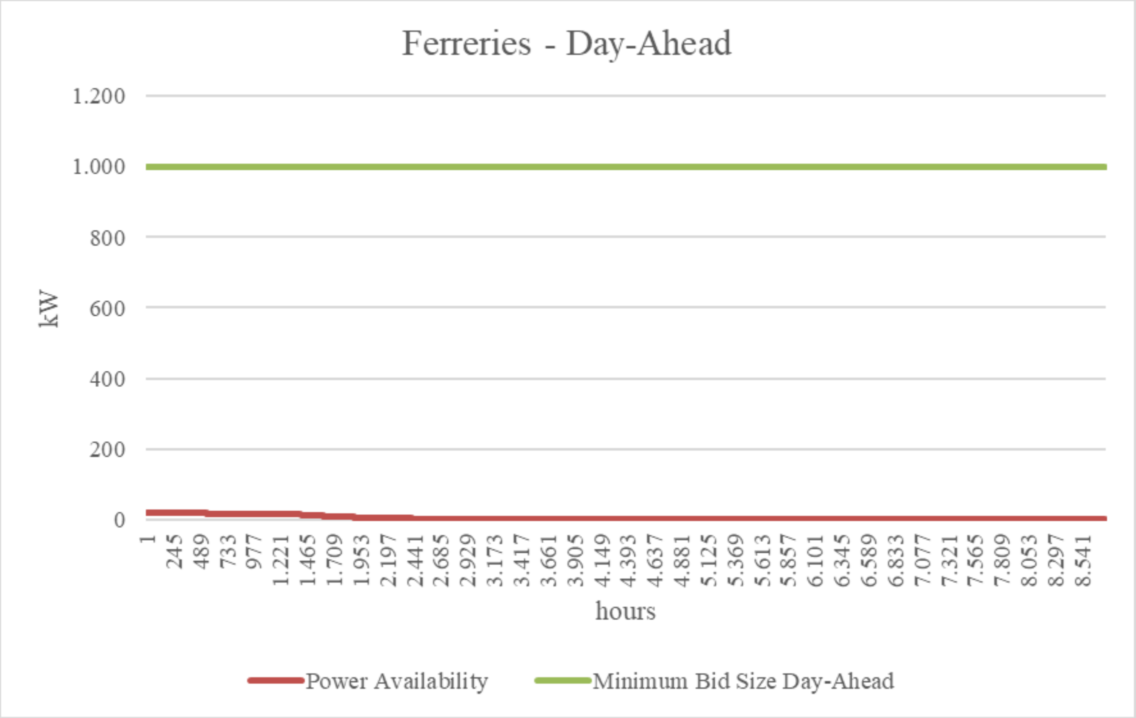


Figure 55: Ferreries Day-Ahead participation capacity.

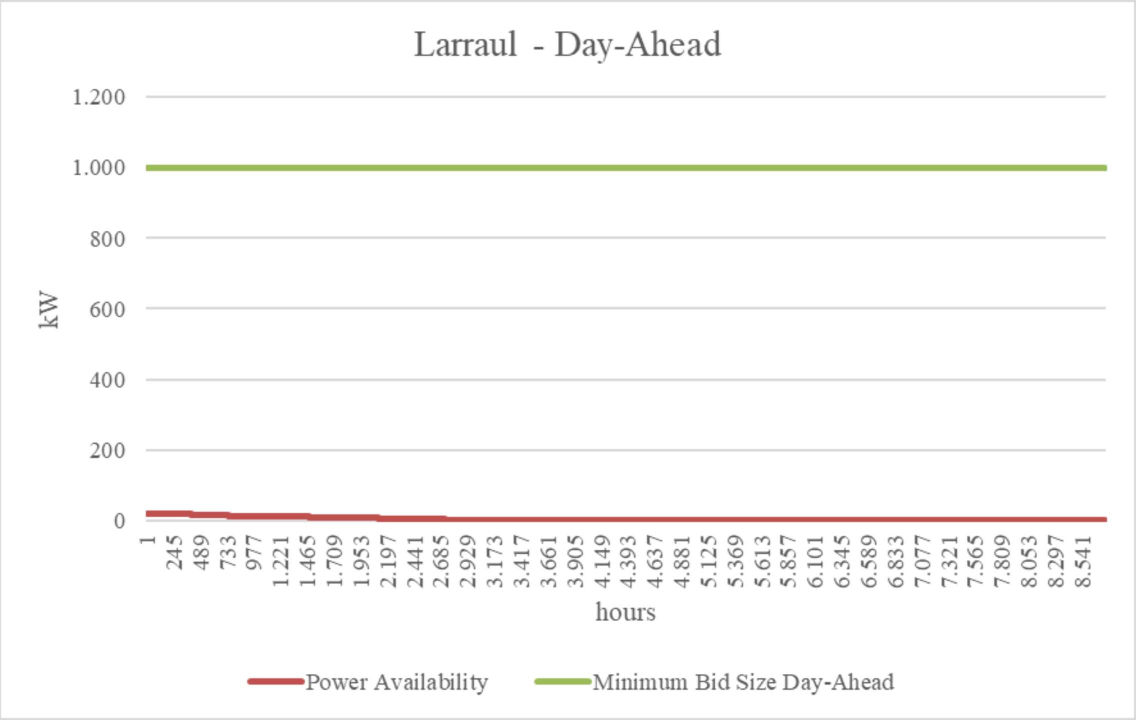


Figure 56: Larraul Day-Ahead participation capacity.

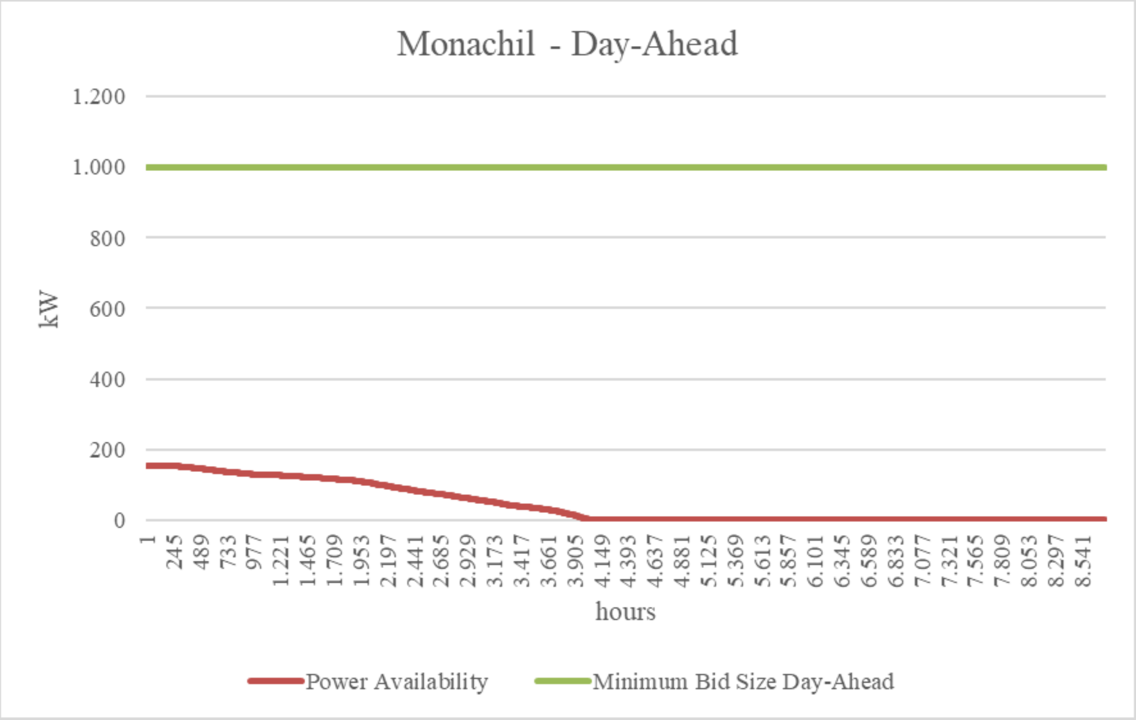


Figure 57: Monachil Day-Ahead participation capacity.

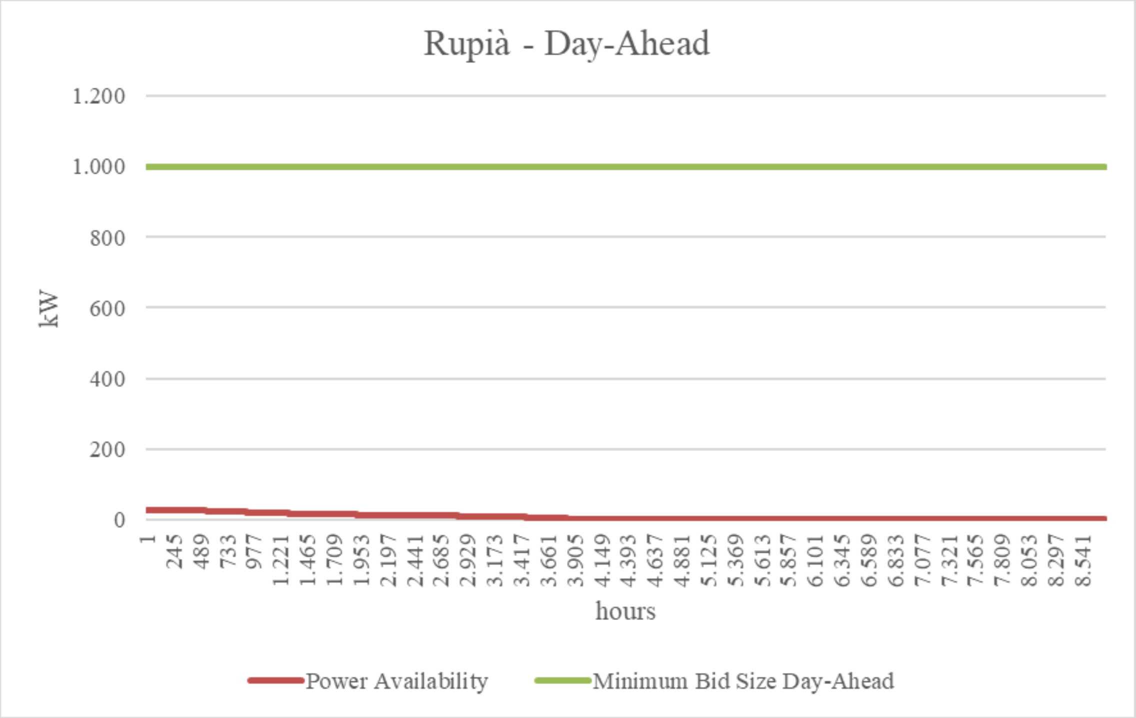


Figure 58: Rupià Day-Ahead participation capacity.

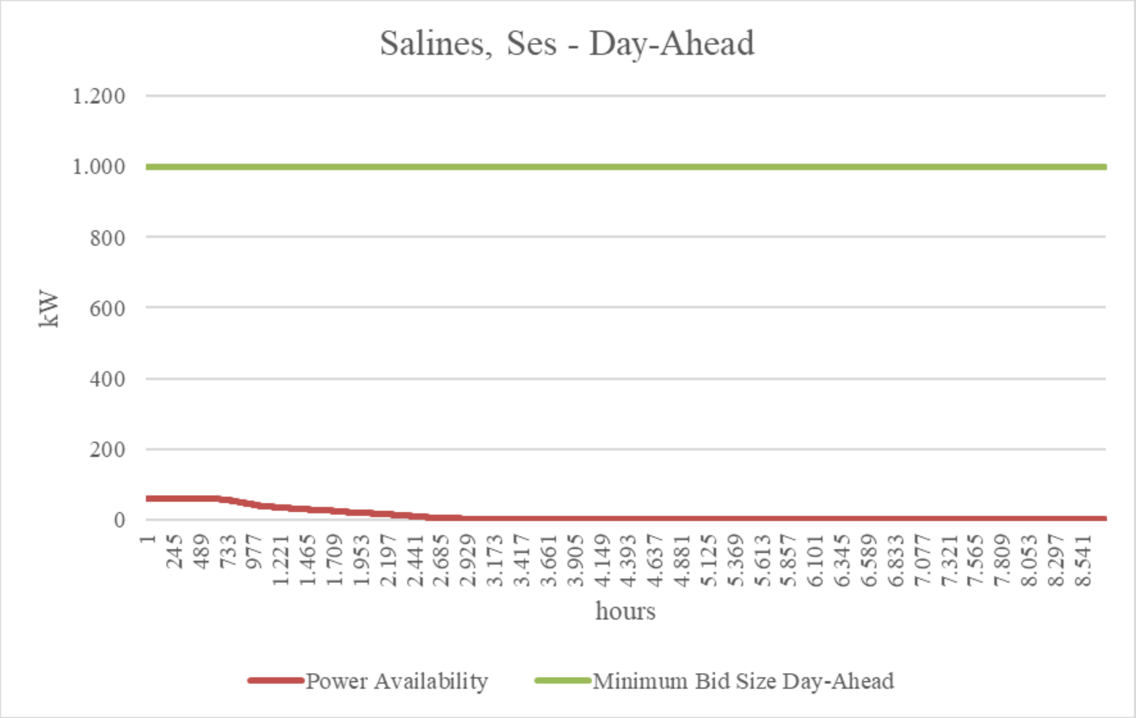


Figure 59: Salines, Ses Day-Ahead participation capacity.

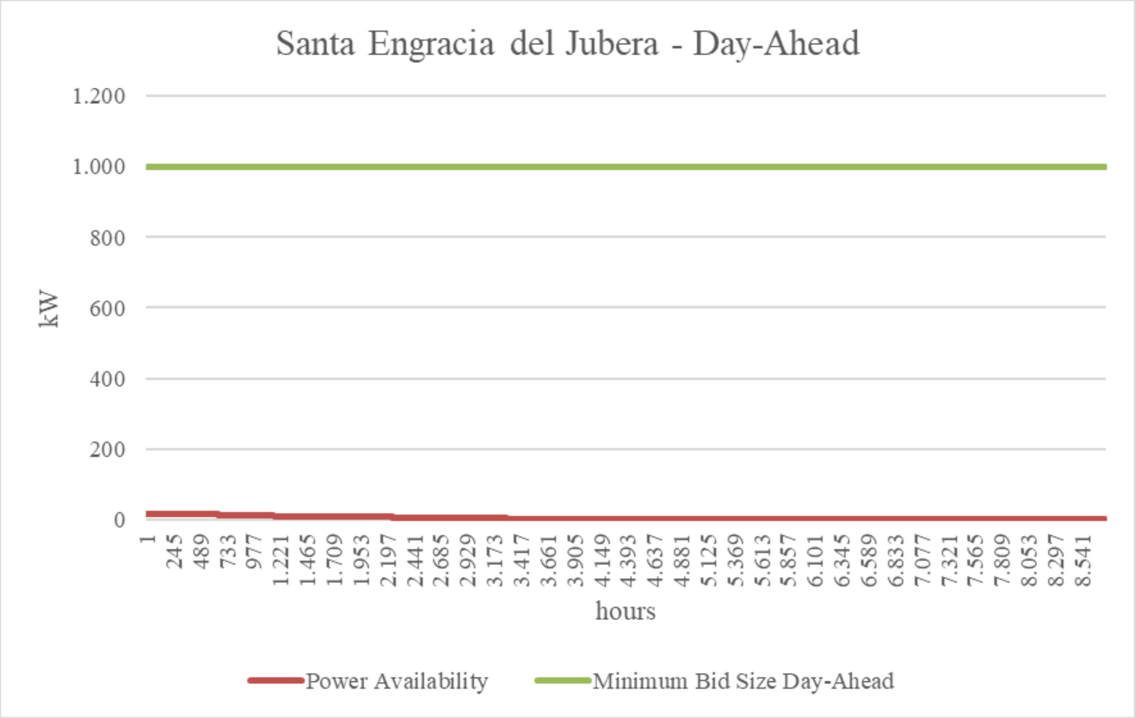


Figure 60: Santa Engrancia del Jubera Day-Ahead participation capacity.

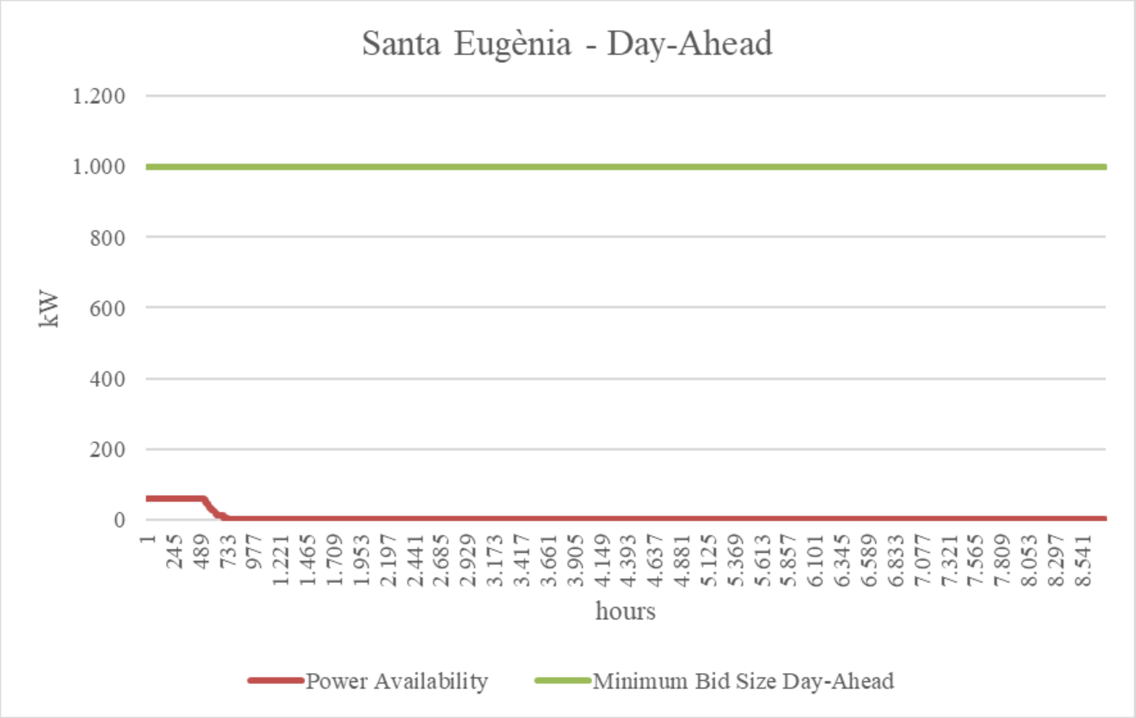


Figure 61:Santa Eugènia Day-Ahead participation capacity.

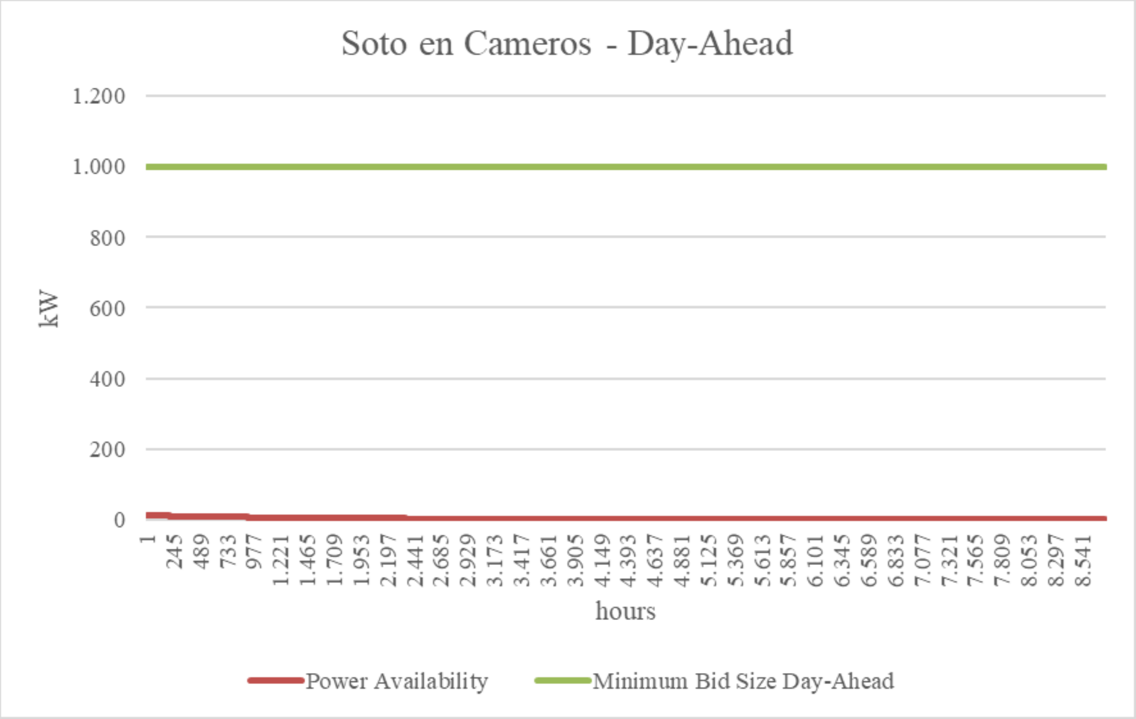


Figure 62: Soto en Cameros Day-Ahead participation capacity.

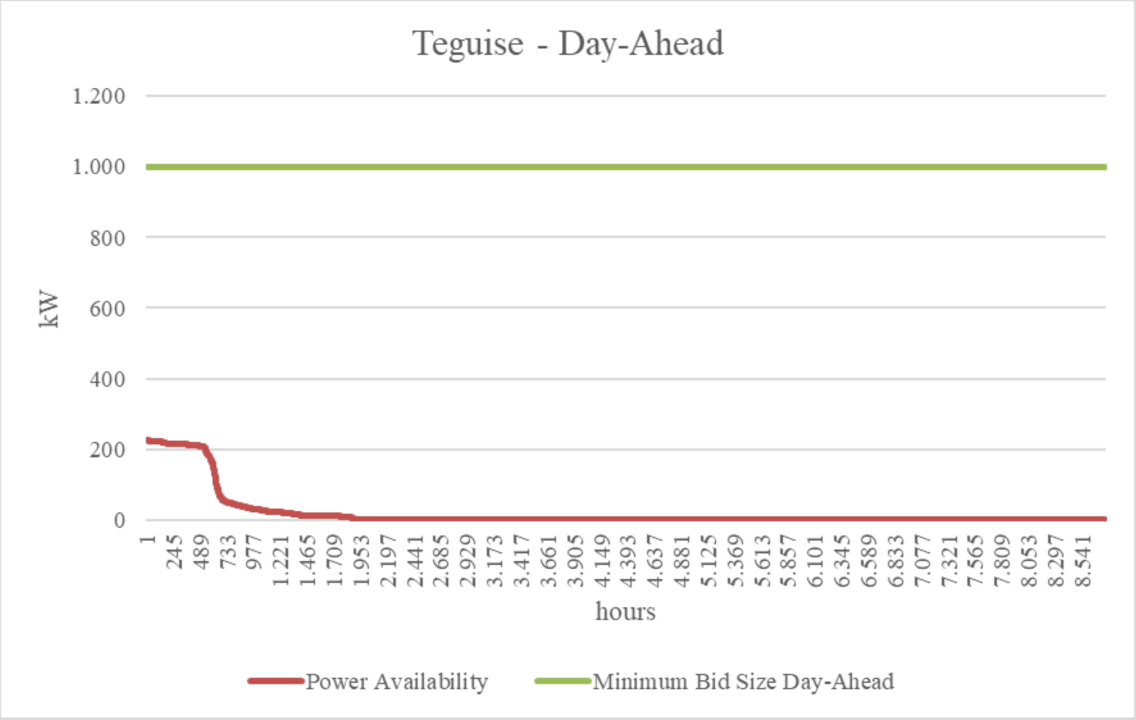


Figure 63: Teguise Day-Ahead participation capacity.

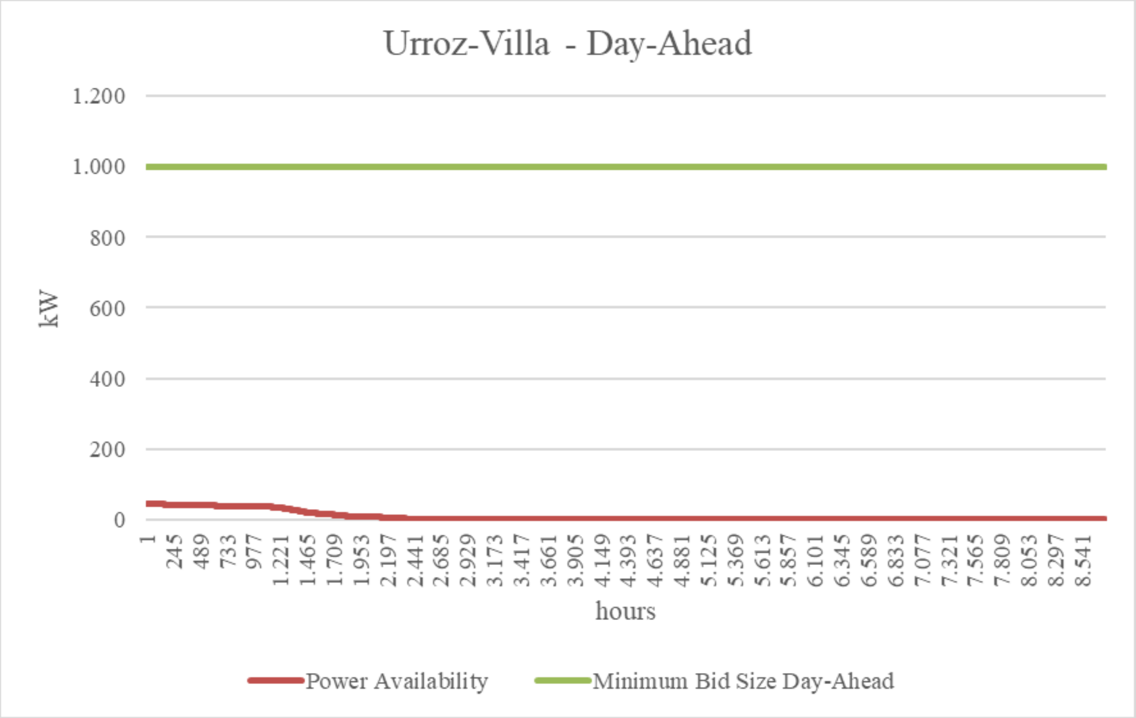


Figure 64: Urroz-Villa Day-Ahead participation capacity.

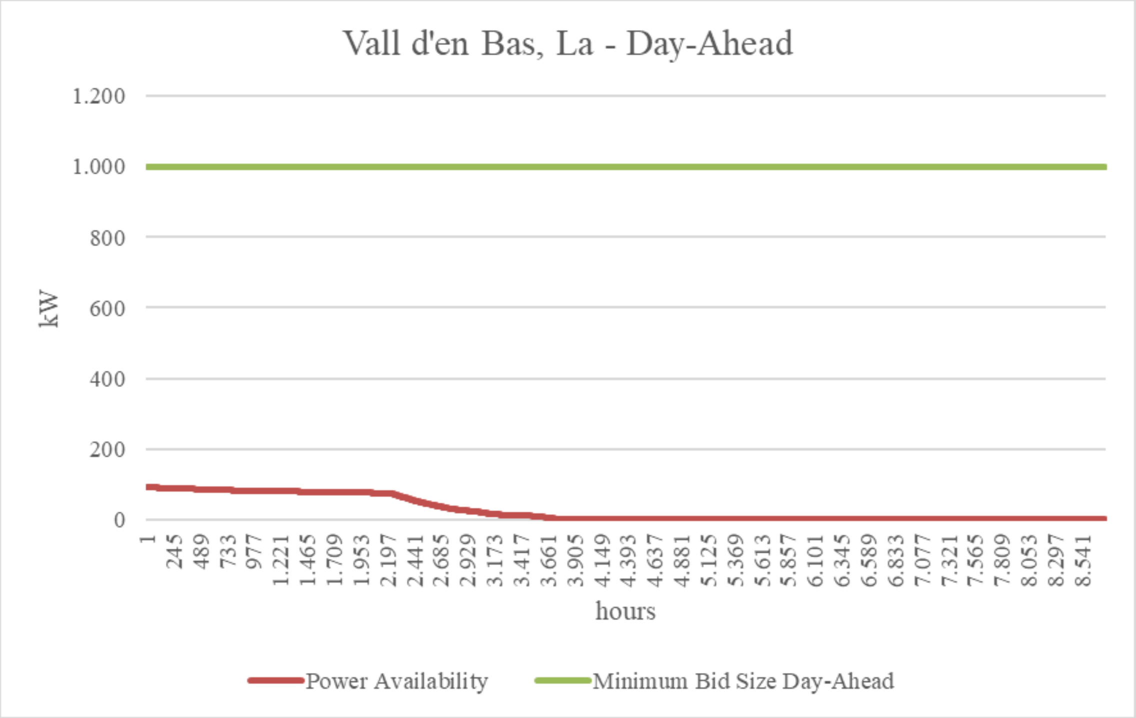


Figure 65: Vall d'en bas, La Day-Ahead participation capacity.

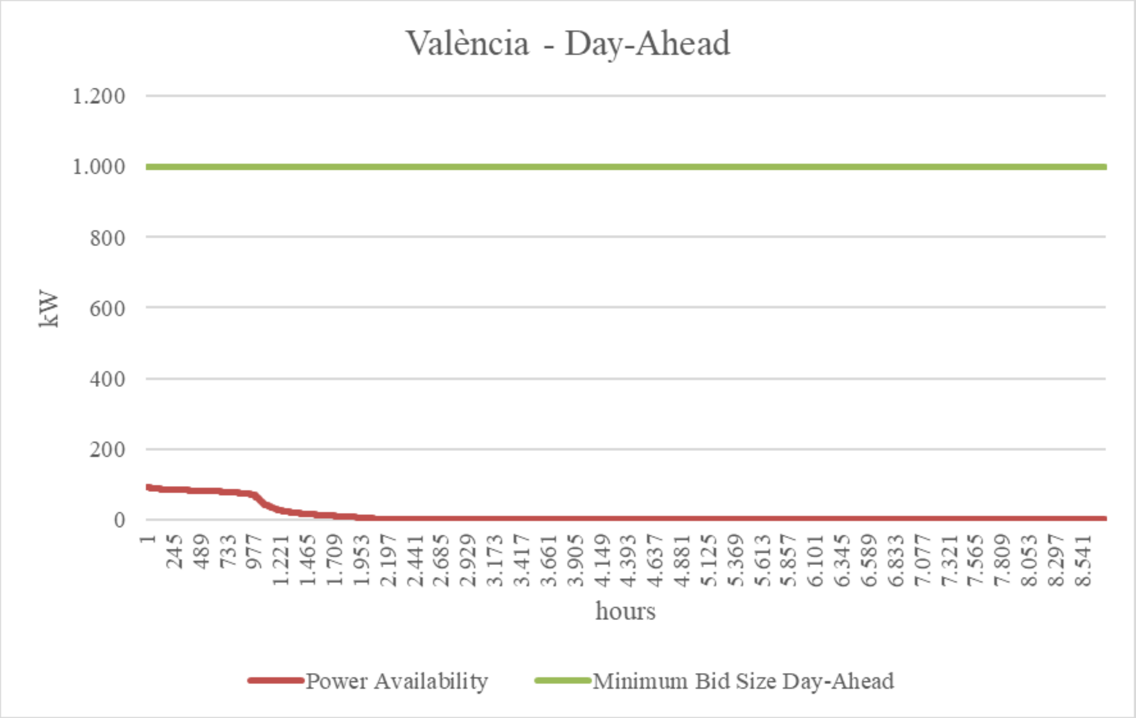


Figure 66: València Day-Ahead participation capacity.

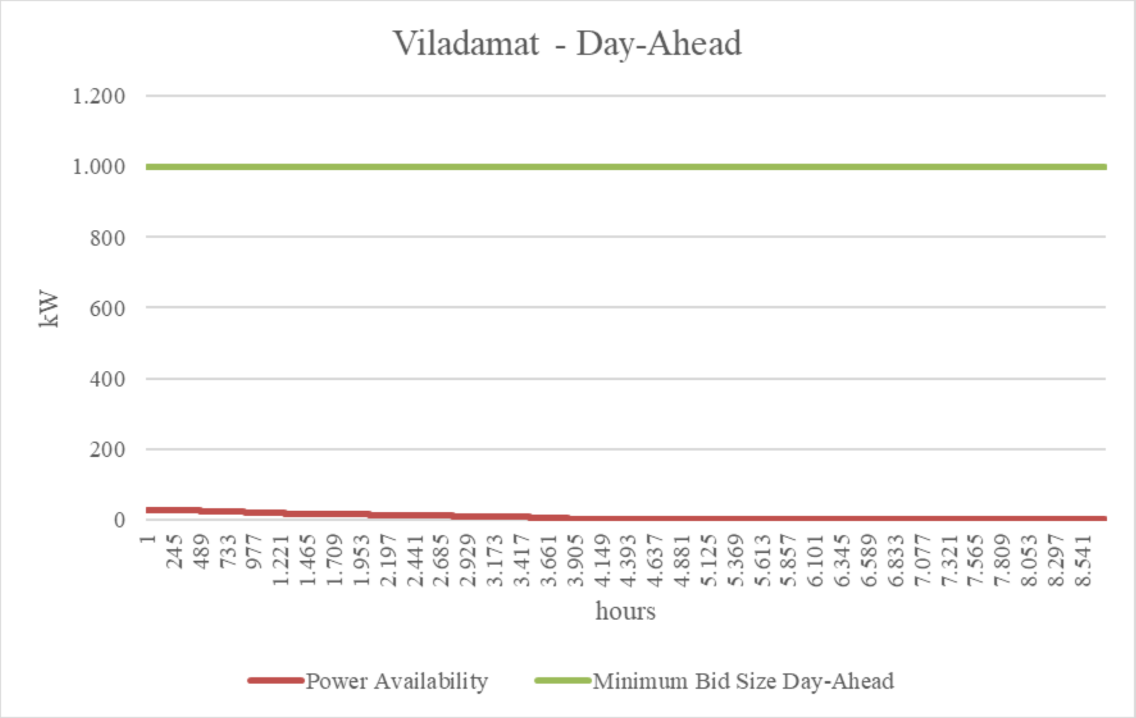


Figure 67: Viladamat Day-Ahead participation capacity.

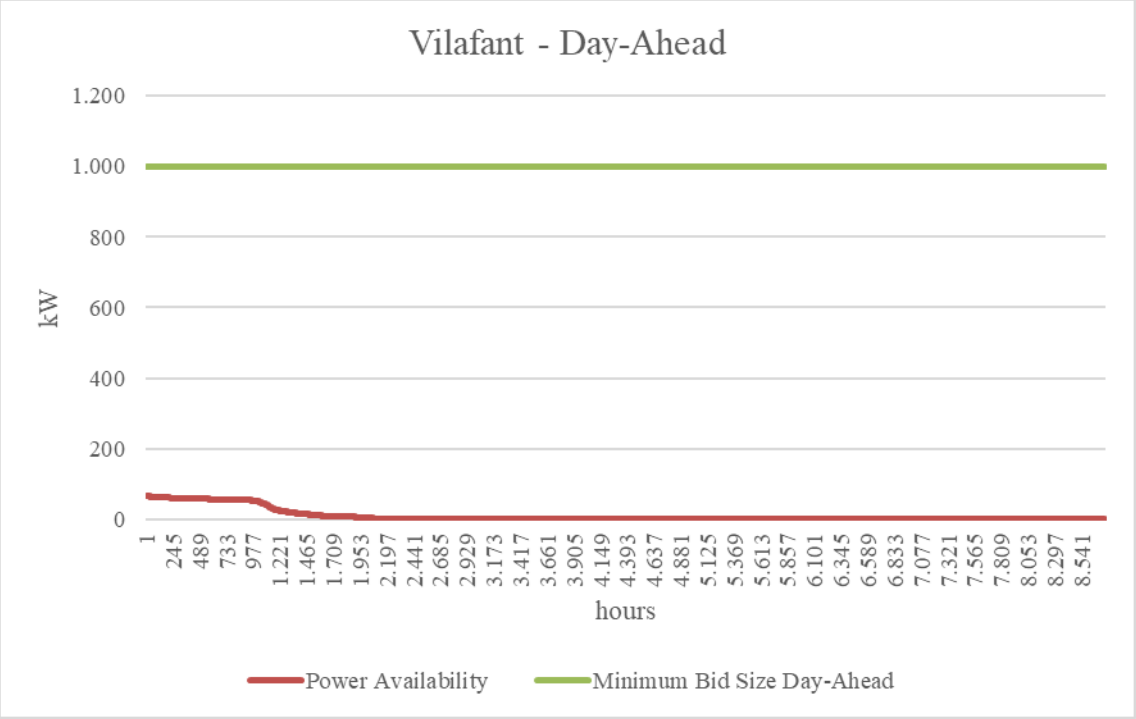


Figure 68: Vilafant Day-Ahead participation capacity.

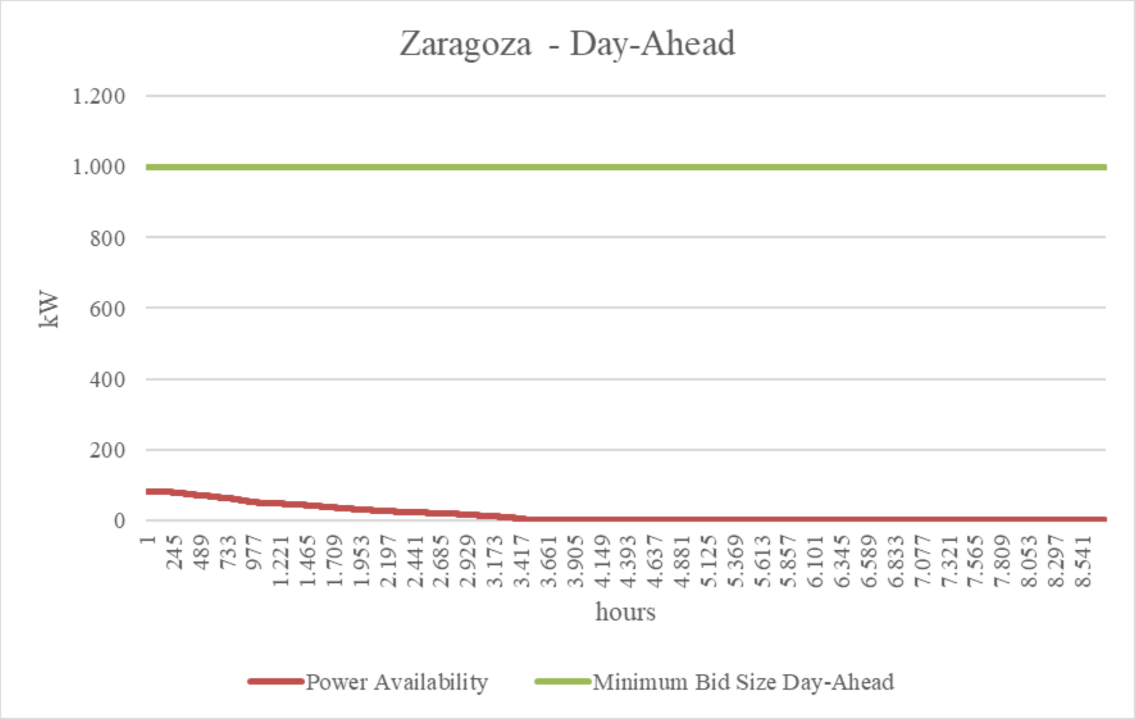


Figure 69: Zaragoza Day-Ahead participation capacity.

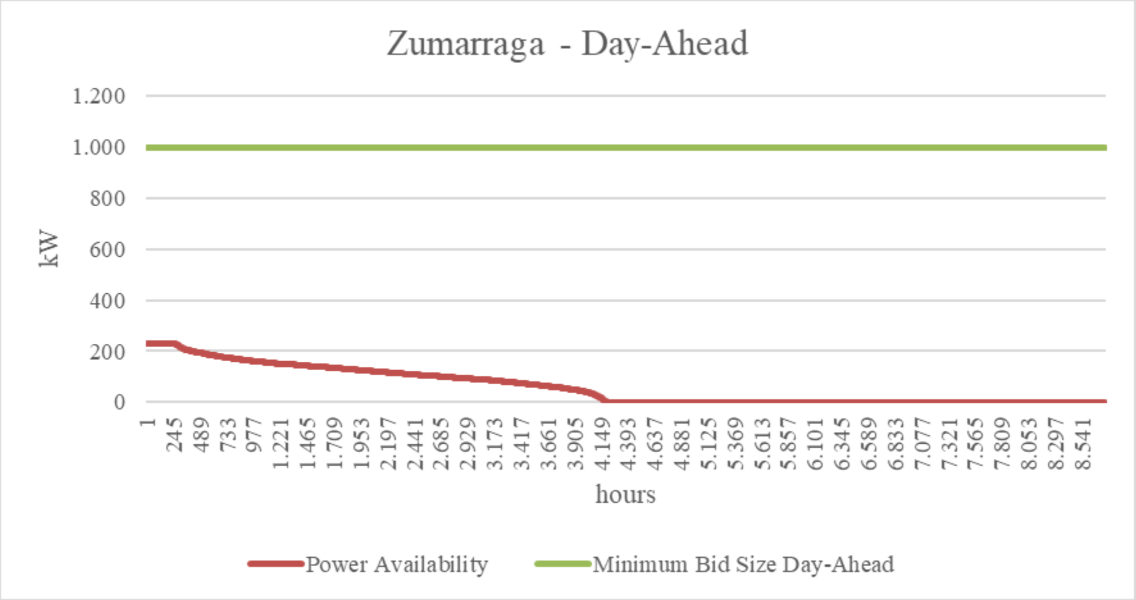


Figure 70: Zumarraga Day-Ahead participation capacity.

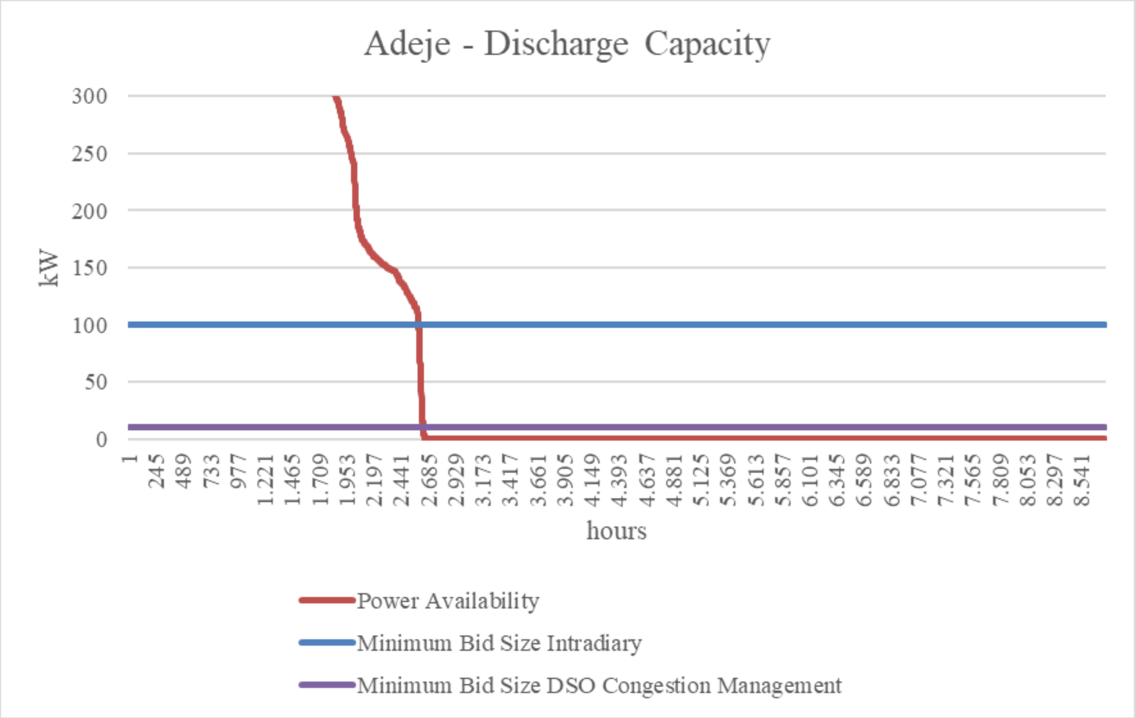


Figure 71: Adeje - Discharge Capacity

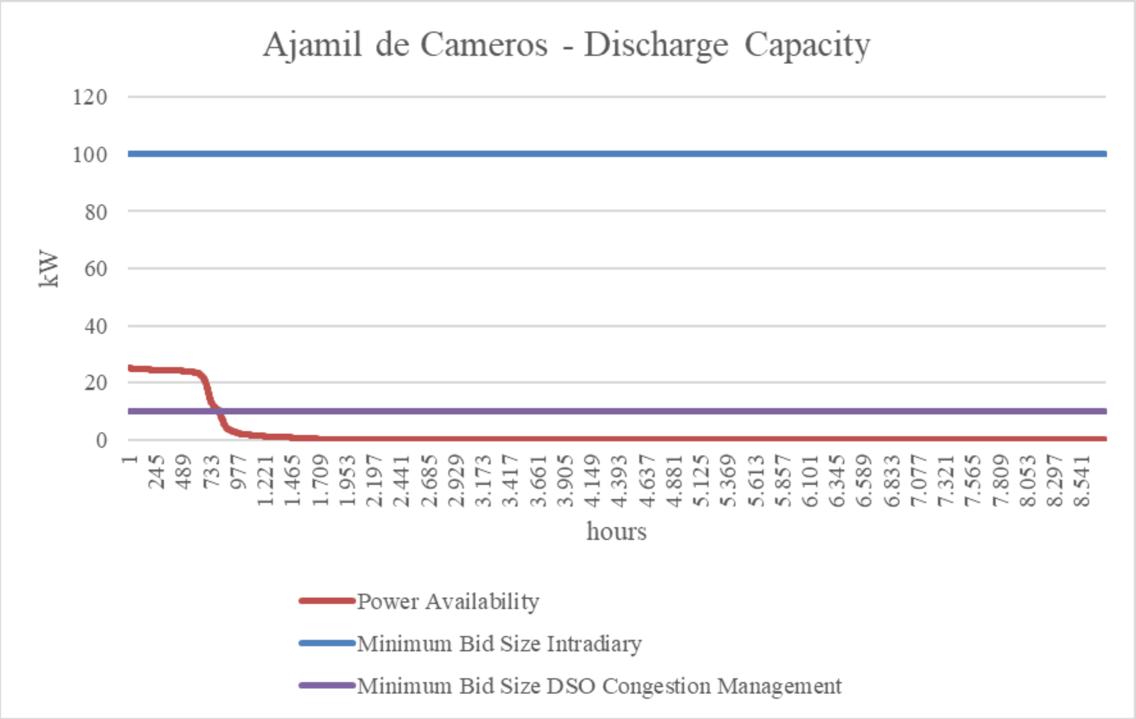


Figure 72: Ajamil de Cameros - Discharge Capacity

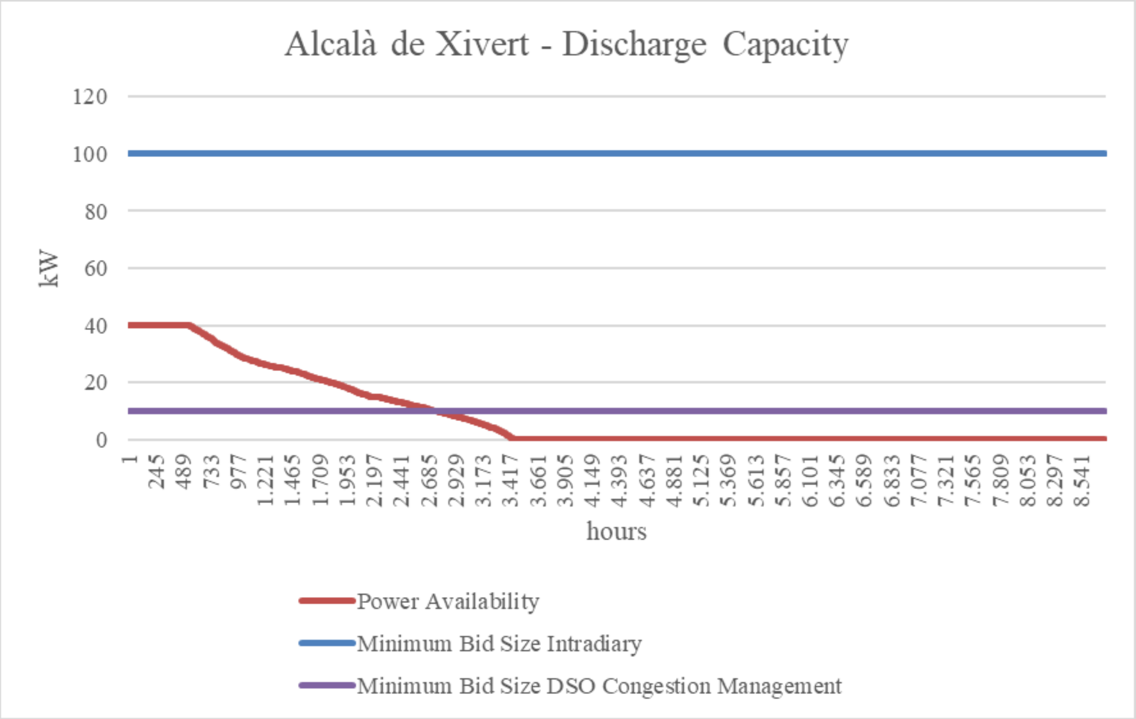


Figure 73: Alcalà de Xivert - Discharge Capacity

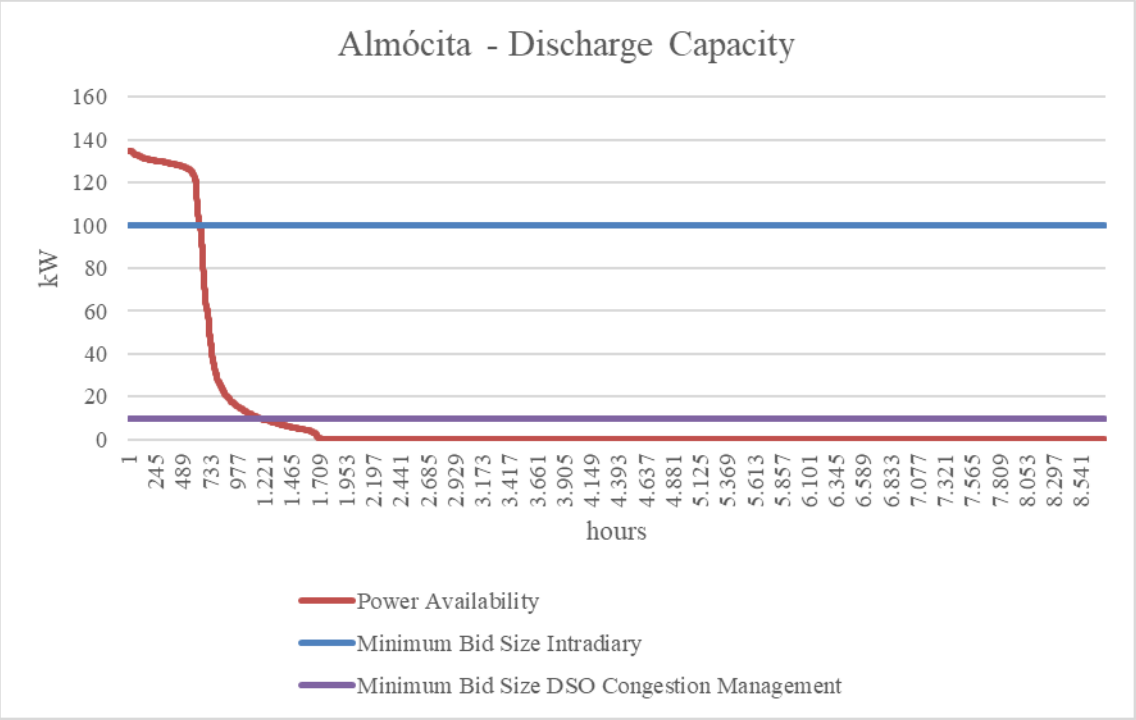


Figure 74: Almócita - Discharge Capacity

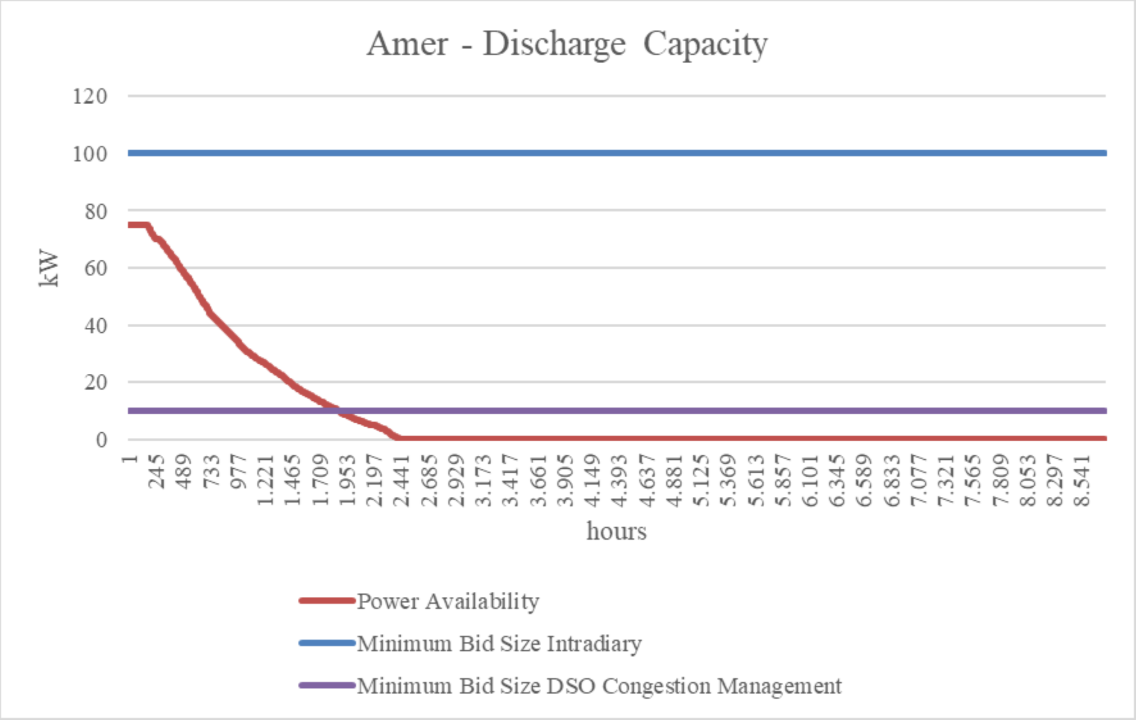


Figure 75: Amer - Discharge Capacity

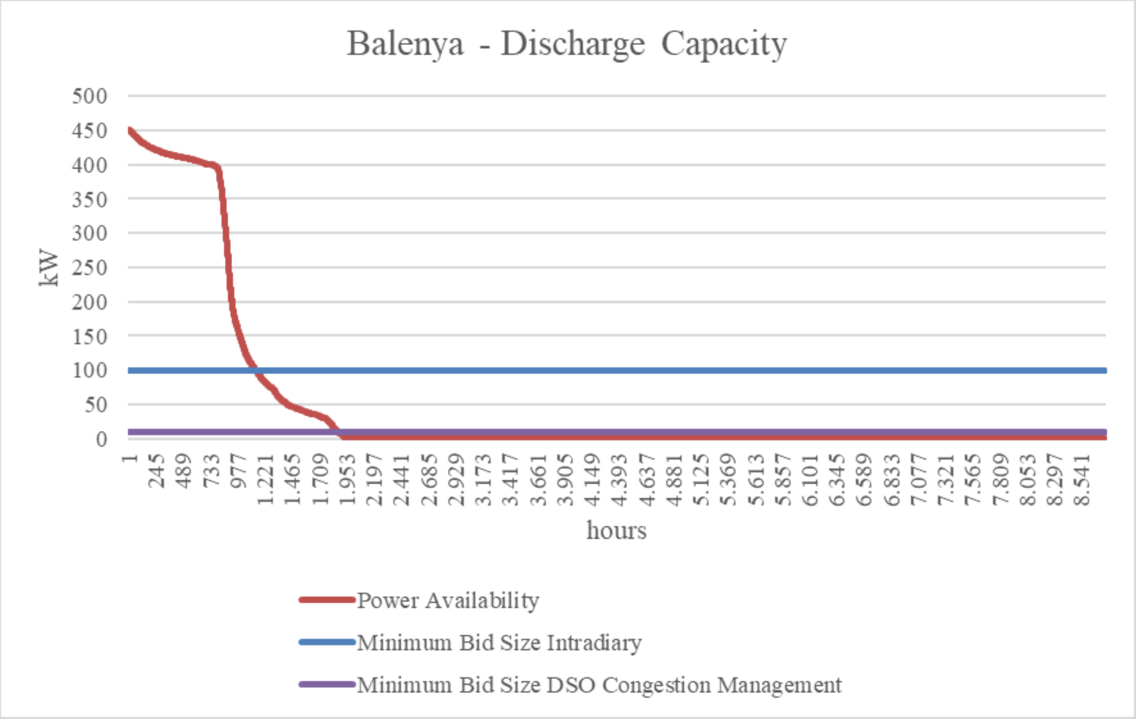


Figure 76: Balenya - Discharge Capacity

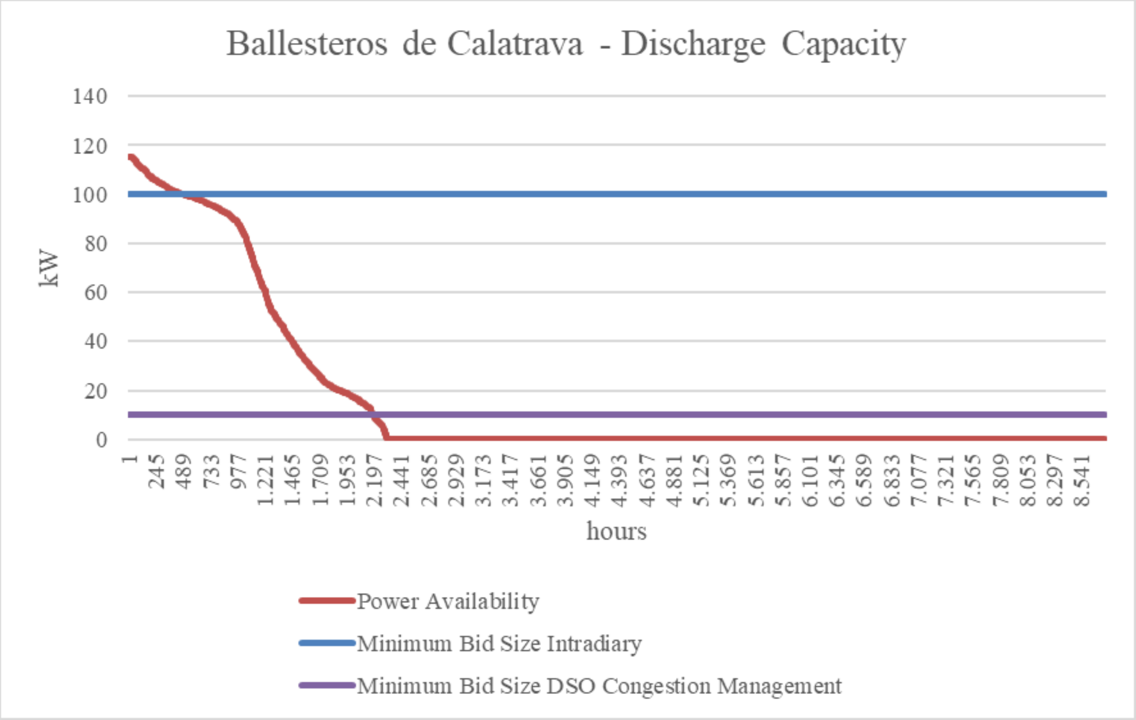


Figure 77: Ballesteros de Calatrava - Discharge Capacity

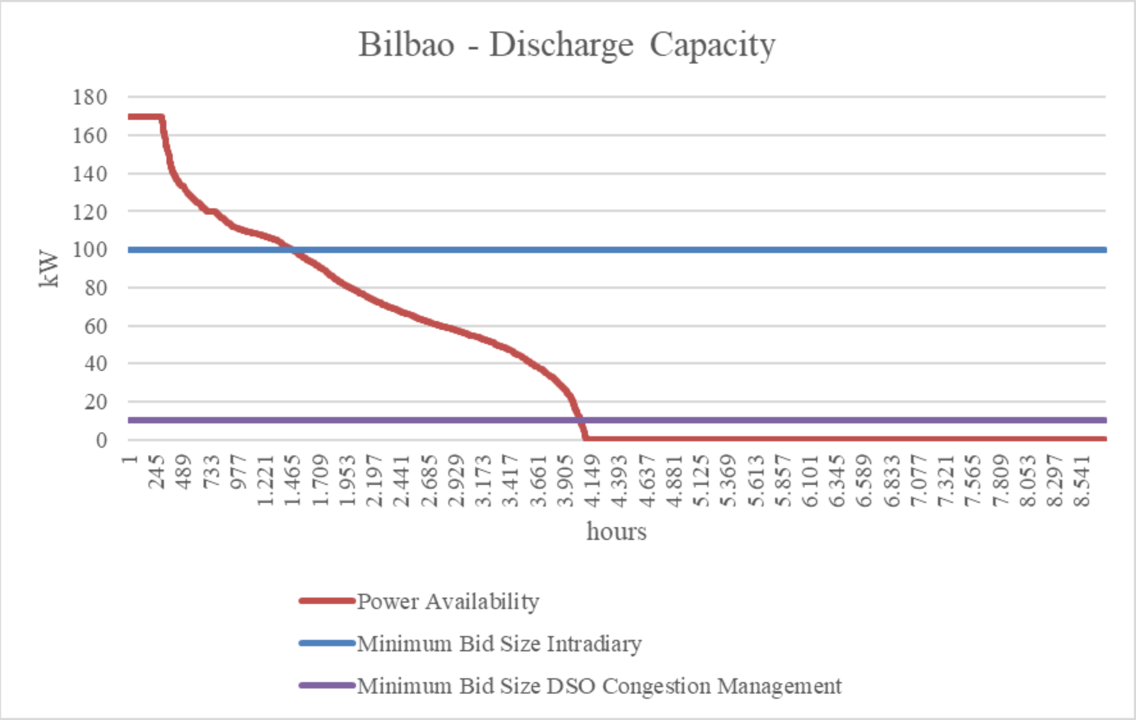


Figure 78: Bilbao - Discharge Capacity

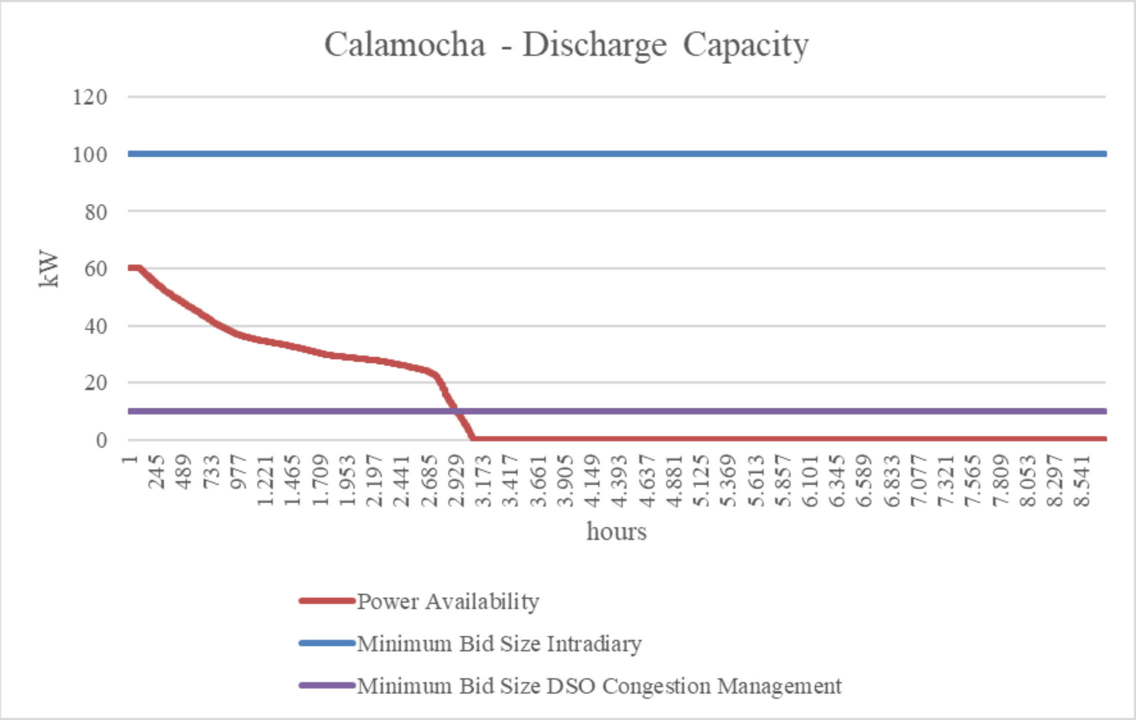


Figure 79: Calamocha - Discharge Capacity

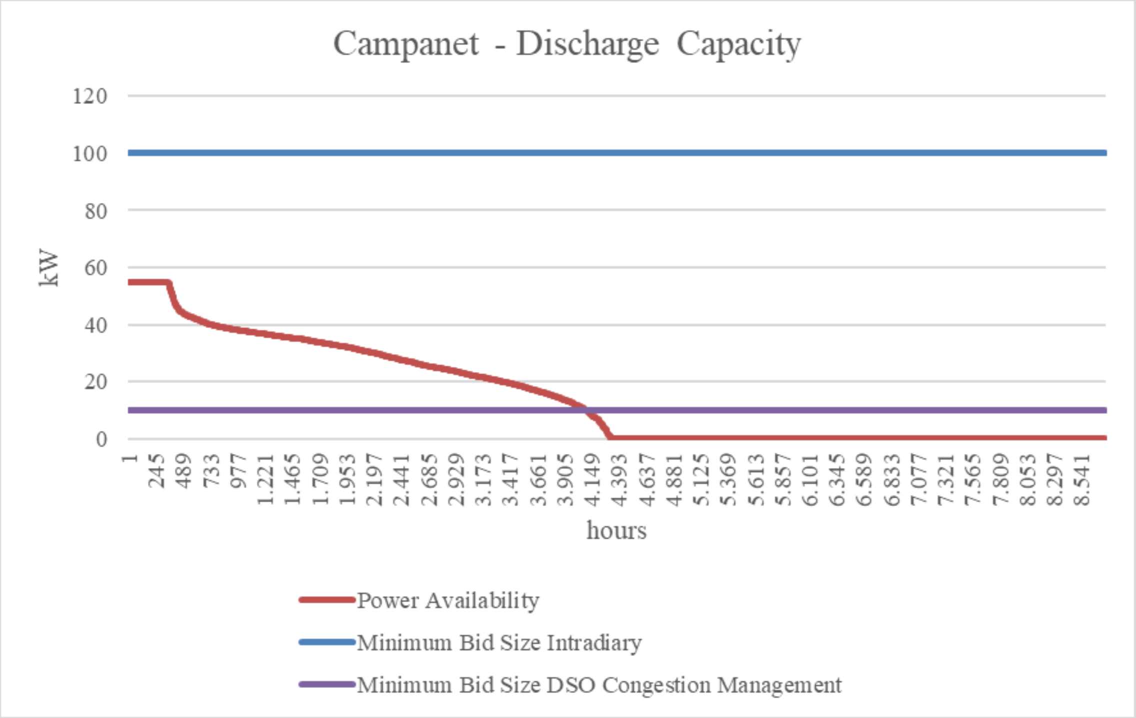


Figure 80: Campanet - Discharge Capacity

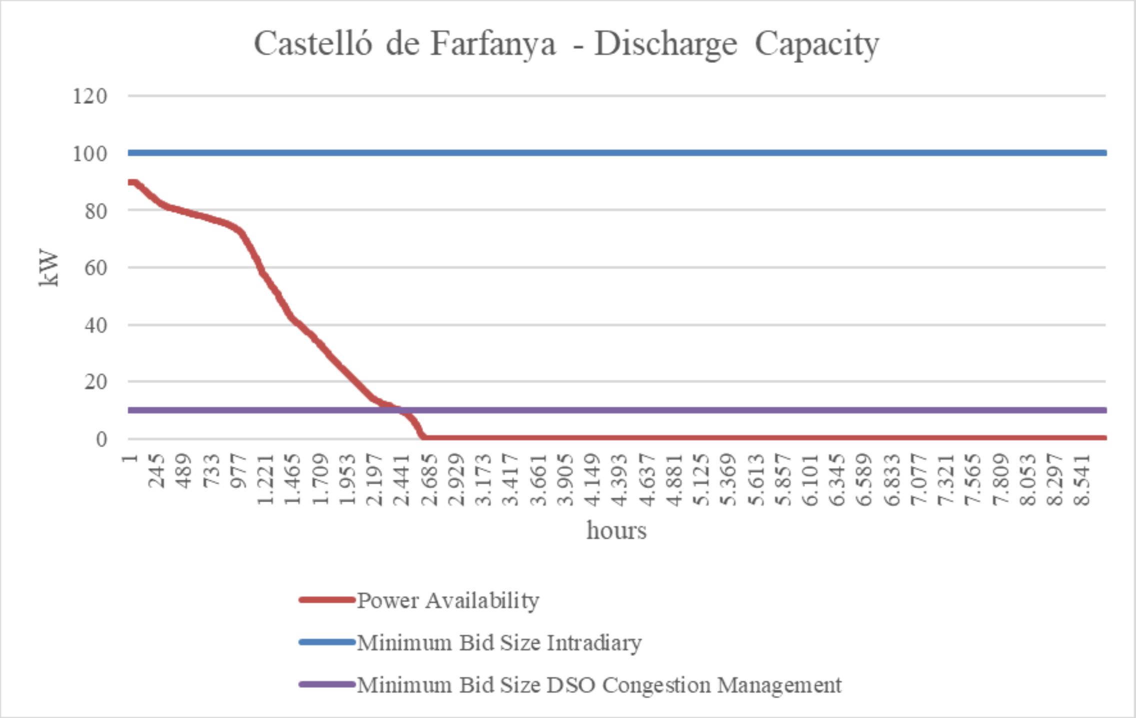


Figure 81: Castelló de Farfanya - Discharge Capacity

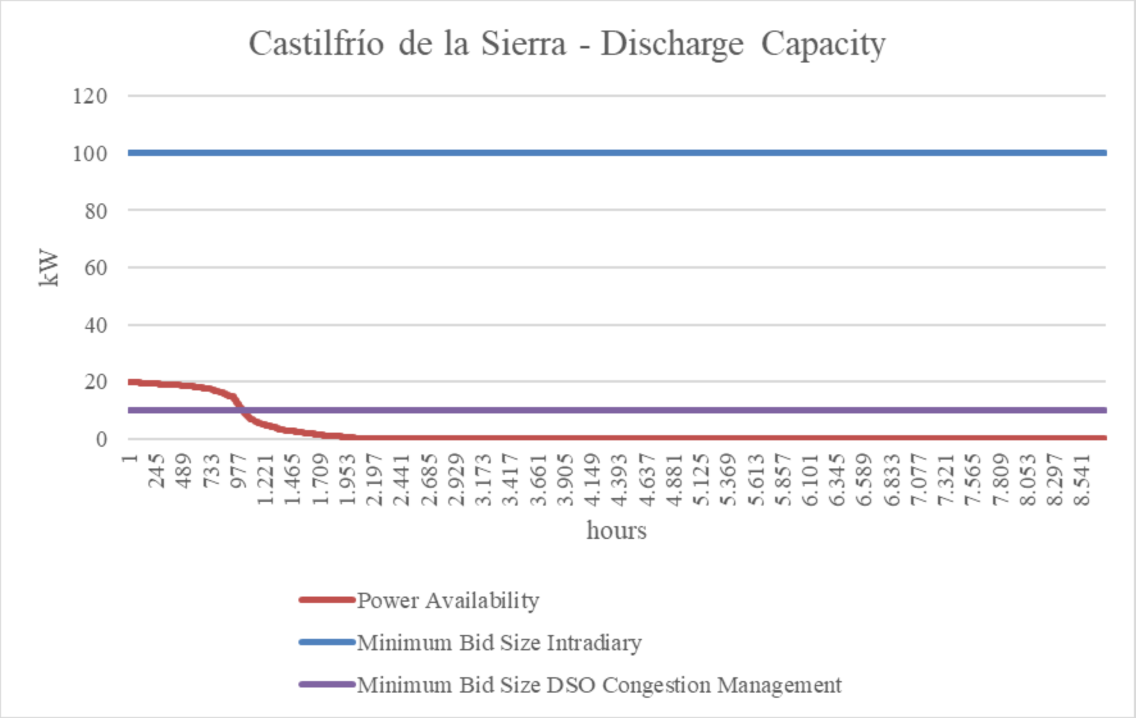


Figure 82: Castilfrío de la Sierra - Discharge Capacity

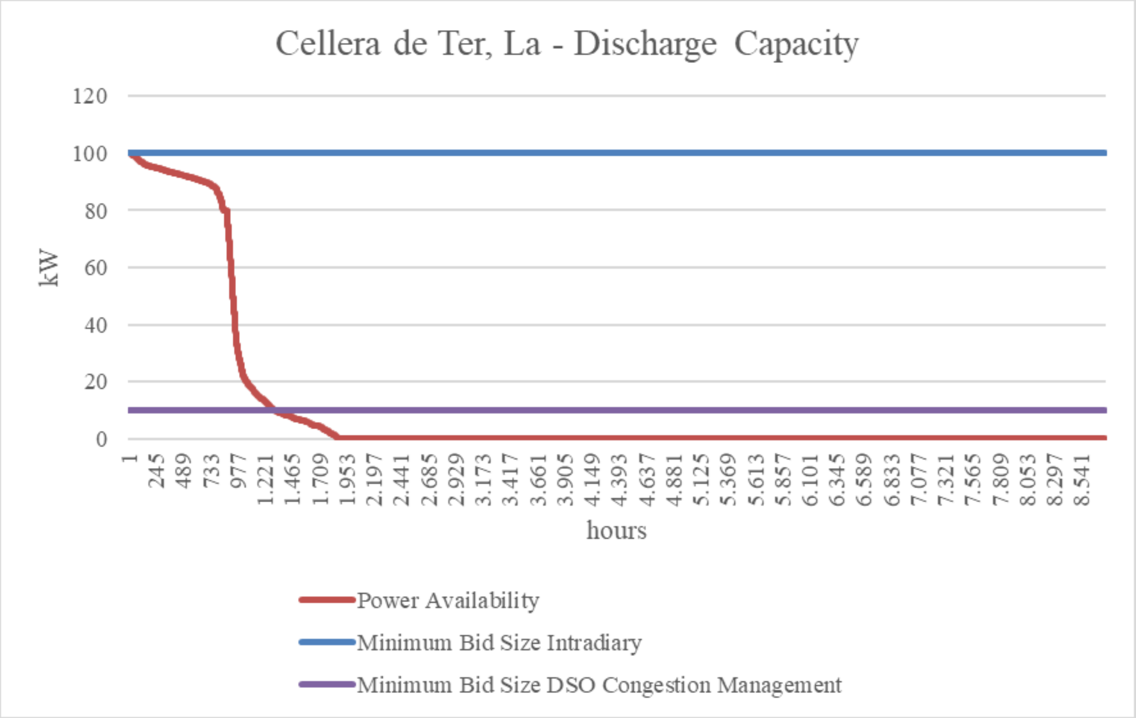


Figure 83: Cellera de Ter,La - Discharge Capacity

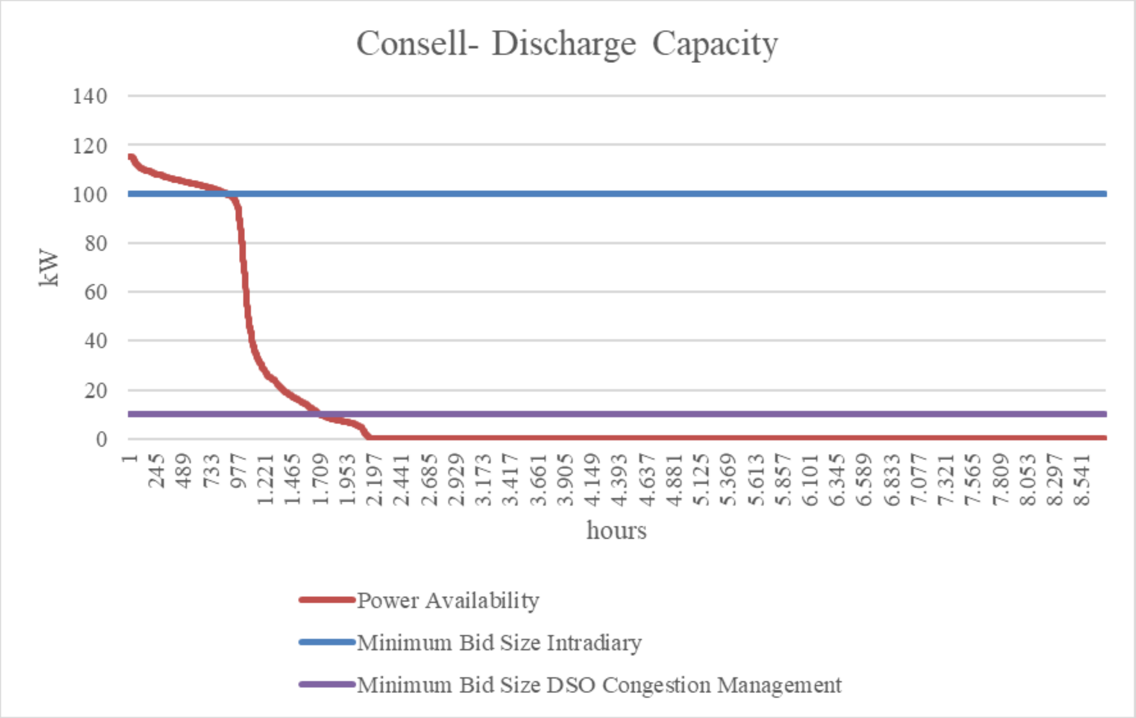


Figure 84: Consell - Discharge Capacity

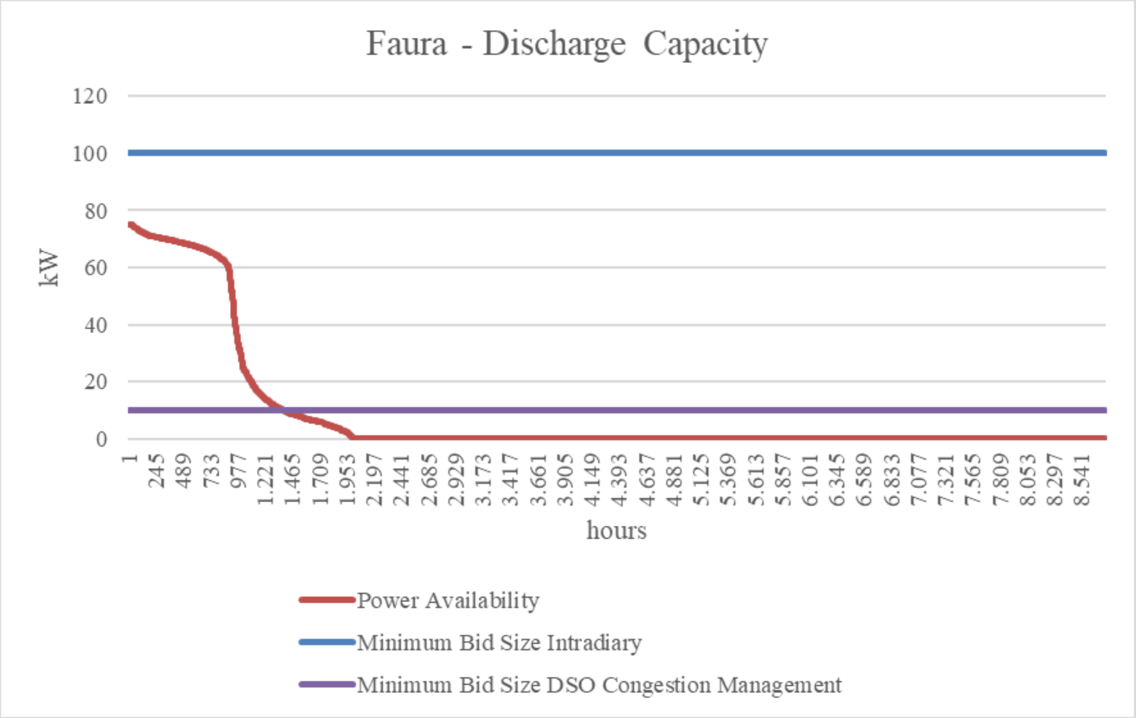


Figure 85: Faura - Discharge Capacity

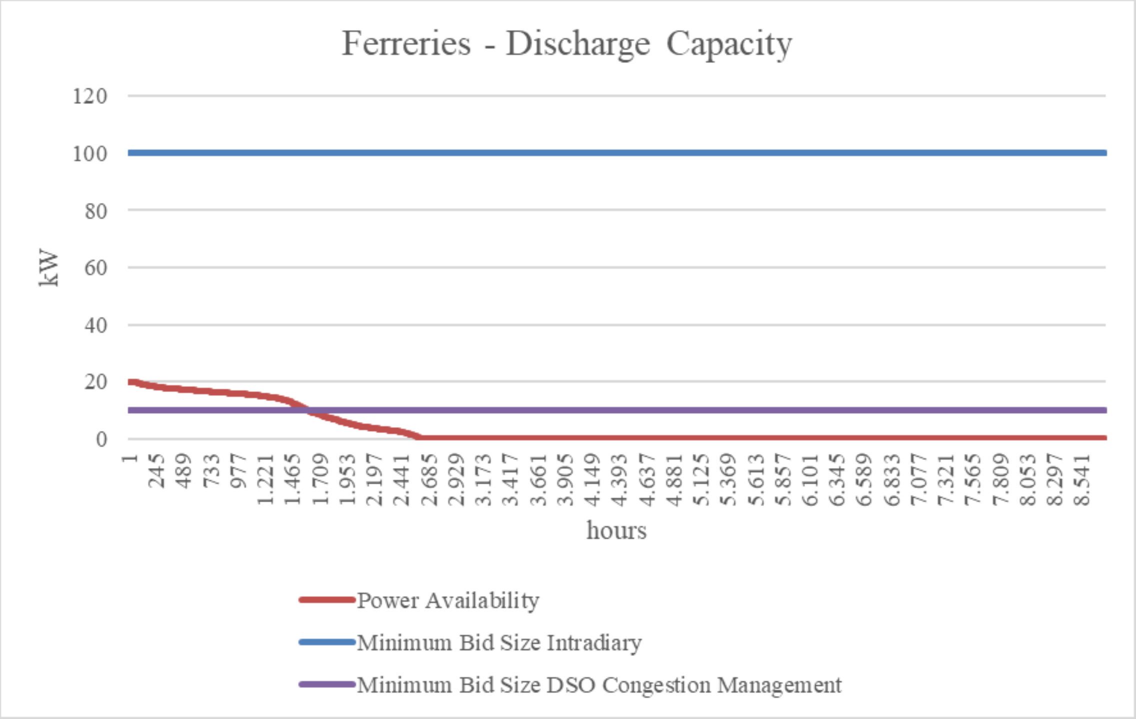


Figure 86: Ferreries - Discharge Capacity

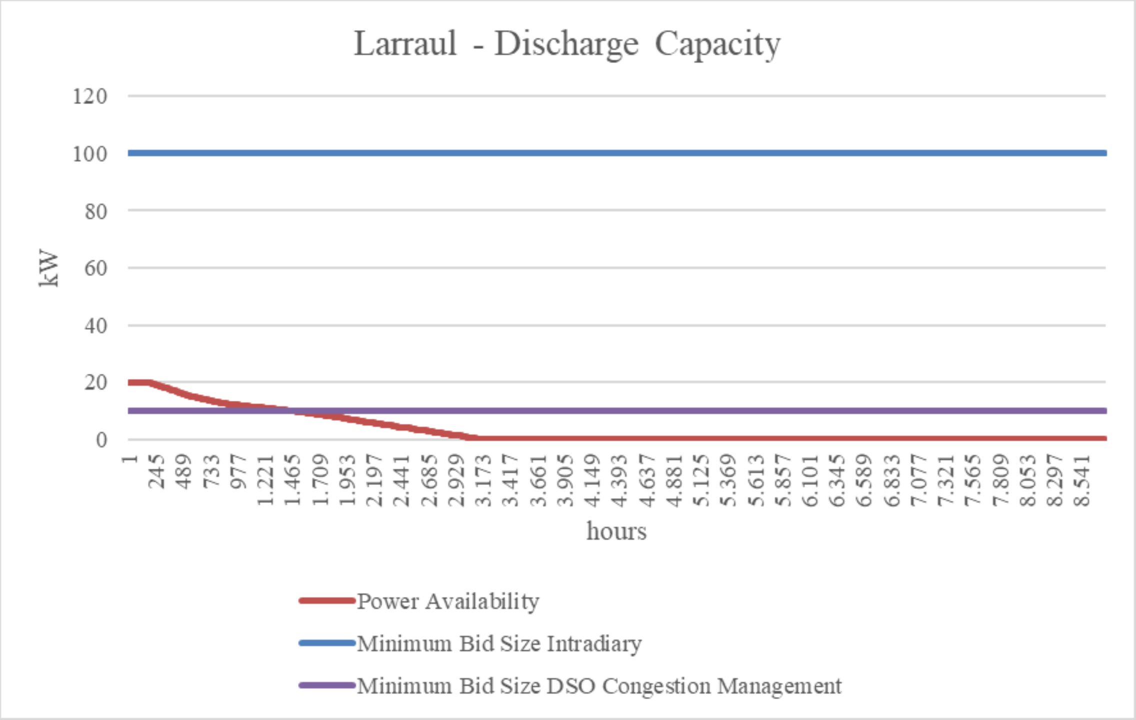


Figure 87: Larraul - Discharge Capacity

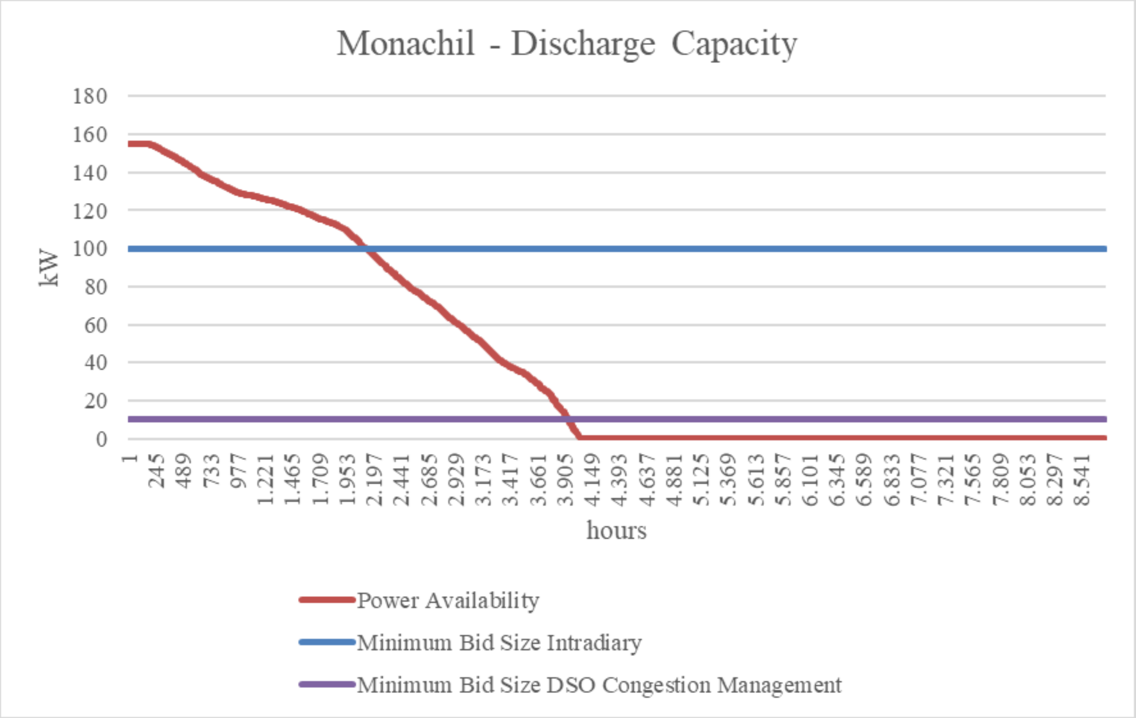


Figure 88: Monachil - Discharge Capacity

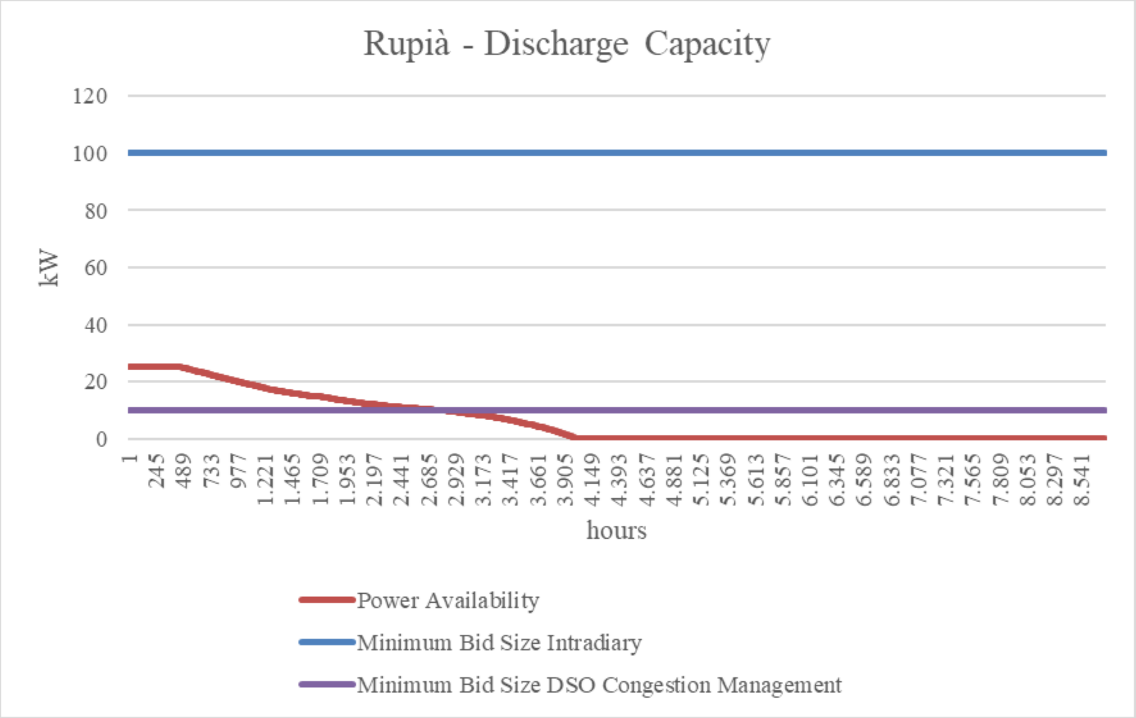


Figure 89: Rupià - Discharge Capacity

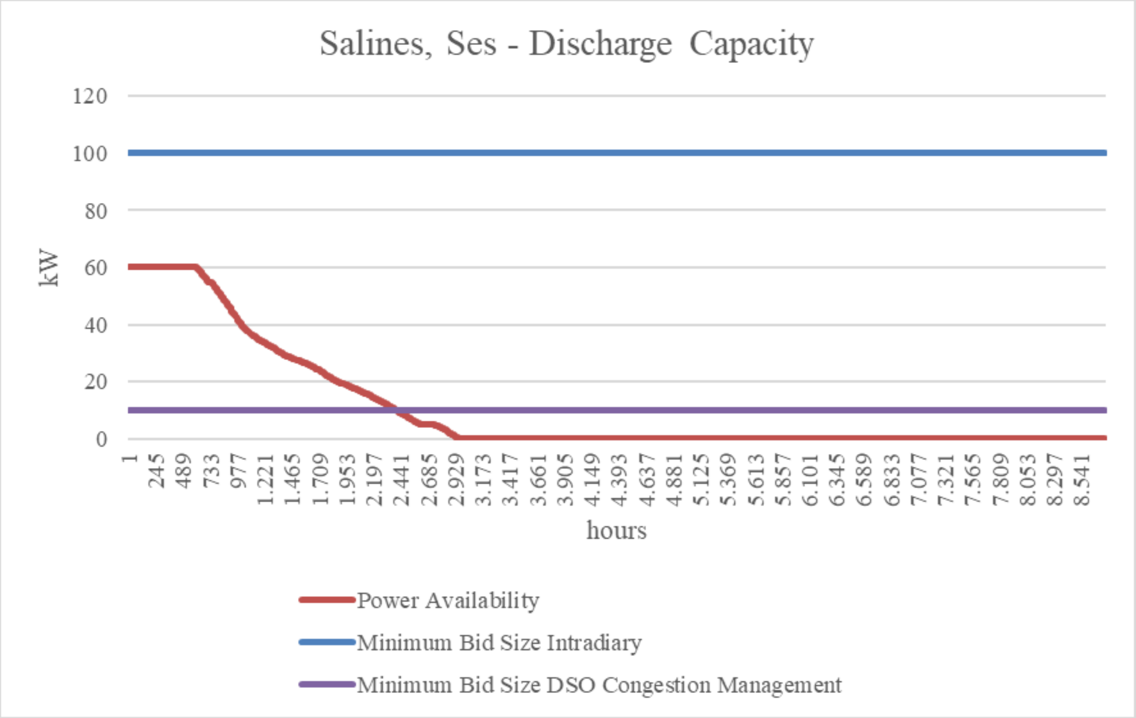


Figure 90: Salines, Ses - Discharge Capacity

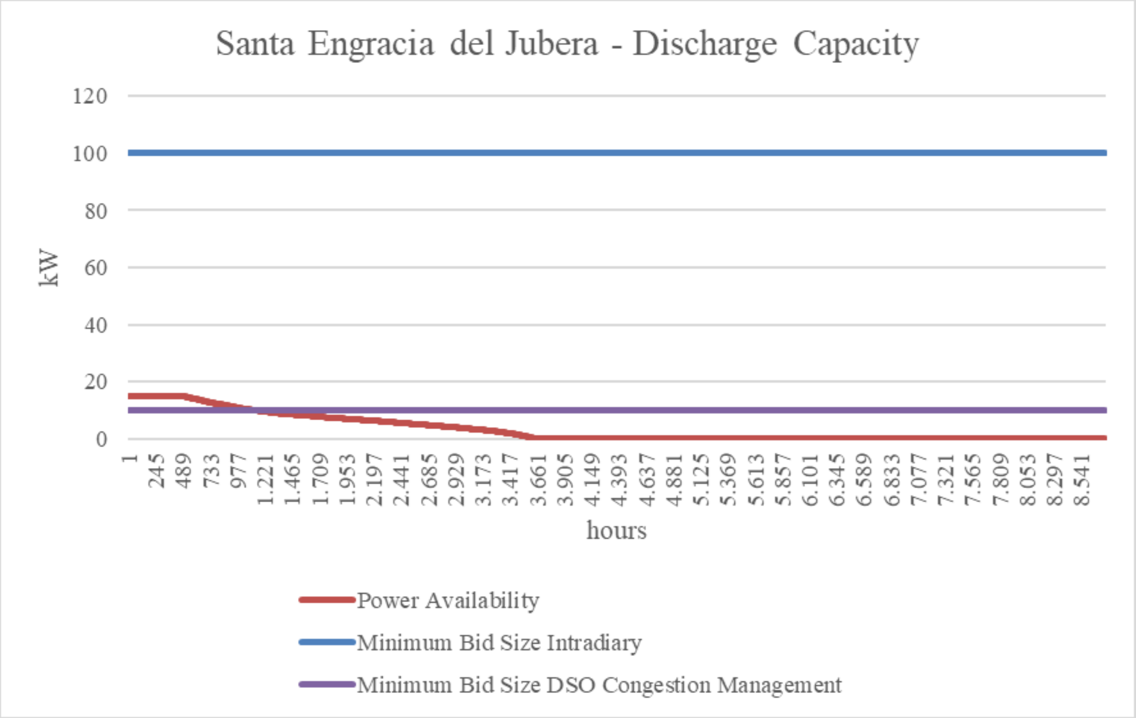


Figure 91: Santa Engracia del Jubera - Discharge Capacity

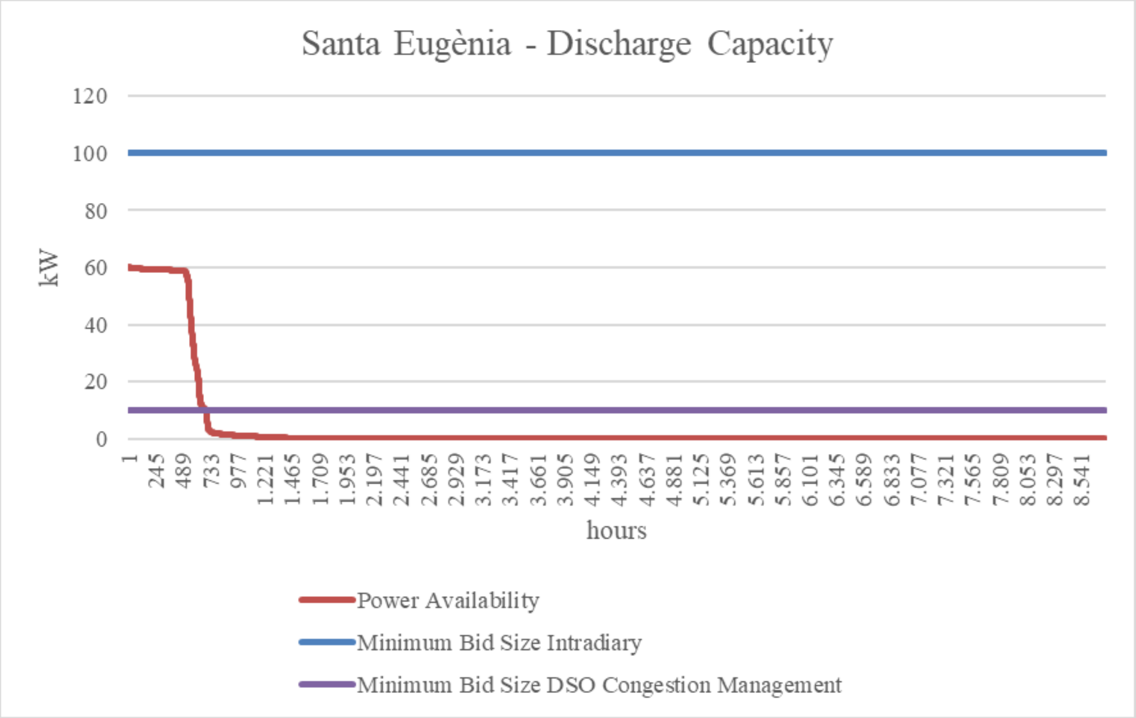


Figure 92: Santa Eugènia - Discharge Capacity

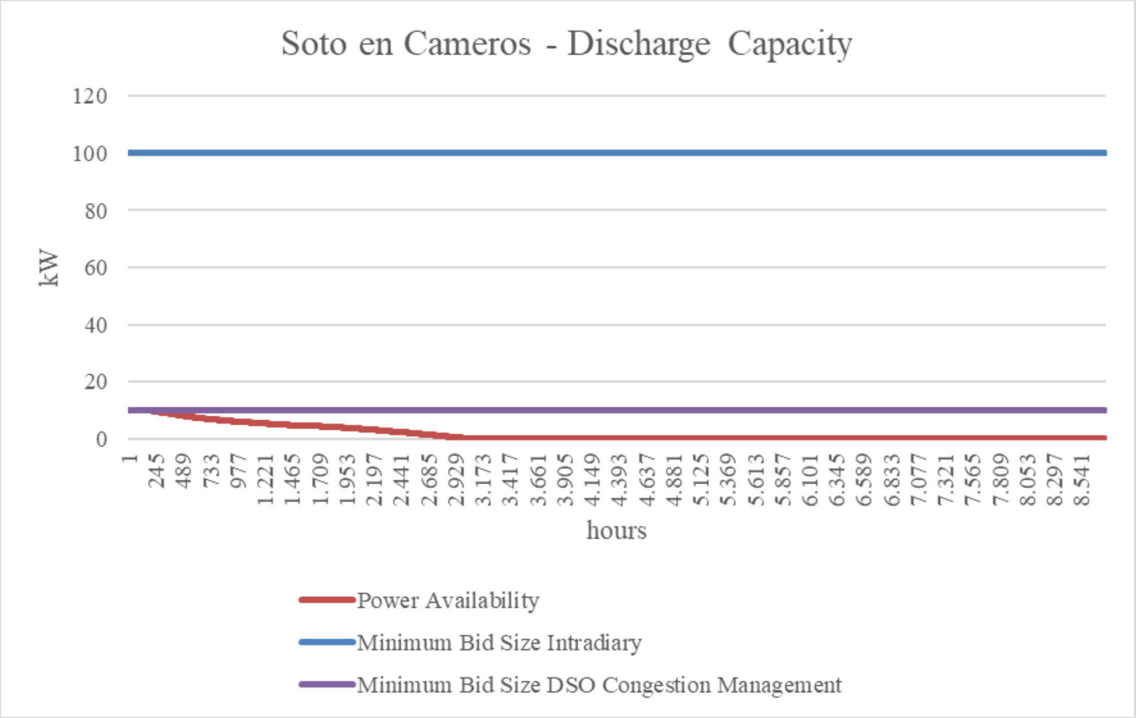


Figure 93: Soto en Cameros - Discharge Capacity

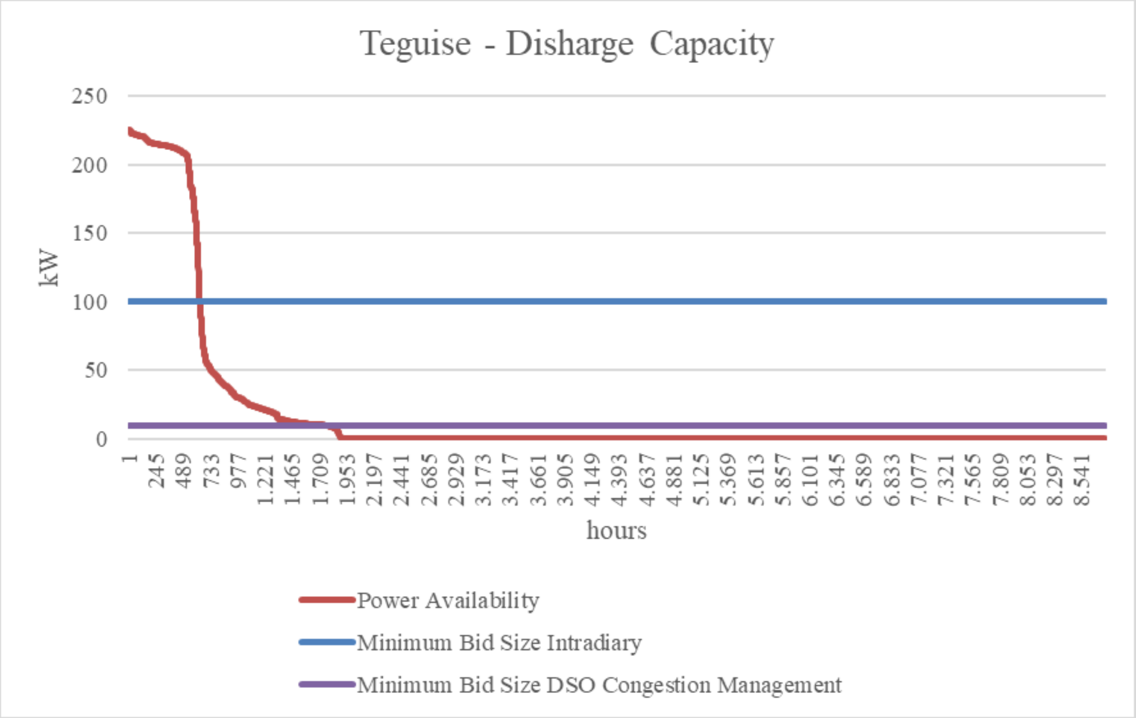


Figure 94: Teguise - Discharge Capacity

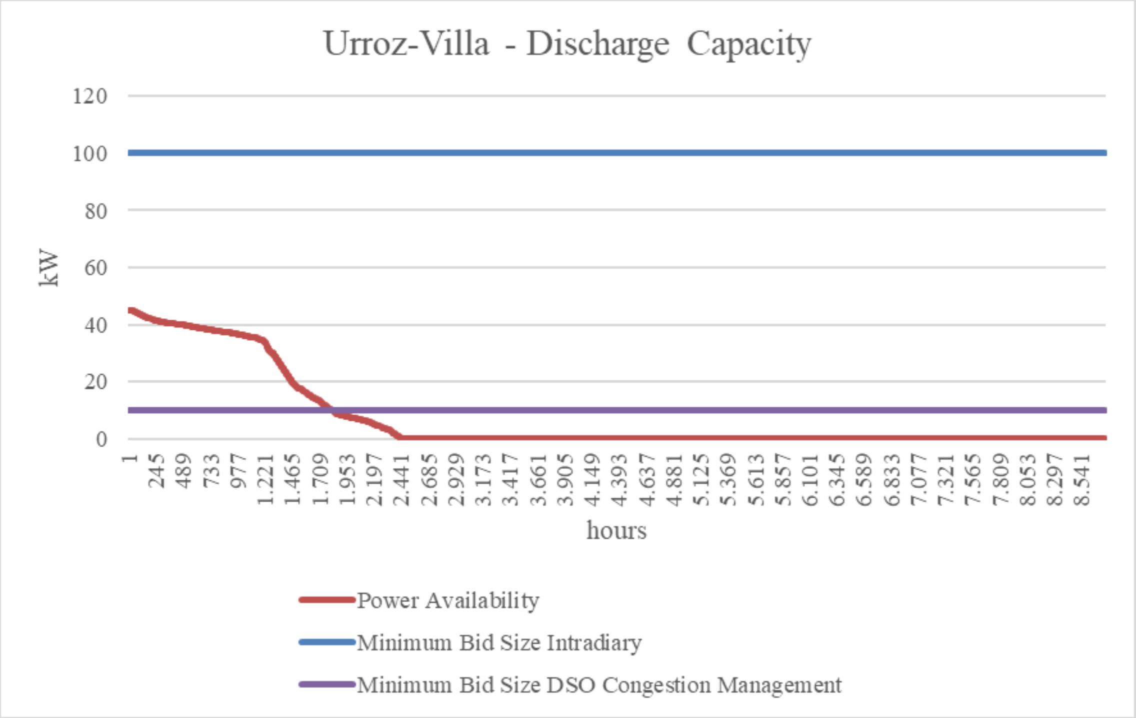


Figure 95: Urroz-Villa - Discharge Capacity

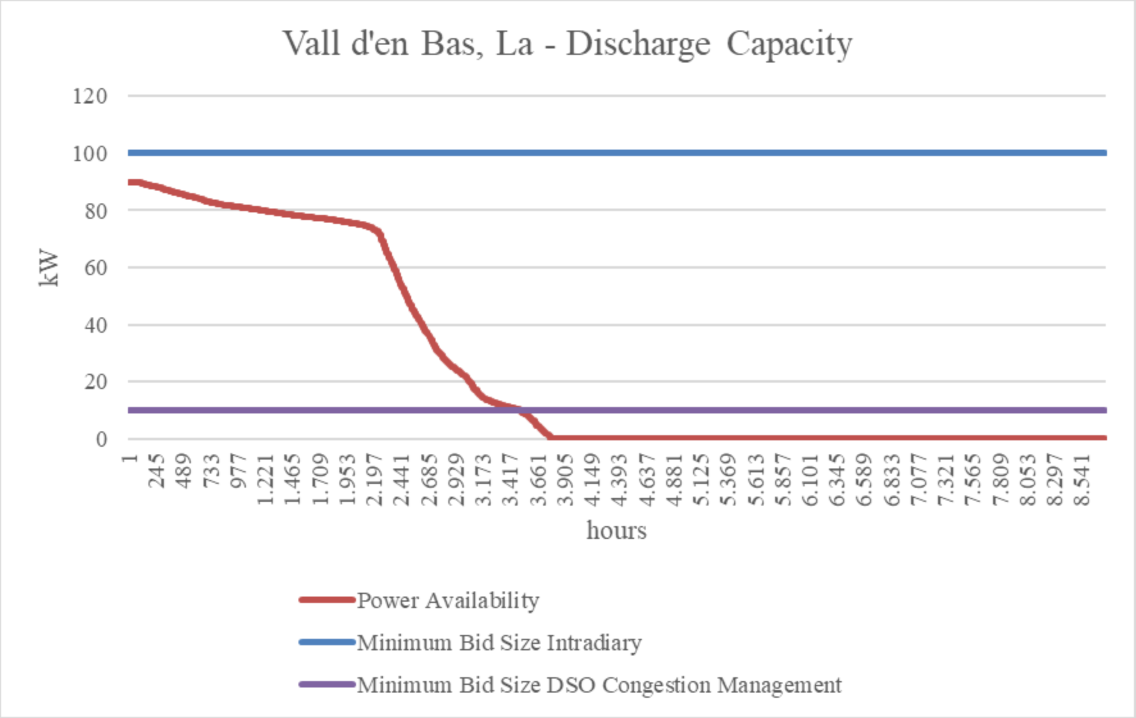


Figure 96: Vall d'en Bas, La - Discharge Capacity

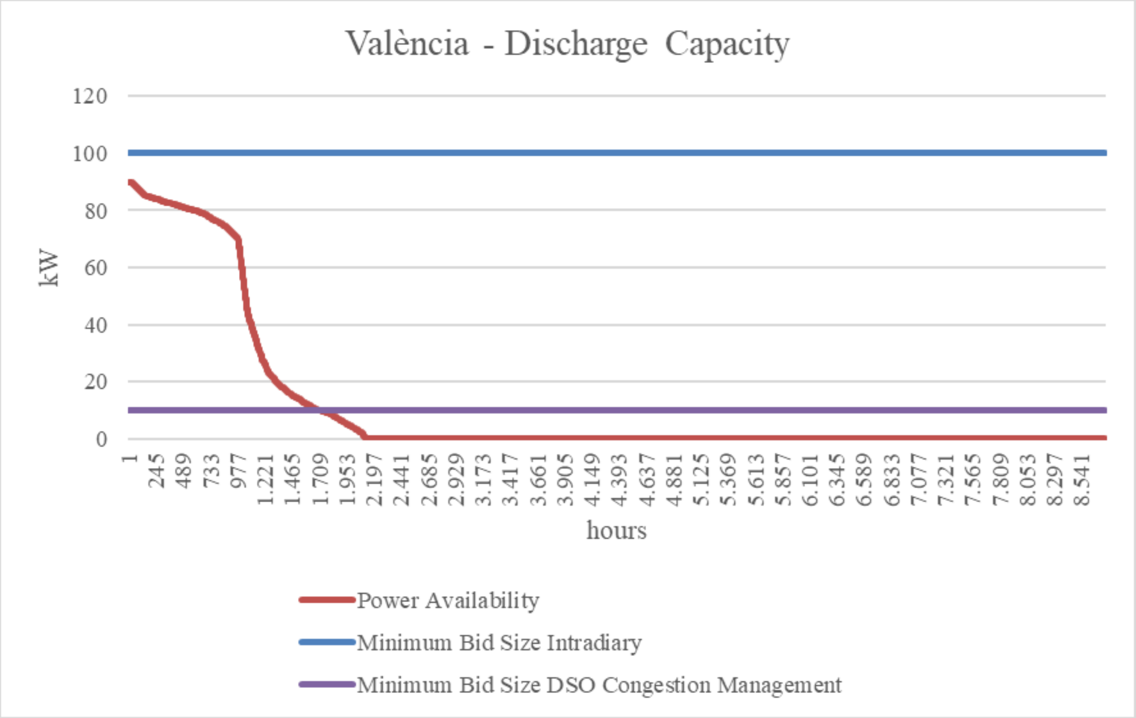


Figure 97: València - Discharge Capacity

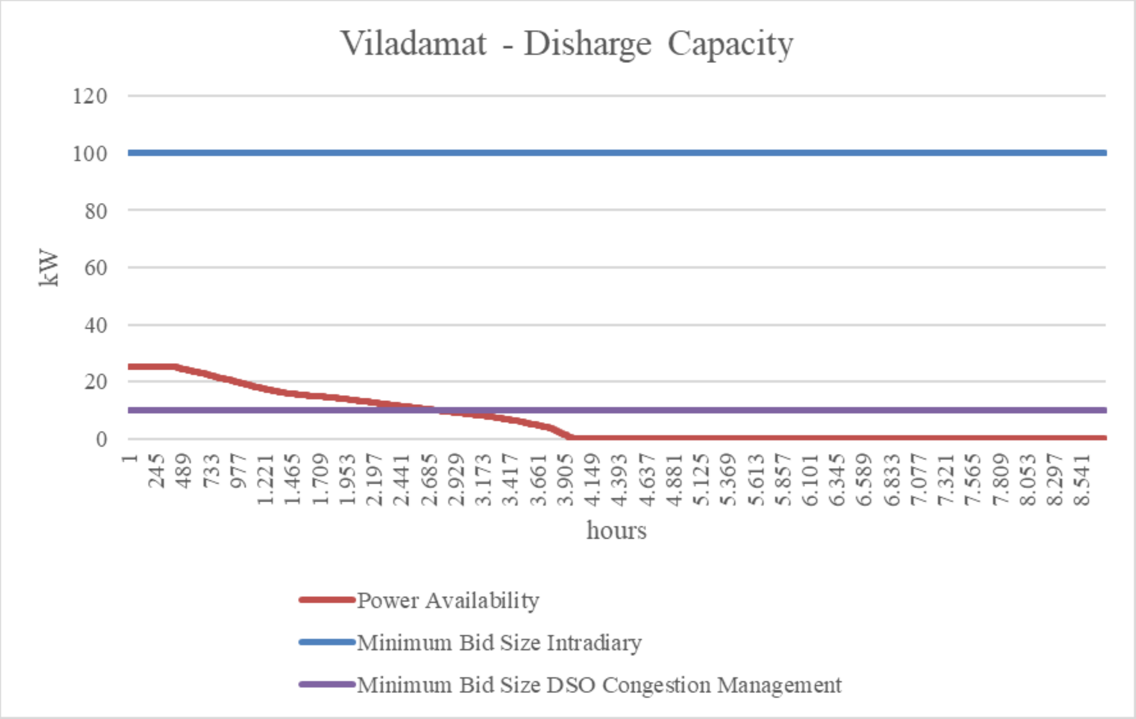


Figure 98: Viladamat - Discharge Capacity

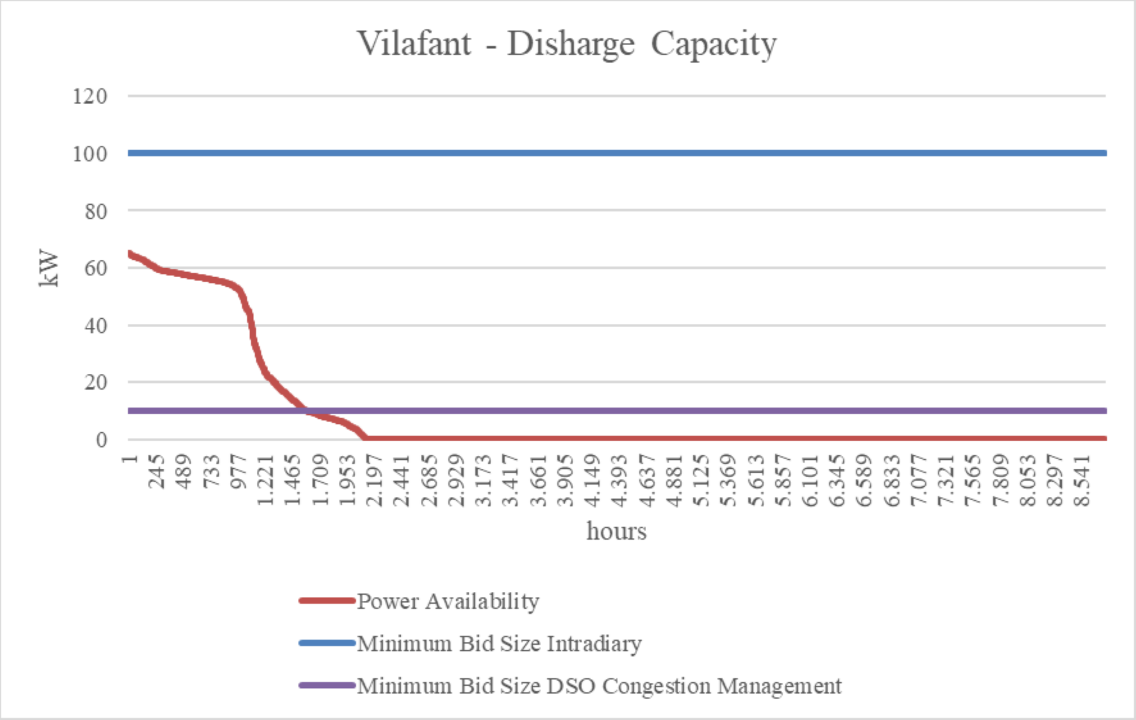


Figure 99: Vilafant - Discharge Capacity

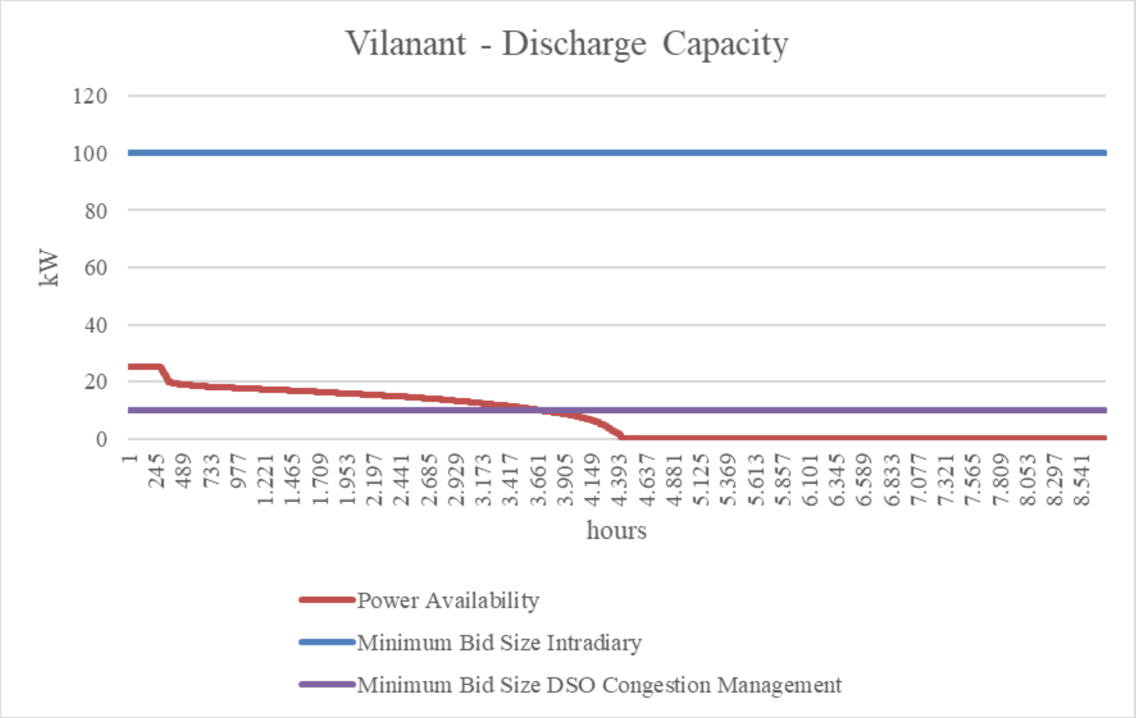


Figure 100: València - Discharge Capacity

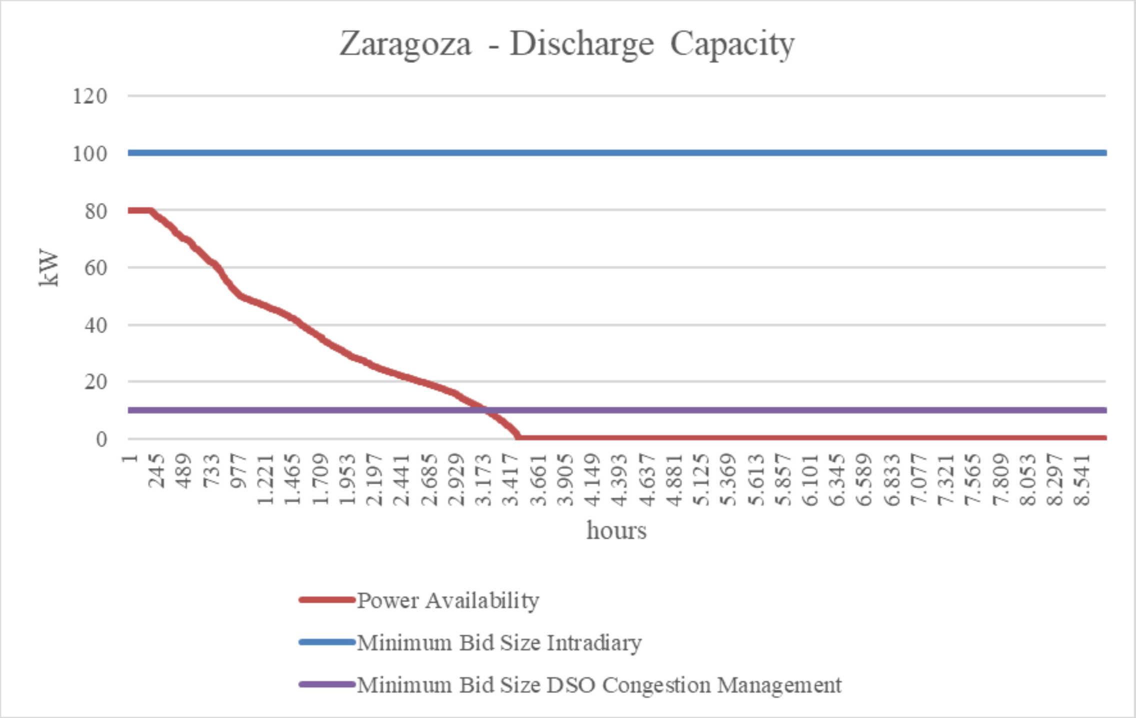


Figure 101: Zaragoza - Discharge Capacity

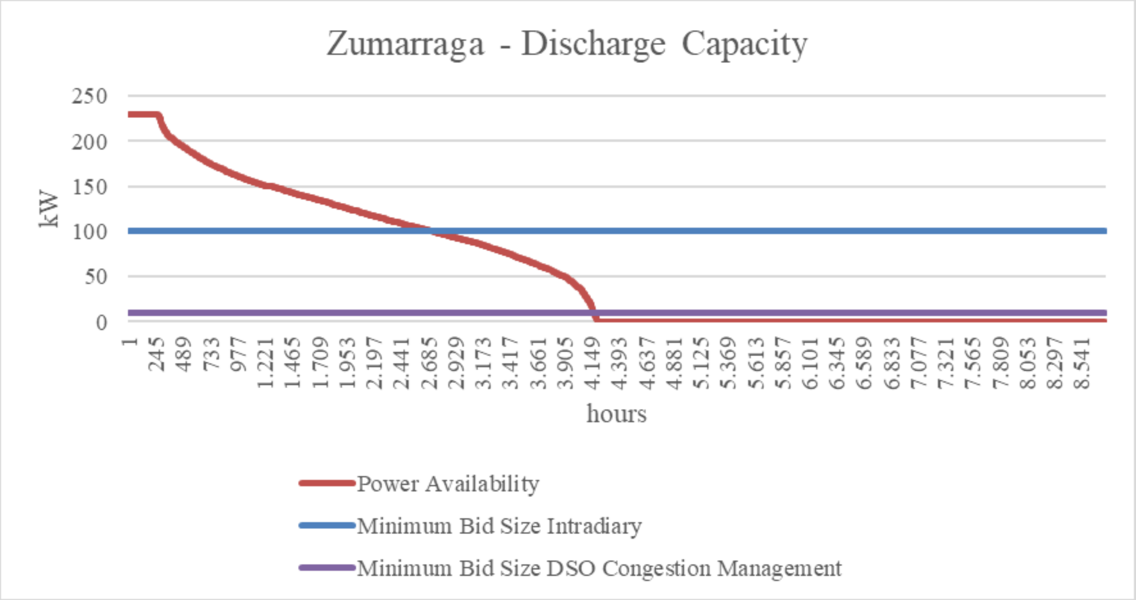


Figure 102: Zumarraga - Discharge Capacity

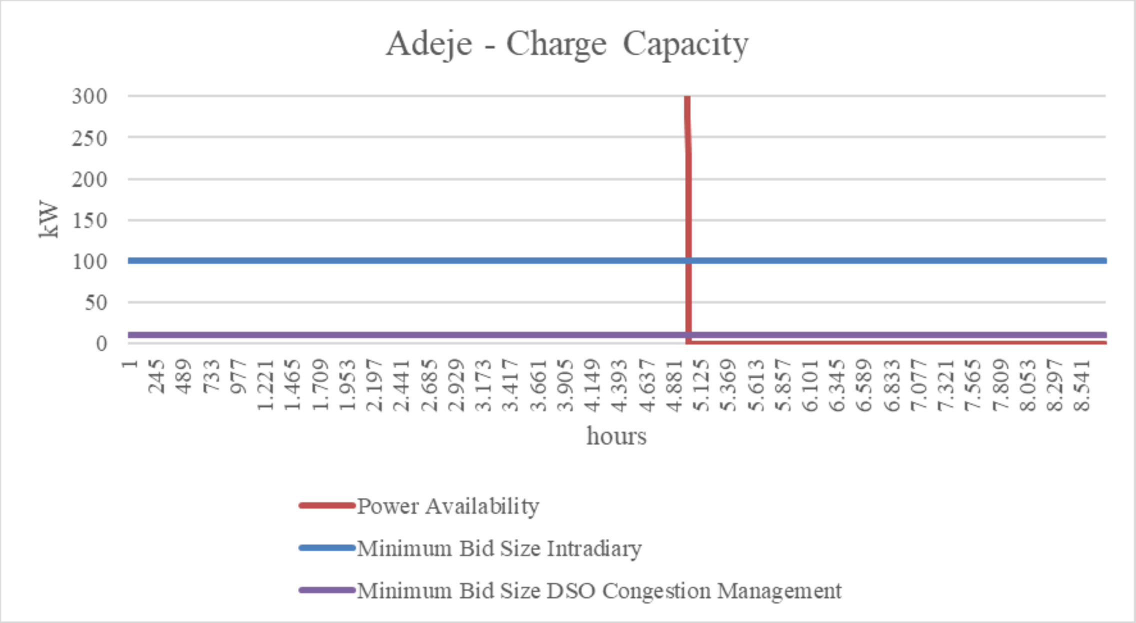


Figure 103: Adeje - Charge Capacity

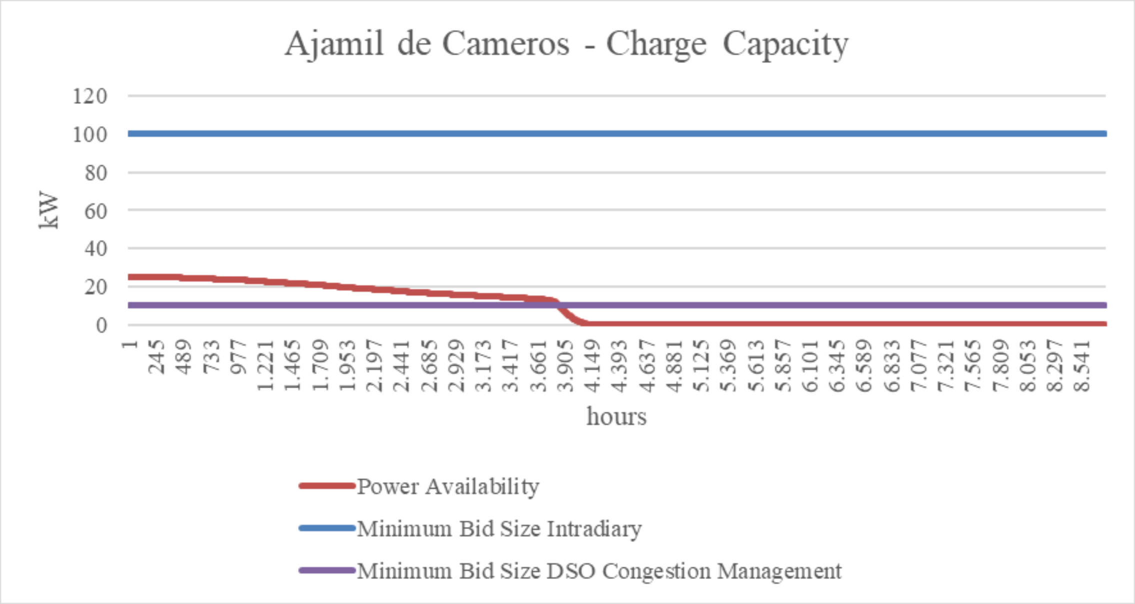


Figure 104: Ajamil de Cameros - Charge Capacity

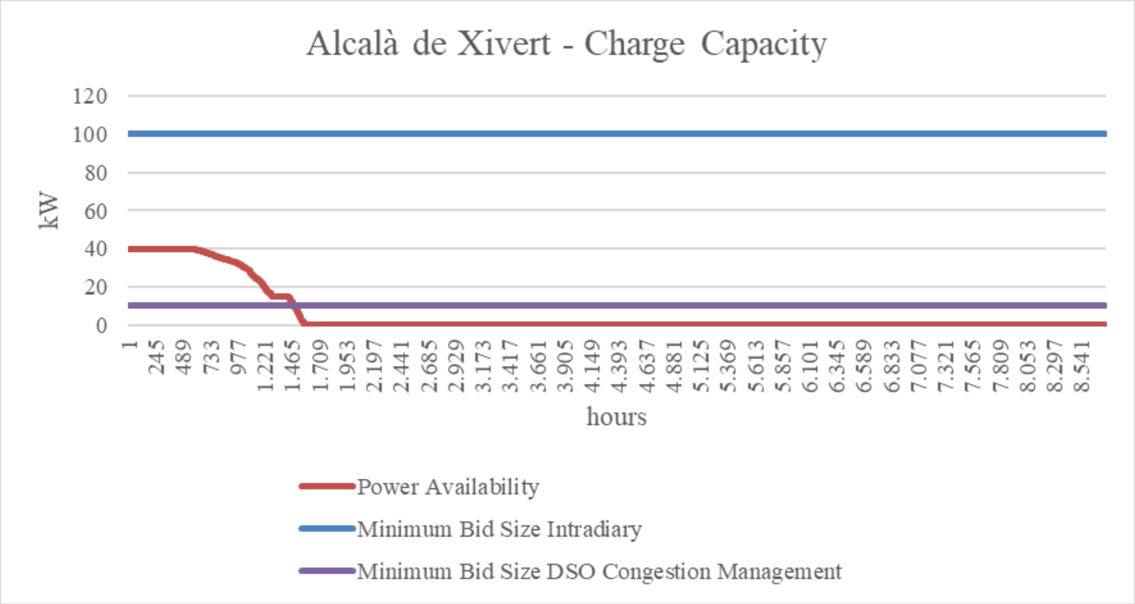


Figure 105: Alcalà de Xivert - Charge Capacity

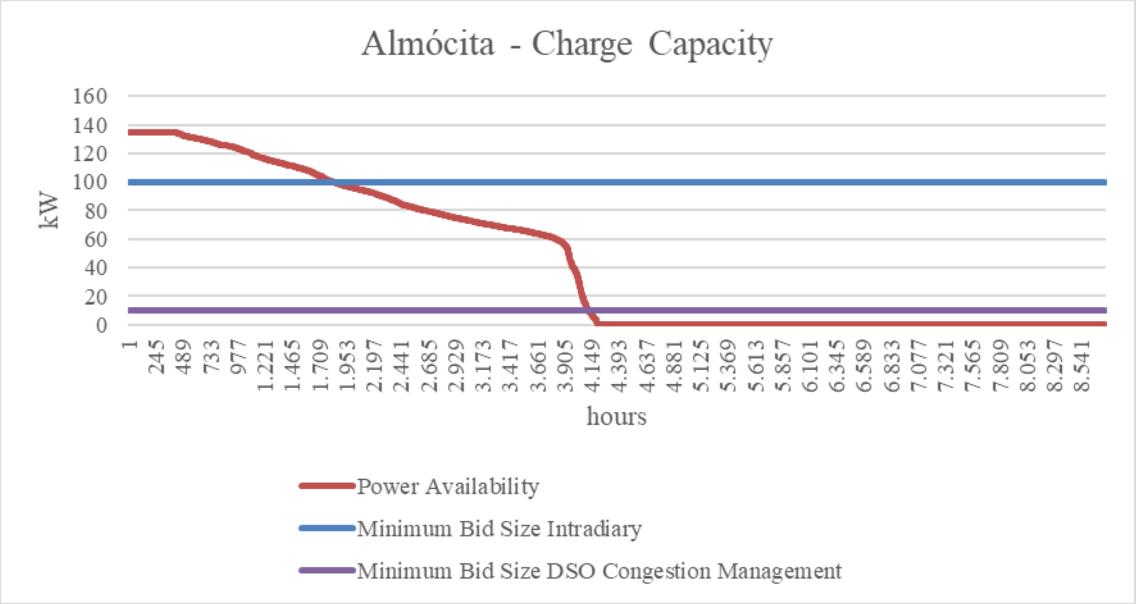


Figure 106: Almócita - Charge Capacity

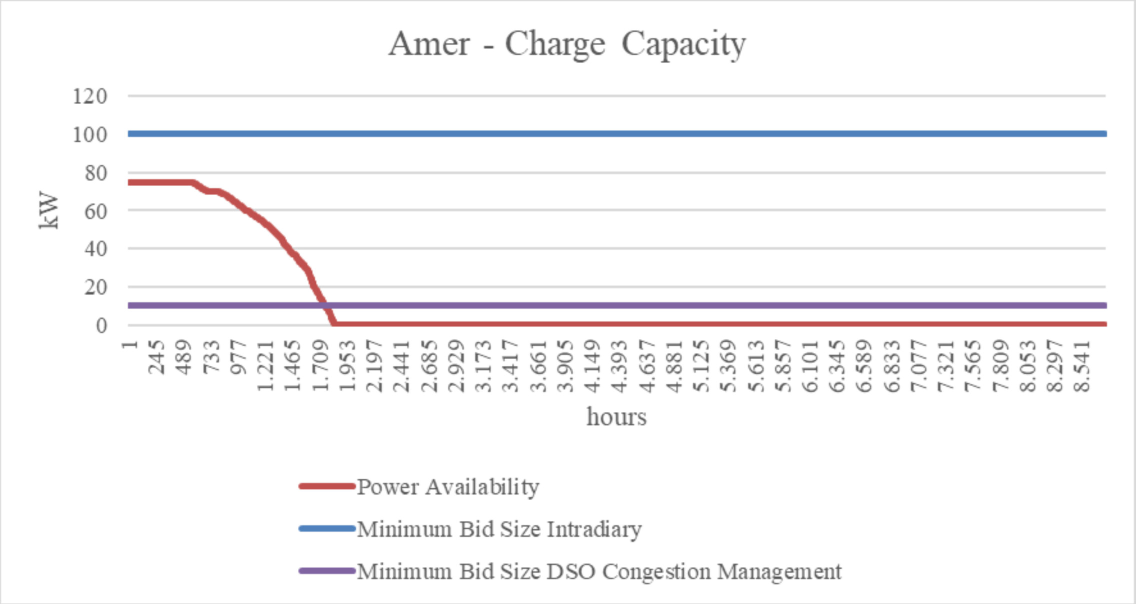


Figure 107: Amer - Charge Capacity

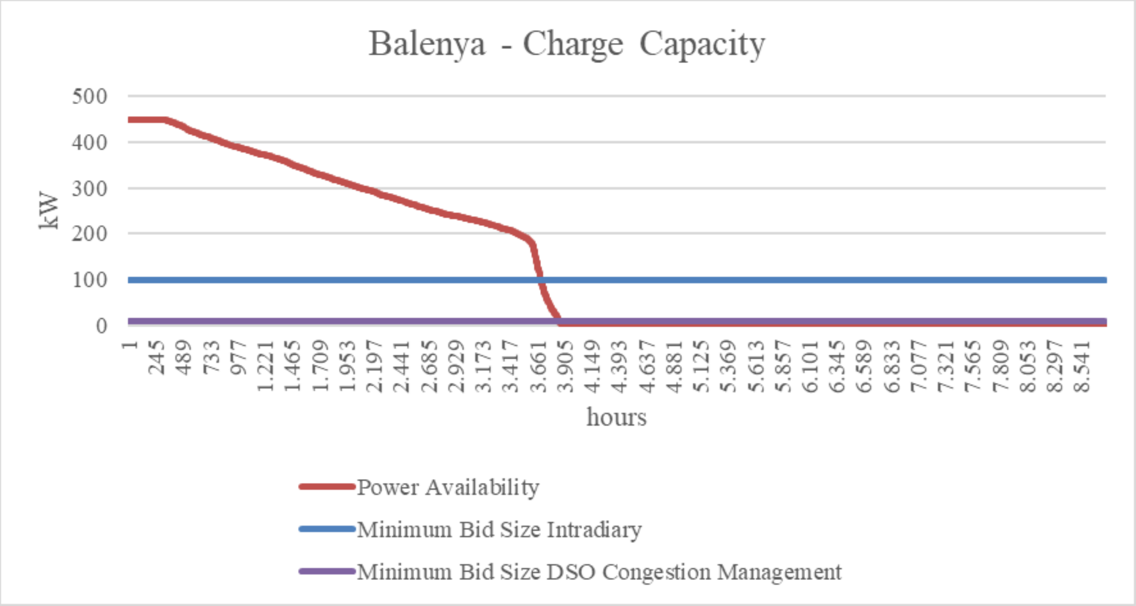


Figure 108: Balenya - Charge Capacity

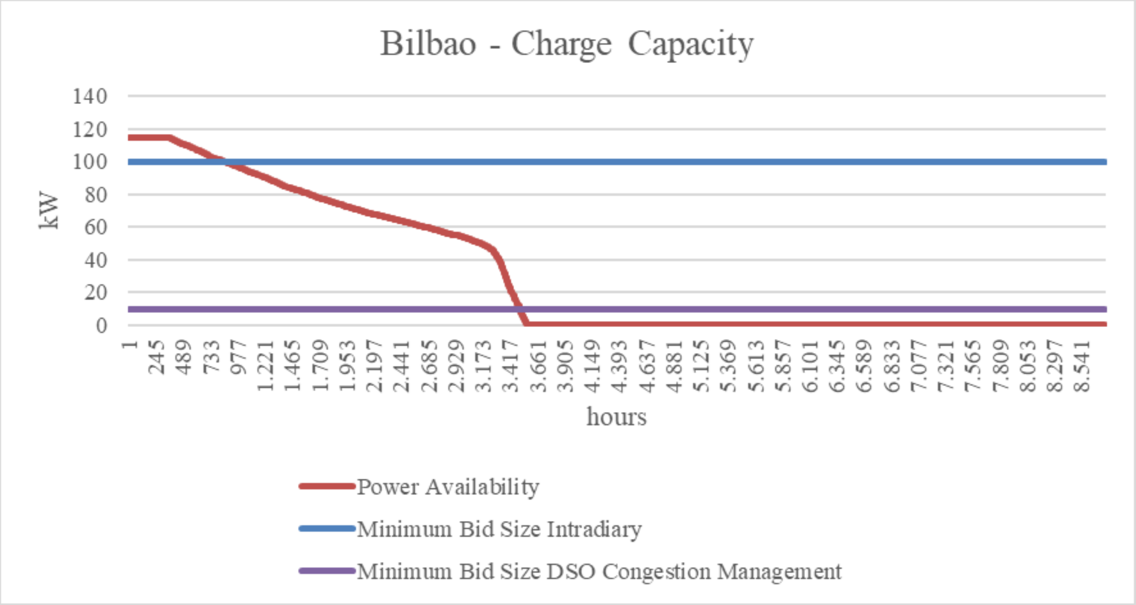


Figure 109: Bilbao - Charge Capacity

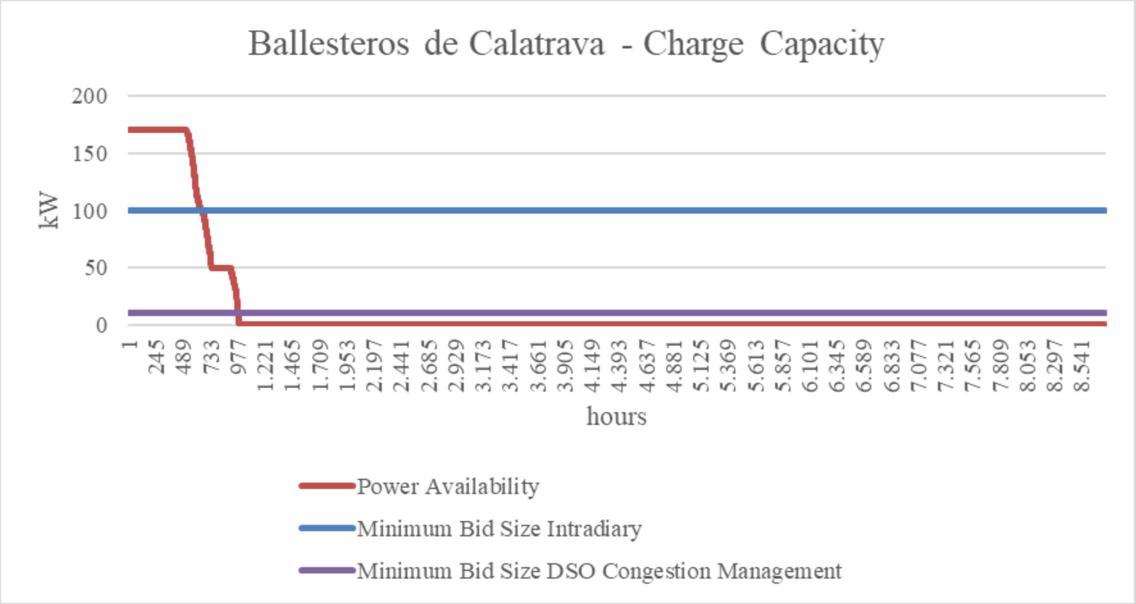


Figure 110: Ballesteros de Calatrava - Charge Capacity

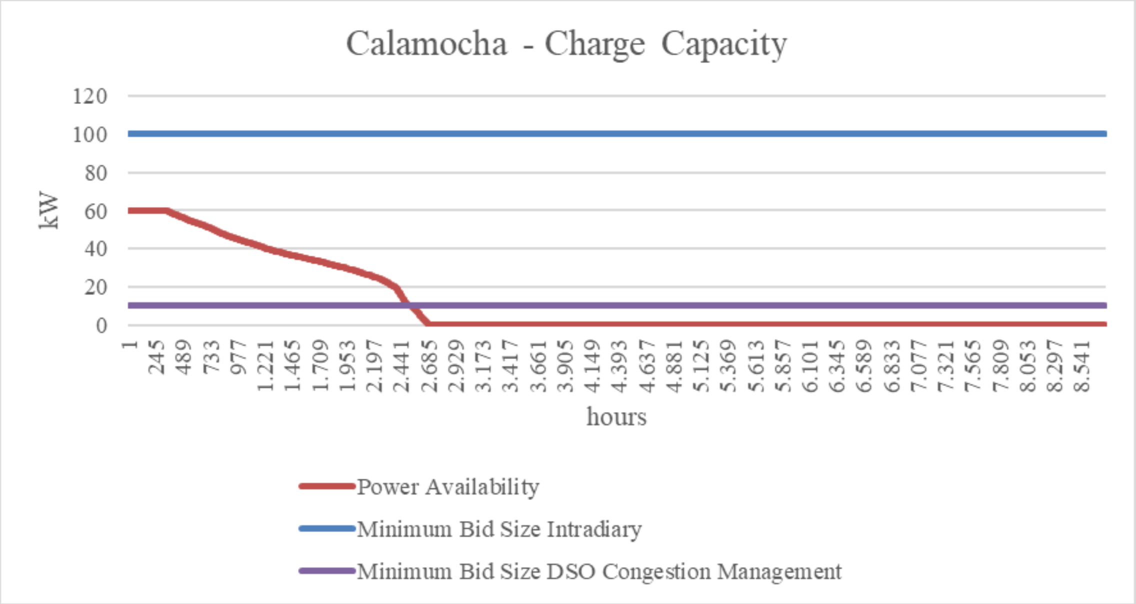


Figure 111: Calamocha - Charge Capacity

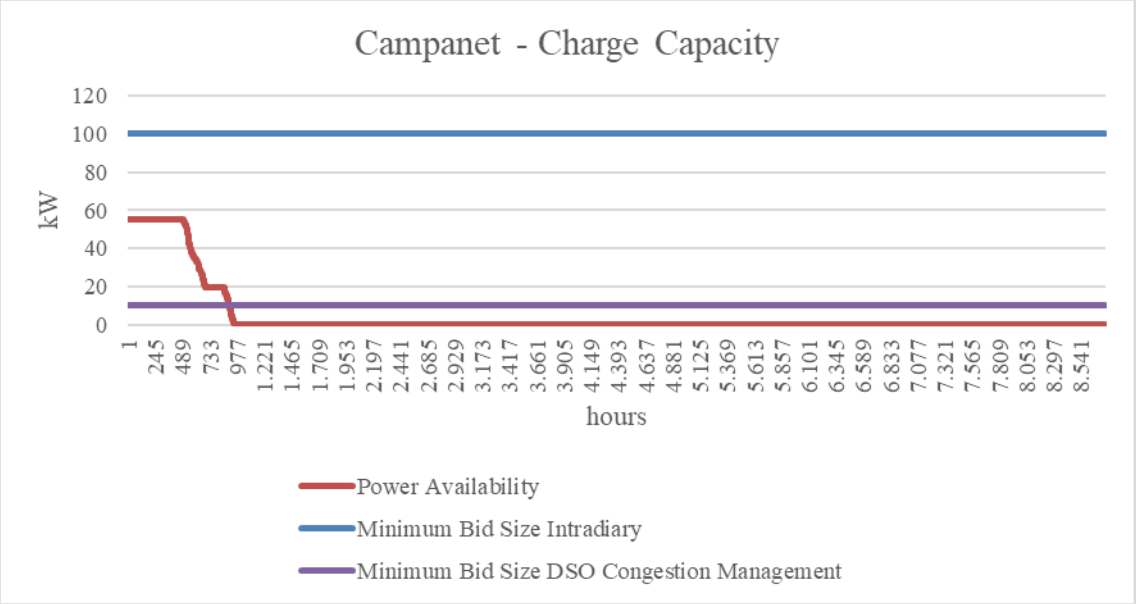


Figure 112: Campanet - Charge Capacity

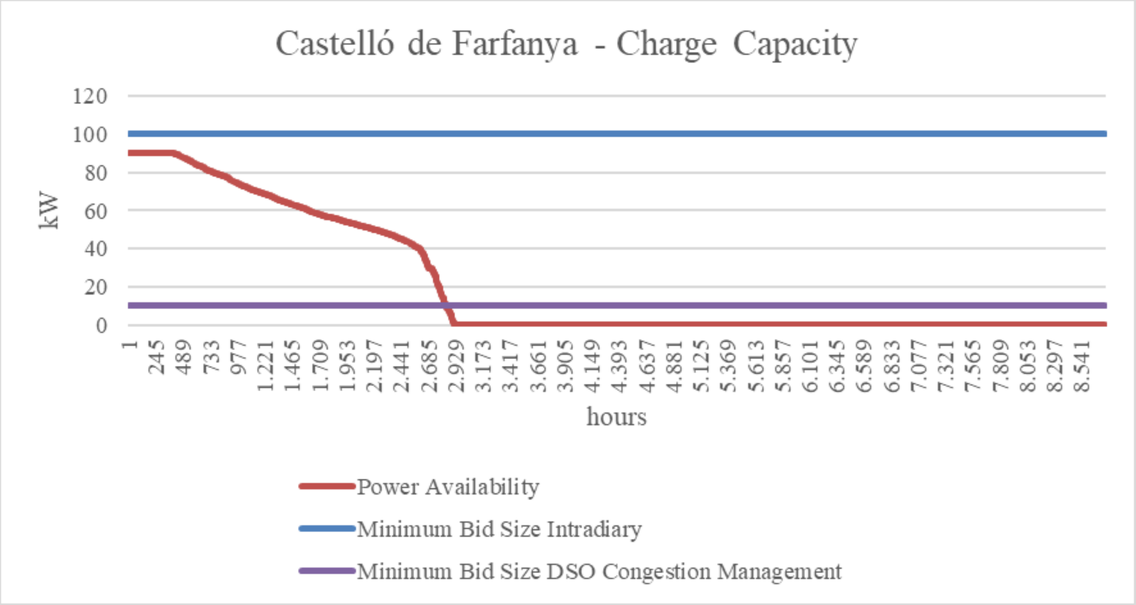


Figure 113: Castelló de Farfanya - Charge Capacity

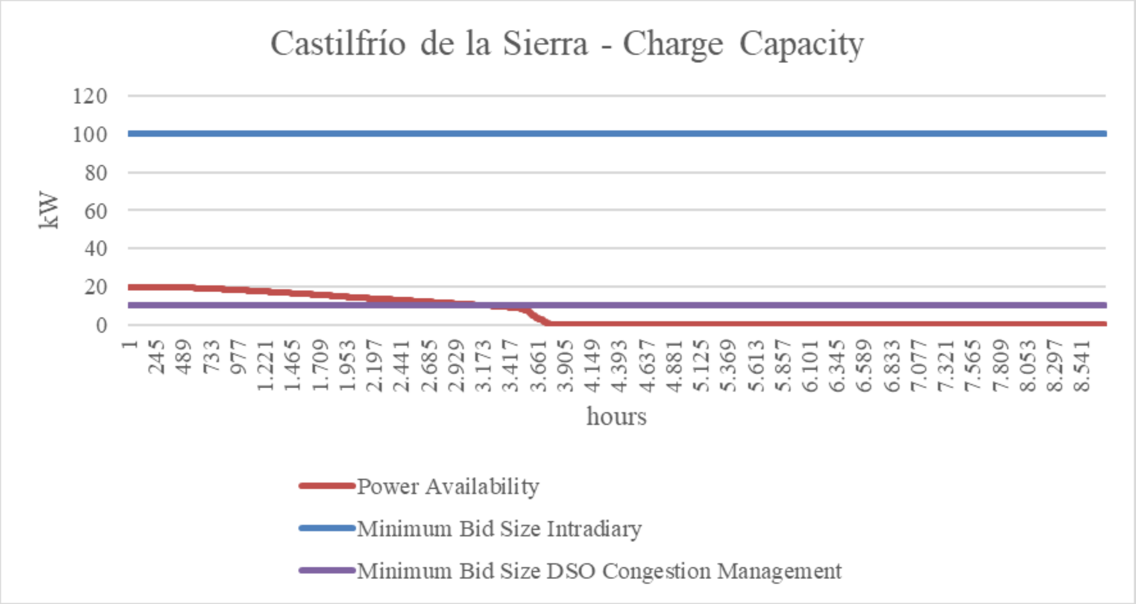


Figure 114: Castilfrío de la Sierra - Charge Capacity

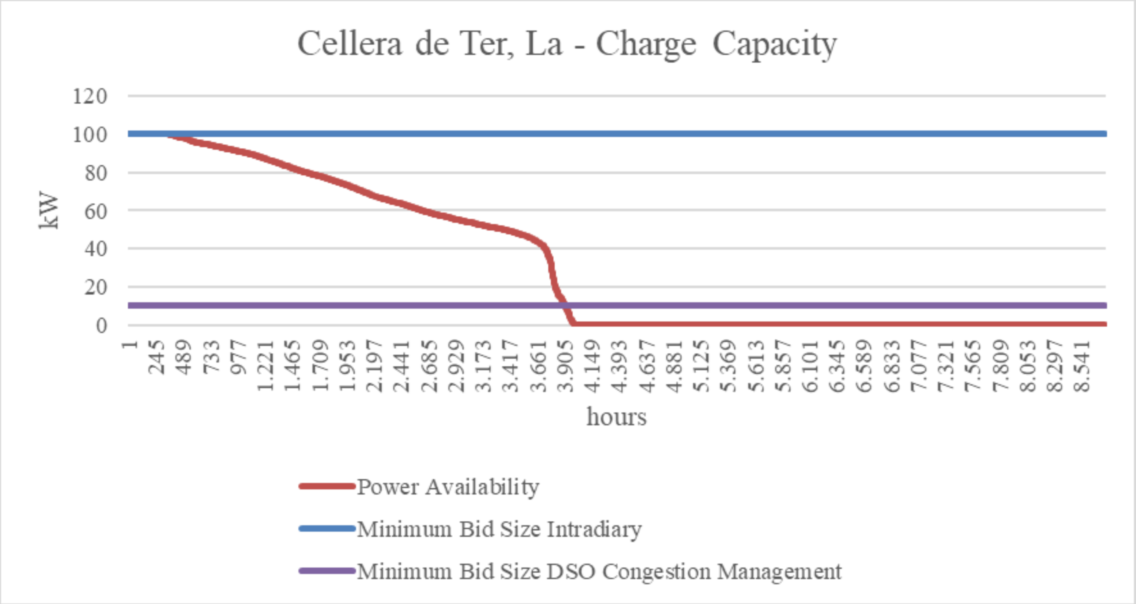


Figure 115: Cellera de la Ter, La - Charge Capacity

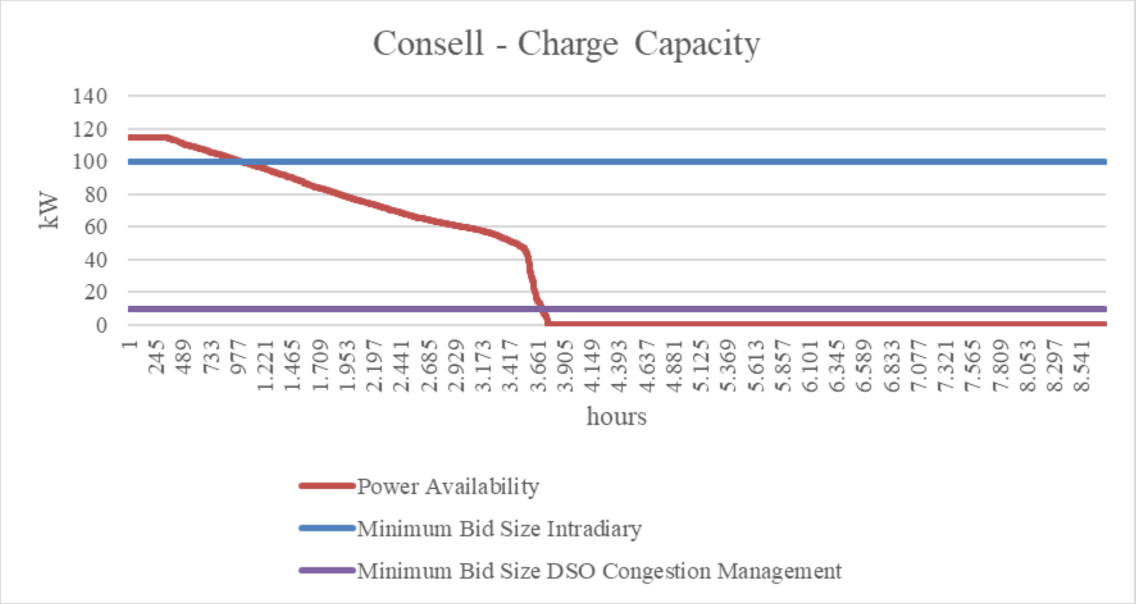


Figure 116: Consell - Charge Capacity

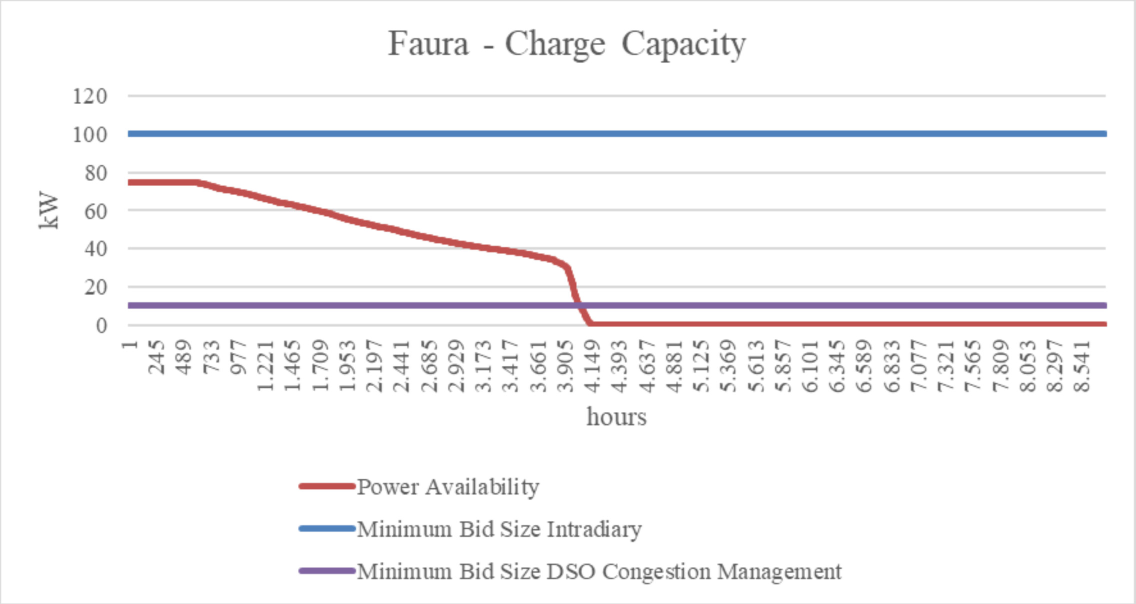


Figure 117: Faura - Charge Capacity

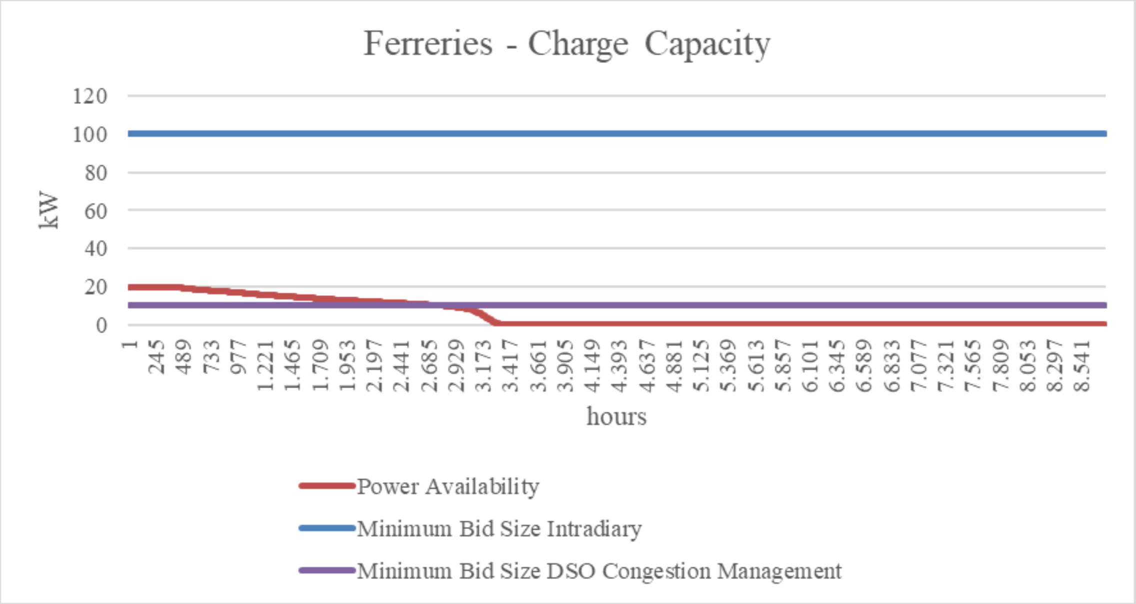


Figure 118: Ferreries - Charge Capacity

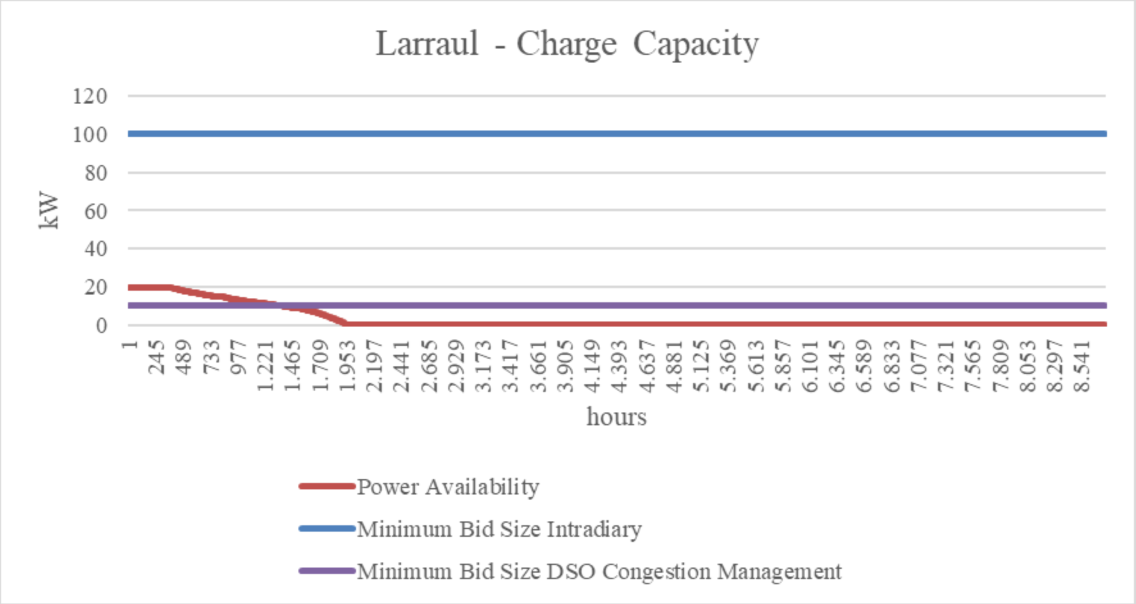


Figure 119: Larraul - Charge Capacity

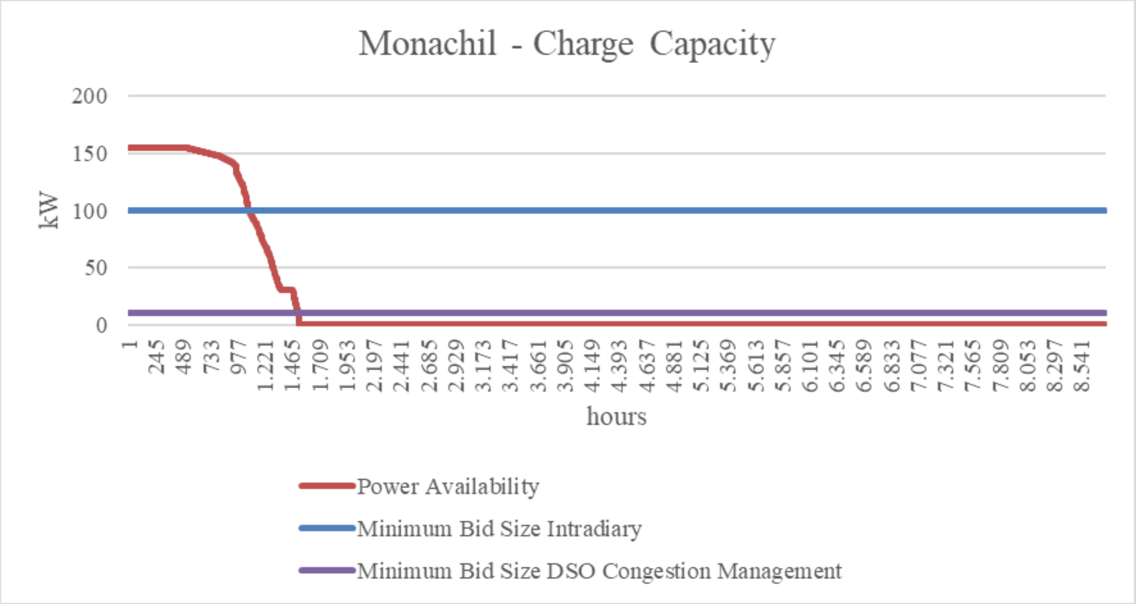


Figure 120: Monachil - Charge Capacity

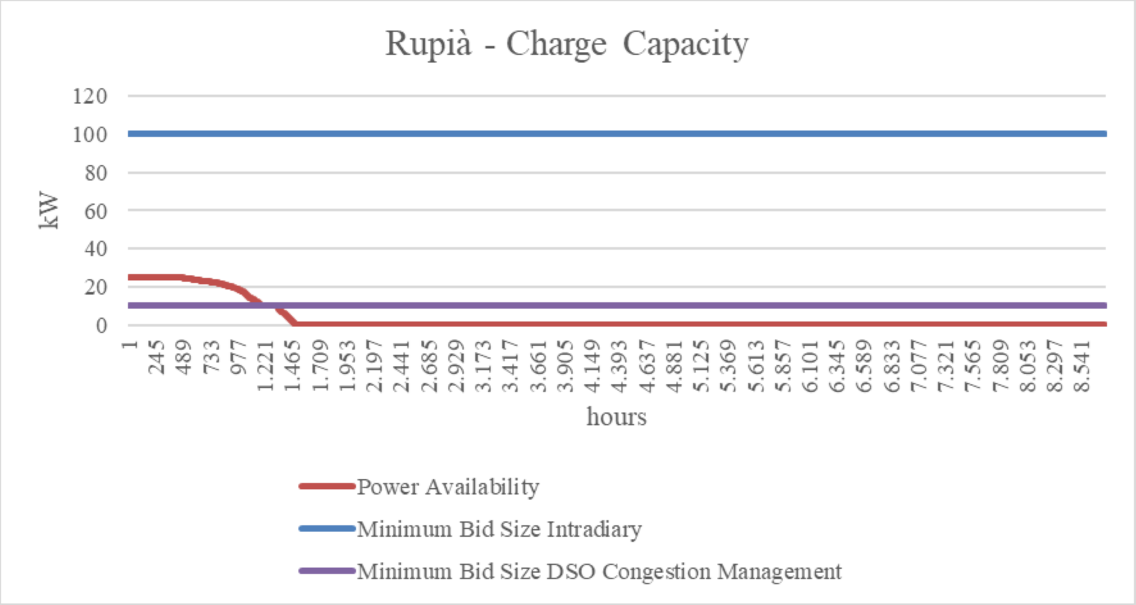


Figure 121: Rupià - Charge Capacity

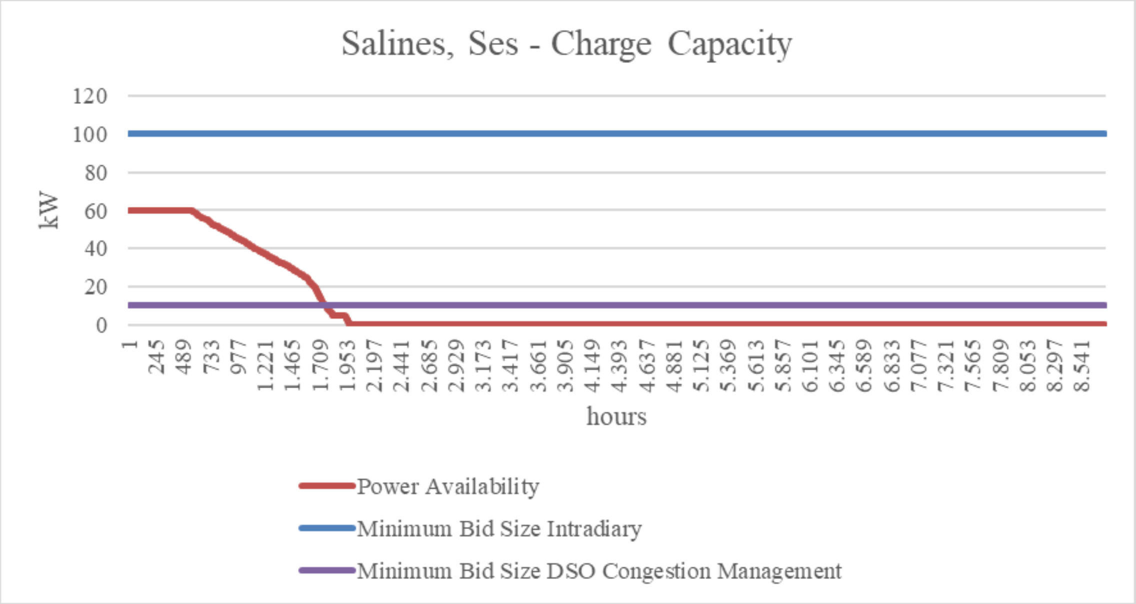


Figure 122: Salines, Ses - Charge Capacity

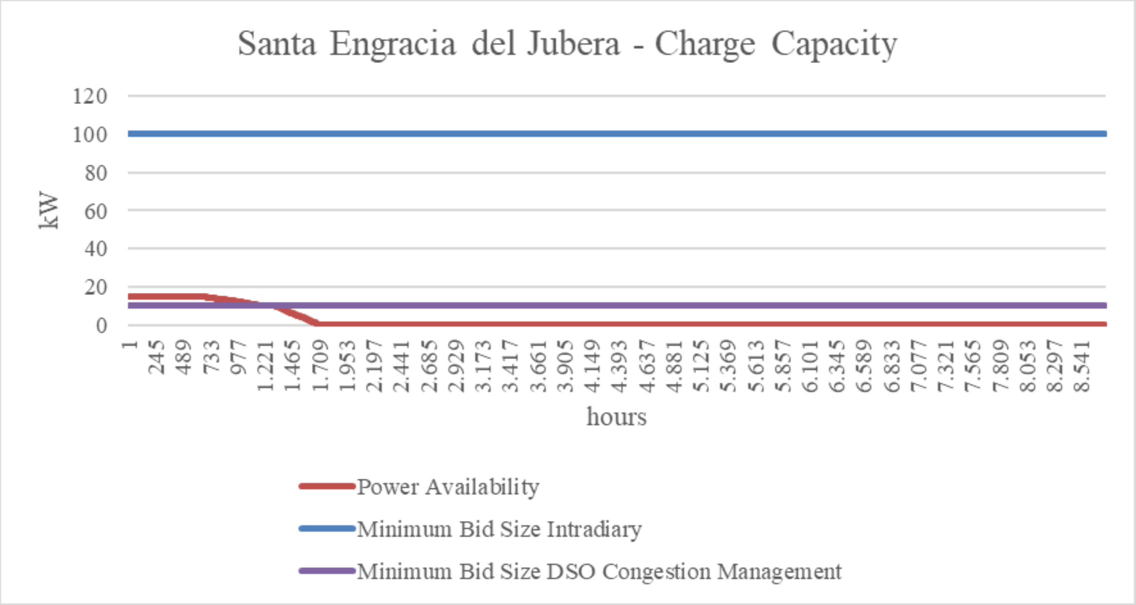


Figure 123: Santa Engracia del Jubera - Charge Capacity

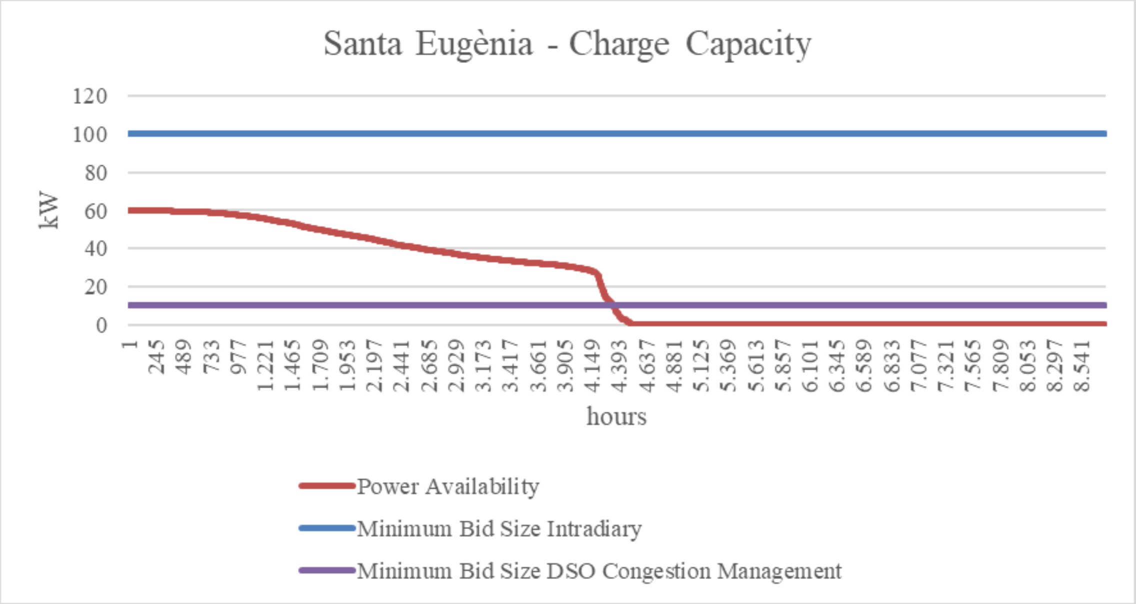


Figure 124: Santa Eugènia - Charge Capacity

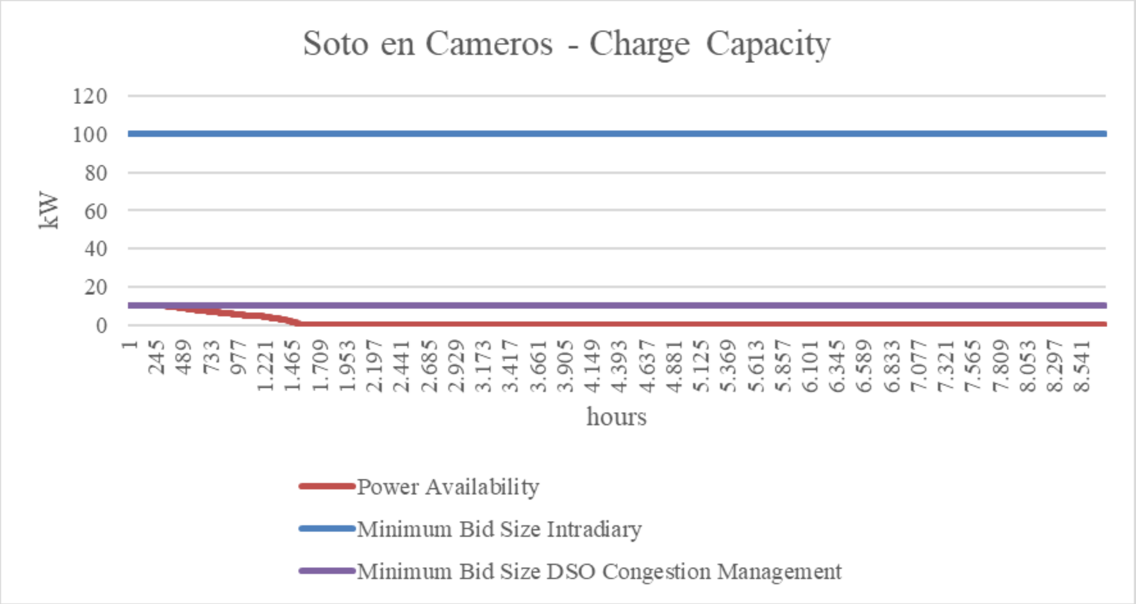


Figure 125: Soto en Cameros - Charge Capacity

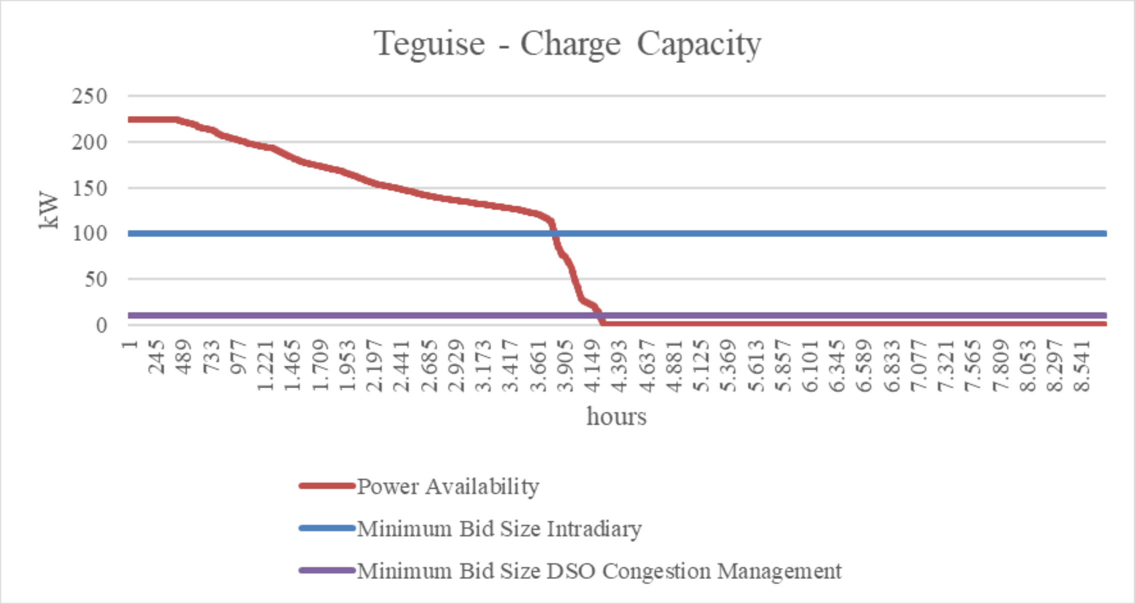


Figure 126: Teguise - Charge Capacity

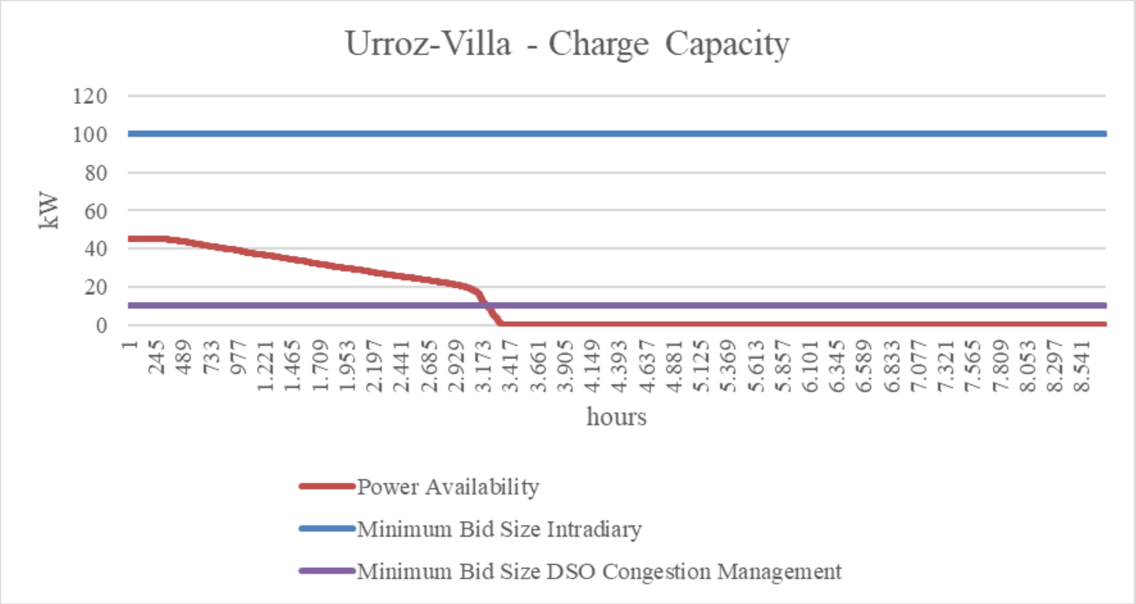


Figure 127: Urroz-Villa - Charge Capacity

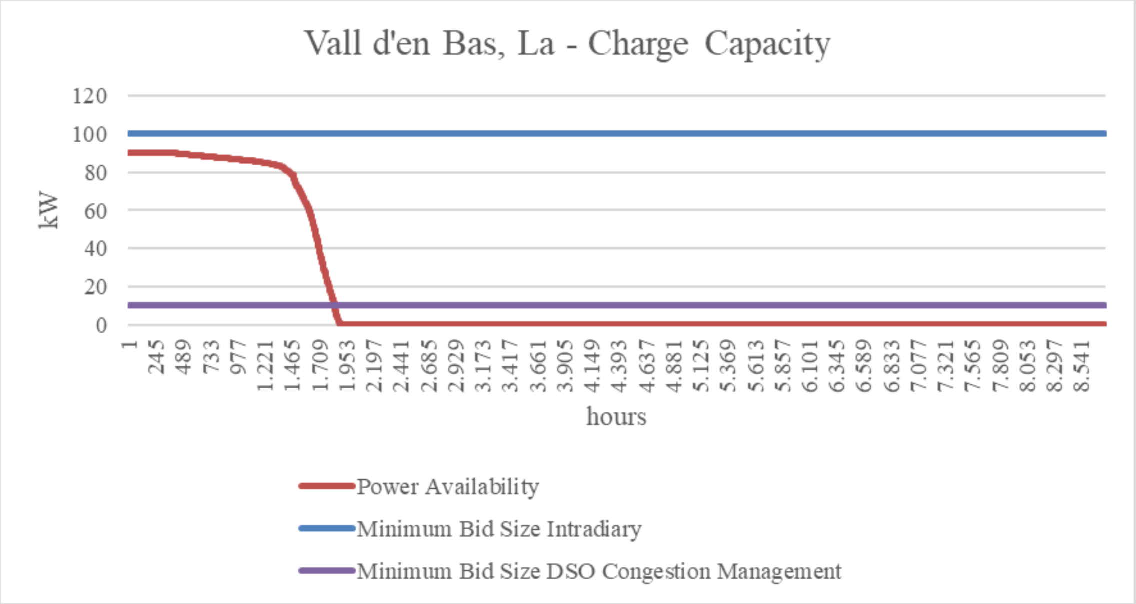


Figure 128: Vall d'en Bas, La - Charge Capacity

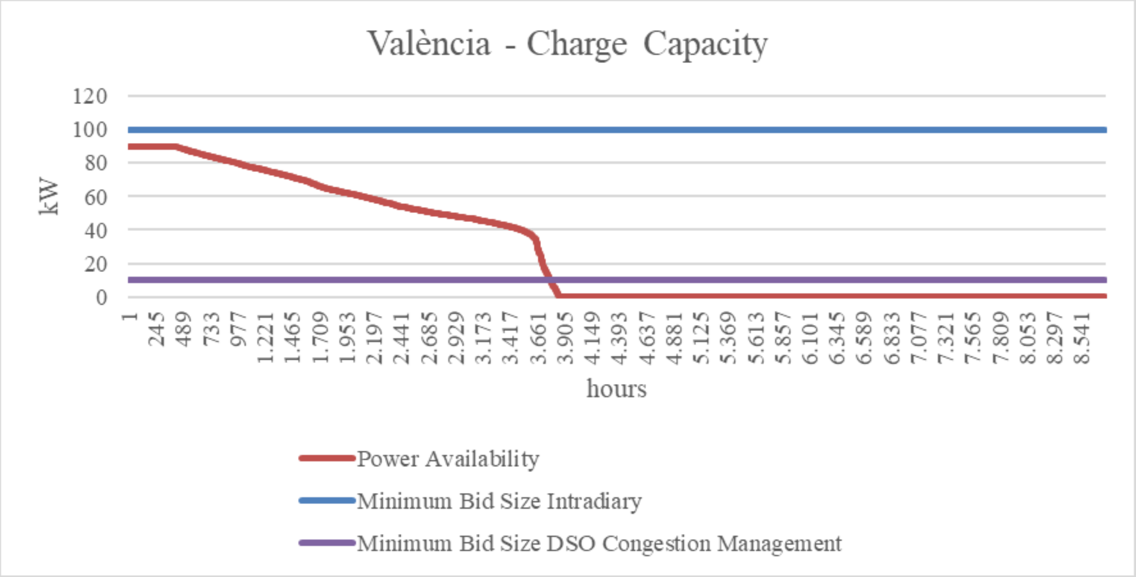


Figure 129: València - Charge Capacity

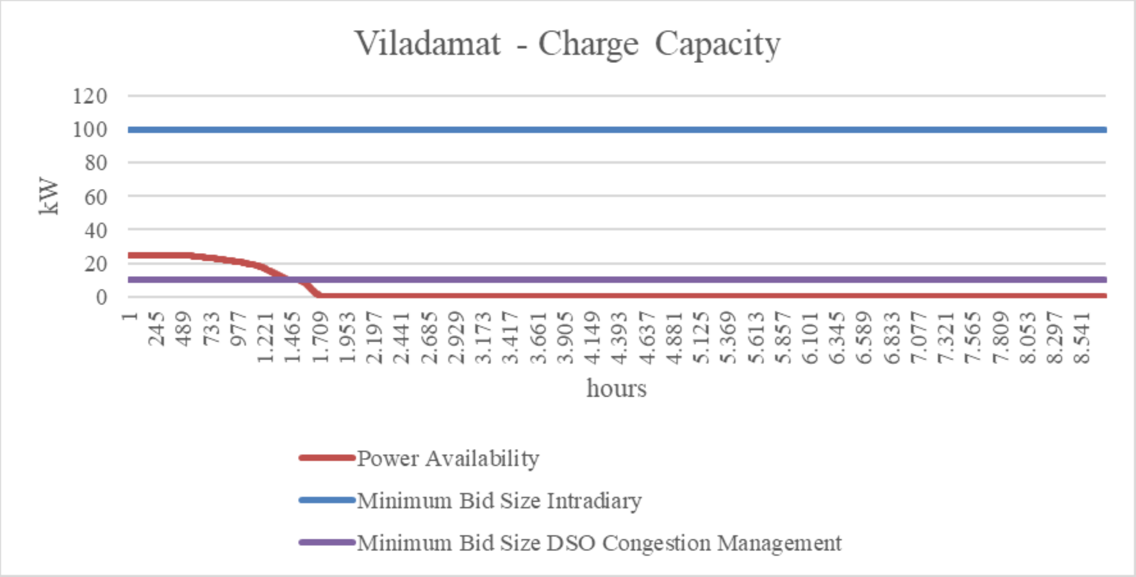


Figure 130: Viladamat - Charge Capacity

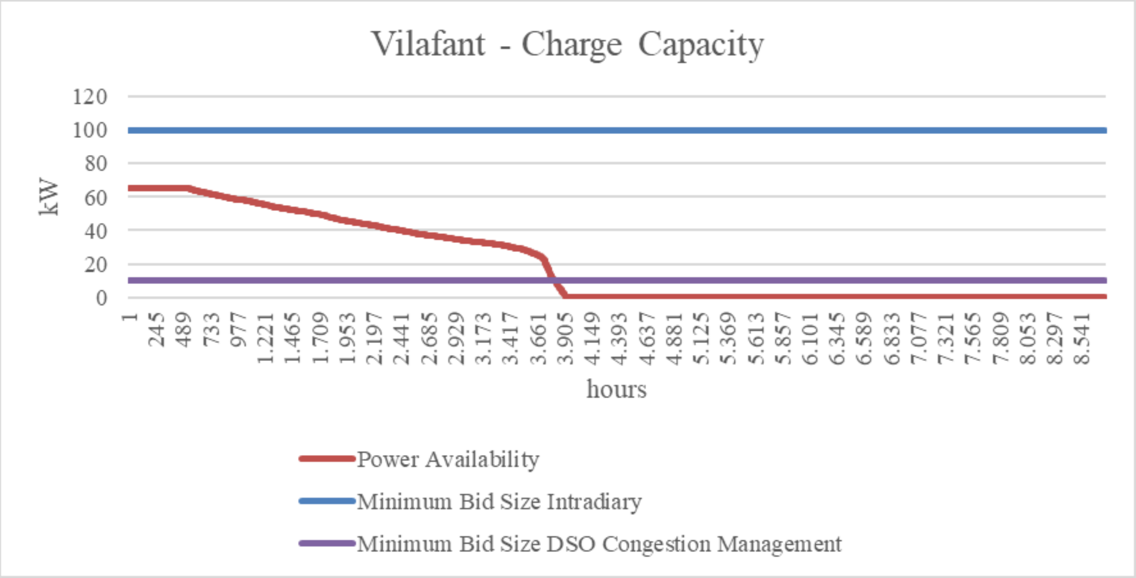


Figure 131: Vilafant - Charge Capacity

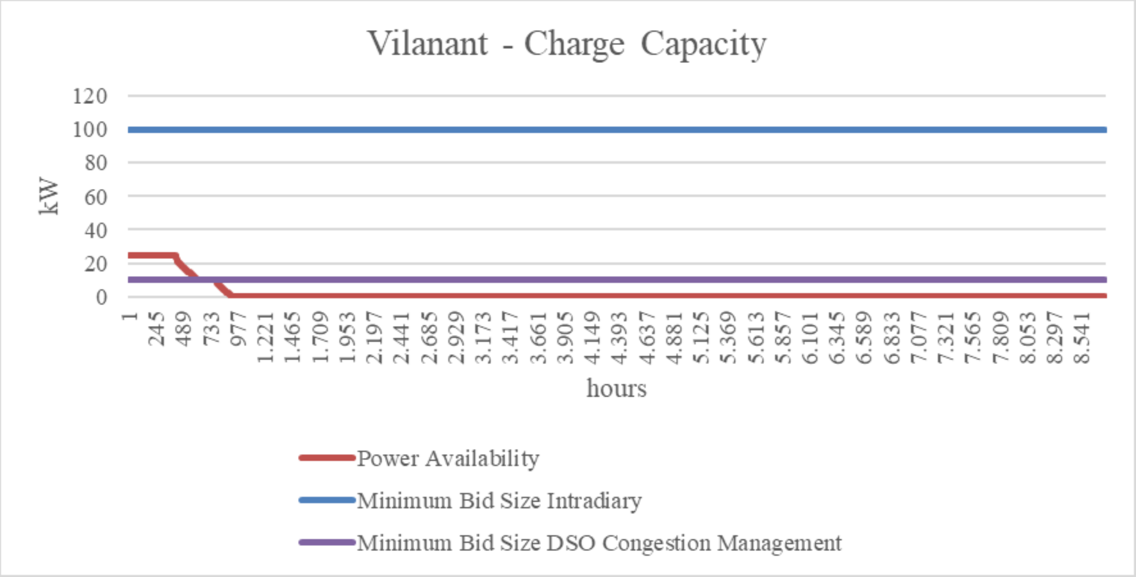


Figure 132: Vilanant - Charge Capacity

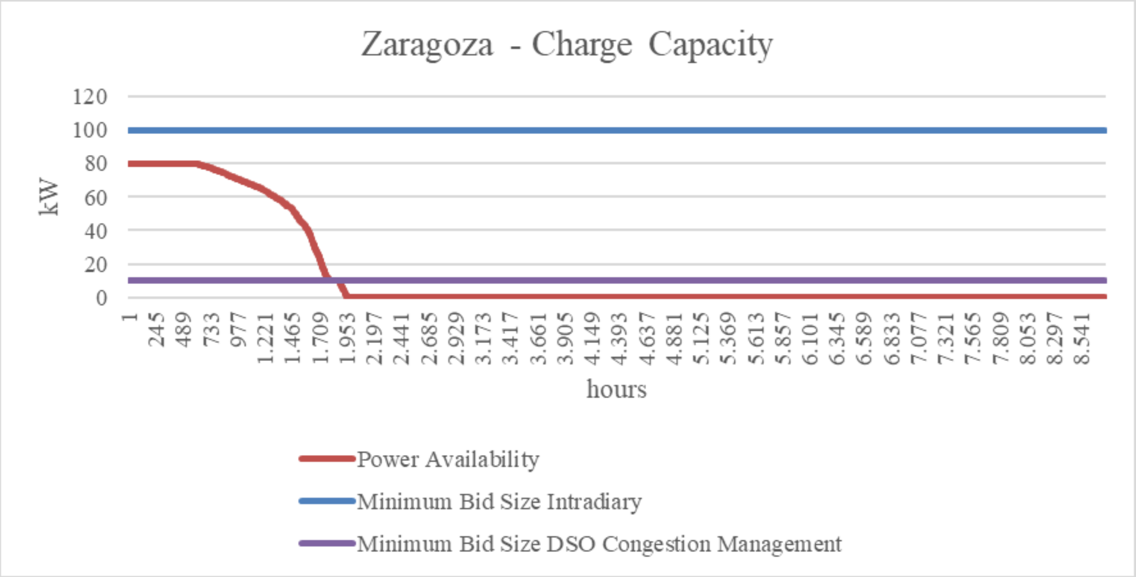


Figure 133: Zaragoza - Charge Capacity

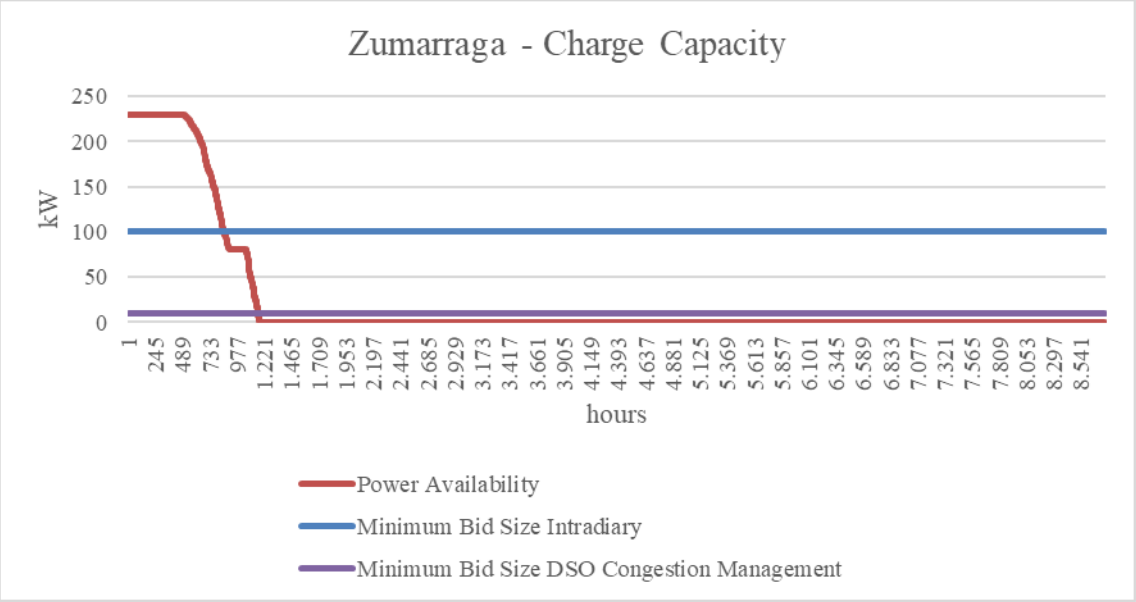


Figure 134: Zumarraga - Charge Capacity

7.2 Survery questions

The specific questions posed in the study are as follows:

1) What resources do you have shared? (Purchased with common money)
2) Do you currently have or are in the process of developing any automation system in homes, premises or services that participate in the EC?
3) What technologies do you use or intend to use?
4) What amount of controllable loads do you have in the EC [kW] in a day?
5) Are there battery storage systems in your EC?
6) Total Storage Capacity [kW]
7) Estimated Maximum Energy Injection to the Grid per Hour [kWh]
8) Have you experienced operational difficulties due to the lack of accurate measurement of the energy generation and consumption that occurs in your EC?
9) What measurement capacity exists in your EC?
10) Approximately how often do you read your meters?
11) Approximately how often do you collect the information that those meters read?
12) Is it more profitable for EC to sell surpluses to the grid or make Power Purchase Agreements (PPA)s?
13) Does the lack of sufficient generation capacity to have the minimum supply size represent a disadvantage for being able to participate in the electricity market? (sell energy from the EC)
14) Would it be more attractive to participants to have a fixed price for the energy that is fed into the grid rather than a variable price?
15) Which of the following actions would the members of your community agree to carry out despite losing well-being due to consuming less energy?
16) What activities would you find useful to delegate to an aggregator?
17) Did you have problems to connect your project to the distribution network?
18) What kind of problems have you had with the distribution network?

19) Could the lack of regulation of the activities of the EC create a problem in developing this new figure?

8. References

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