MASTER'S DEGREE IN INDUSTRIAL ENGINEERING

TFM

STANDARDIZATION AND HARMONIZATION OF THE FLEXIBILITY MARKET IN THE SPANISH AND EUROPEAN ELECTRICITY WHOLESALE MARKET

Author: Diego Sagaz Spottorno

Director: José Pablo Chaves Ávila

Co-director: Shilpa Bindu

Author's signature:

Director's approval:

Co-director's approval:

Madrid

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Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

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Fdo.: Diego Sagaz Spottorno Fecha: 29/ 08/ 2023

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: José Pablo Chaves Ávila Fecha: 29/ 08/ 2023

LA CODIRECTORA DEL PROYECTO

Fdo.: Shilpa Bindu Fecha: 29/ 08/ 2023

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Author: Sagaz Spottorno, Diego

Co-Director: Bindu, Shilpa

Director: Chaves Ávila, José Pablo

Collaborating Entity: ICAI – Comillas Pontifical University

ABSTRACT

This project studies the coordination potential between local flexibility markets and existing wholesale electricity markets, with an especial focus on the coordination between the flexibility market proposed in the OneNet Project and several existing electricity markets in Spain. This thesis creates an overview of good practices and methodology in the design of local flexibility market and analyzes coordination, harmonization, and potential barriers to increase the efficiency of the overall electricity system.

Keywords: Harmonization, Coordination, Bid forwarding, Bid Processing, Aggregation, Flexibility markets, Electricity markets.

1. Introduction

As established in the Spanish National Energy and Climate Plan for the 2023-2030 period, 84% of the electricity generation must be produced by renewable sources (1). As it is known, these energy sources usually are not manageable (i.e., cannot choose the time and quantity produced) and depend on external factors, like the wind and sun.

In order to correctly operate the electricity system, there needs to be a constant balance of generation and demand. The typical solution to this need was to change the generation so it could follow the demand, but nowadays, since generation is not controllable anymore, the only solution is to adapt the demand to meet the generation pattern.

One of the ways to adjust to this shift from the traditional system operation, is through flexibility, that can be procured as demand-side management or some other sources. This flexibility provides small changes in the generation or demand side, that allows the system operator to maintain the balance between demand and production

2. OneNet Project

OneNet is a European project whose objective is to create a coordinated and flexible market in a consumer-centric environment that allows the integration of all the different players in the electricity sector throughout Europe. In addition to including flexibility providers in the market, this project aims to standardize the products participating in the different markets, and to have them managed from a common platform (2).

In addition to better management, achieving harmonization and coordination of the electricity market will serve to increase the liquidity of many markets, such as balancing energies or the new flexibility markets. This increase in liquidity will be decisive in making them economically viable, as well as facilitating the participation of new agents in the markets.

From the OneNet project, the flexibility market proposed for local congestion management is specifically studied, with which the potential for coordination with various electricity markets in Spain is analyzed. A systematic methodology is established to carry out a correct and orderly analysis of the possible compatibility between two markets. To this end, a basis for the harmonization of products and services is established, in which certain attributes and characteristics capable of defining them are selected, so that a comparison can then be made between markets.

3. Coordination between OneNet and the Spanish markets

Once the standardized attributes that should define the different markets are known, a selection of several electricity markets in Spain is made to study their compatibility for coordination and bidding between this market and the OneNet flexibility market. Among the possible Spanish markets, three markets corresponding to balancing energies are selected for the study: secondary regulation, tertiary regulation and replacement reserve market, the day ahead, and the intraday energy market.

In order to analyze the compatibility between both markets, each of the characteristics that define the market must be compared one by one, following the methodology mentioned above. This comparison is carried out to analyze the possibility of coordinating and sending offers from one market to the other.

The most interesting practice is to be able to send offers from the OneNet flexibility market to the rest of the existing markets. As, in general, these are markets with greater restrictions, it will be necessary to modify, in some way, the bids in the flexibility market in order to be able to send the offers to the different markets, this process is known as bid processing. These modifications include aggregating small bids, typical of smaller flexibility and demand management providers, in order to get blocks of larger bids accepted in the markets, or making a filter that only allows access to technologies that meet the technical requirements of the market they want to access.

4. Results

In the five cases studied (i.e., each of the five Spanish electricity markets compared, one by one, with the OneNet flexibility market), it has been determined that both the balancing energy markets, that is, secondary, tertiary regulation and substitution reserve and the intraday energy market are compatible, with some conditions, so they have the potential to forward bids with the OneNet flexibility market.

In the case of the day ahead energy market, it has been determined that bid forwarding in this regard is not possible due to time constraints in the markets. In addition, coordination in that direction of these two markets would not be beneficial. On the contrary, In the opposite direction, (i.e., sending bids from the daily market to the flexibility market), is not only possible, but would be beneficial to increase the liquidity of this market.

As for the other markets, a system has been set up to overcome the barriers identified in the compatibility study. This bid processing system allows bids to be modified so that they can access the new market, as shown in *Figure 1* below.

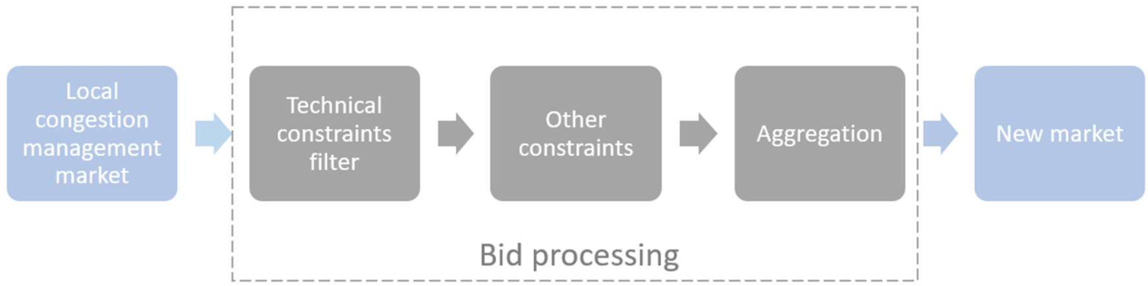

Figure 1. General bid processing method developed.

Taking into account the characteristics of all the markets, it can be concluded that, although the balancing markets are compatible and a coordination process with the flexibility market should be carried out, it has been determined that the market that would benefit most from a coordination process with the local flexibility market would be the intraday energy market. This is due to the technical characteristics of the market, its timeframe and its objectives and main uses, which would enable the access of flexibility service providers that would increase the liquidity of the market.

5. Conclusions

In view of these results, it can be stated that, after having carried out an analysis of the conditions and benefits of a harmonized, standardized and interrelated electricity system, not only at a national level, but throughout the European continent, it has been possible to define a clear methodology and process to achieve this objective. To this end, an exhaustive study of the OneNet project has been carried out, elaborating on the flexibility market it proposes.

Clear parameters were then established to analyze the potential for coordination and compatibility between different markets. These attributes are capable of maintaining the standardization of the different services required for the operation of the electricity system, but, at the same time, they must also be able to define in detail each of the different products.

Once the basis for comparing different markets has been established, a study of the potential for coordination between the flexibility market proposed by OneNet and several of the existing markets in Spain has been carried out. By performing this study, it has been determined that most of these markets have a high potential for coordination and bid forwarding between them.

In addition, possible barriers that may prevent this coordination have been detected, proposing measures and solutions to make the harmonization of products and markets in Spain and Europe feasible. With this, it has been demonstrated that all the objectives proposed in this project have been met.

6. References

[1] Ministry for the Ecological Transition and the Demographic Challenge. (2023). *Draft for the National Energy and Climate Plan 2023-2030.* Madrid.

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ESTANDARIZACIÓN Y ARMONIZACIÓN DEL MERCADO DE FLEXIBILIDAD EN EL MERCADO ELÉCTRICO ESPAÑOL Y EUROPEO

Autor: Sagaz Spottorno, Diego

Codirectora: Bindu, Shilpa

Director: Chaves Ávila, José Pablo

Entidad colaboradora: ICAI – Universidad Pontificia de Comillas

RESUMEN DEL PROYECTO

Este proyecto estudia el potencial de coordinación entre los mercados locales de flexibilidad y los mercados mayoristas de electricidad existentes, con especial atención a la coordinación entre el mercado de flexibilidad propuesto en el Proyecto OneNet y varios mercados de electricidad existentes en España. Este trabajo crea una visión general de las buenas prácticas y metodología en el diseño del mercado de flexibilidad local y analiza la coordinación, armonización y barreras potenciales para aumentar la eficiencia global del sistema eléctrico.

Palabras clave: Armonización, Coordinación, Envío de ofertas, Procesamiento de ofertas, Agregación, Mercados de flexibilidad, Mercados de energía.

1. Introducción

Tal y como establece el Plan Nacional de Energía y Clima de España para el periodo 2023-2030, el 84% de la generación eléctrica debe ser producida por fuentes renovables (1). Como es sabido, estas fuentes de energía no suelen ser gestionables, es decir, no se puede elegir el momento y la cantidad producida, y dependen de factores externos, como el viento y el sol.

Para que el sistema eléctrico funcione correctamente, es necesario que exista un equilibrio constante entre generación y demanda. La solución típica a esta necesidad era cambiar la generación para que siguiera a la demanda, pero hoy en día, dado que la generación ya no es controlable, la única solución es adaptar la demanda al patrón de generación.

Una de las formas de adaptarse a este cambio del funcionamiento tradicional del sistema es la flexibilidad, que puede obtenerse mediante la gestión de la demanda u otras fuentes. Esta flexibilidad proporciona pequeños cambios en la generación o la demanda que permiten al operador del sistema mantener el equilibrio entre demanda y producción.

2. Proyecto OneNet

OneNet es un proyecto europeo cuyo objetivo es crear un mercado coordinado y flexible en un entorno centrado en el consumidor que permita la integración de todos los distintos agentes del sector eléctrico en toda Europa. Además de incluir a los proveedores de flexibilidad en el mercado, este proyecto tiene como propósito la estandarización de los productos que participan en los distintos mercados, y que sean gestionados desde una plataforma común (2).

Además de una mejor gestión, conseguir la armonización y coordinación del mercado eléctrico servirá para aumentar la liquidez de muchos mercados, como las energías de balance, o los nuevos mercados de flexibilidad. Este aumento de liquidez será decisivo para que sean viables económicamente, además de favorecer y facilitar la participación de nuevos agentes en los mercados.

Del proyecto OneNet, se estudia, en concreto, el mercado de flexibilidad que se propone para la gestión local de las congestiones, con el que se analiza el potencial de coordinación que hay con diversos mercados eléctricos en España. Se establece una metodología sistemática para realizar un análisis correcto y ordenado de la posible compatibilidad entre dos mercados. Para ello, se establecen unas bases para la armonización de los productos y servicios, en las que se seleccionan ciertos atributos y características capaces de definirlos, para poder después hacer una comparativa entre mercados.

3. Coordinación entre OneNet y los mercados españoles

Una vez se conocen los atributos estandarizados que deben definir los distintos mercados, se hace una selección de varios mercados de electricidad en España para estudiar su compatibilidad para la coordinación y el envío de ofertas entre dicho mercado y el mercado de flexibilidad de OneNet. De entre los posibles mercados españoles, se seleccionan para el estudio tres mercados que corresponden a las energías de balance: mercado de regulación secundaria, regulación terciaria y de reserva de sustitución y con el mercado diario e intradiario de energía.

Para analizar la compatibilidad entre ambos mercados, se debe comparar una a una cada una de las características que definen el mercado, siguiendo la metodología mencionada anteriormente. Esta comparativa se lleva a cabo para analizar la posibilidad de coordinación y de envío de ofertas de un mercado a otro.

Lo más interesante es poder enviar ofertas desde el mercado de flexibilidad de OneNet al resto de mercados ya existentes. Como, en general, son mercados con mayores restricciones, será necesario modificar, de alguna forma, las ofertas que hay en el mercado de flexibilidad para poder enviar las ofertas a los distintos mercados, este proceso es conocido como el procesamiento de ofertas. Dentro de estas modificaciones se incluye agregar ofertas pequeñas, típicas de proveedores menores de flexibilidad y gestión de la demanda, para conseguir bloques de ofertas de mayor tamaño aceptadas en los mercados, o hacer un filtro que solo permita acceder a las tecnologías que cumplan con los requisitos técnicos del mercado al que quieren acceder.

4. Resultados

En los cinco casos estudiados, es decir, cada uno de los cinco mercados eléctricos españoles comparados, uno a uno, con el mercado de flexibilidad de OneNet, se ha determinado que tanto los mercados de balance, esto es, regulación secundaria, terciaria y reserva de sustitución y el mercado intradiario de energía sí son compatibles, con alguna condición, por lo que tienen potencial para el envío de ofertas con el mercado de flexibilidad de OneNet.

En el caso del mercado diario de energía, se ha determinado que no se puede realizar el envío de ofertas en ese sentido, por restricciones en cuanto al tiempo de los mercados. Además, no resultaría beneficioso la coordinación en ese sentido de estos dos mercados. En el sentido contrario, es decir, enviar ofertas desde el mercado diario al de flexibilidad, no solo es posible, sino que resultaría beneficioso para incrementar la liquidez de este mercado.

En cuanto al resto de mercados, se ha establecido un sistema que permite superar las barreras identificadas en el estudio de la compatibilidad. Este sistema de procesamiento de las ofertas permite modificar las ofertas para que puedan acceder al nuevo mercado, tal y como se muestra, a continuación, en la *Figura 1*.

Figura 1. Método general de procesamiento de ofertas desarrollado.

Teniendo en cuenta las características de todos los mercados, se puede concluir que, a pesar de que los mercados de balance son compatibles y debería llevarse a cabo un proceso de coordinación con el mercado de flexibilidad, se ha podido determinar que el mercado que más se beneficiaría de un proceso de coordinación con el mercado local de flexibilidad sería el mercado intradiario de energía. Esto se debe a las características técnicas del mercado, su desarrollo temporal y sus objetivos y usos, que permitiría el acceso de proveedores de flexibilidad que aumentasen la liquidez del mercado.

5. Conclusiones

A la vista de estos resultados, se puede afirmar que, después de haber realizado un análisis de las condiciones y beneficios que tiene un sistema eléctrico armonizado, estandarizado e interrelacionado, no solo a nivel nacional, sino en todo el continente europeo, se ha podido definir una clara metodología y proceso para llegar a ese objetivo. Para ello, se ha hecho un estudio exhaustivo del proyecto OneNet, elaborando en el mercado de flexibilidad que propone.

A continuación, se han establecido unos parámetros claros para analizar el potencial de coordinación y de compatibilidad entre distintos mercados. Estos atributos son capaces de mantener la estandarización de los diferentes servicios que requiere la operación del sistema eléctrico, pero, a la vez, también deben poder definir con detalle cada uno de los diferentes productos.

Una vez ha sido establecida la base para comparar diferentes mercados, se ha llevado a cabo un estudio del potencial de coordinación que existe entre el mercado de flexibilidad propuesto por OneNet y varios de los mercados existentes en España. Al realizar este estudio, se ha podido determinar que la mayoría de los mercados tienen un alto potencial para la coordinación y envío de ofertas entre ellos. Además, se han detectado posibles barreras que puedan impedir esta coordinación, proponiendo medidas y soluciones para que sea viable la armonización de productos y mercados en España y Europa. Con esto, queda demostrado que se cumplen todos los objetivos propuestos en este proyecto.

6. Referencias

[1] Ministerio para la Transición Ecológica y el Reto Demográfico. (2023). *Borrador del Plan Nacional Integrado de Energía y Clima 2023-2030.* Madrid.

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Madrid
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Chapter 1. Introduction

1.1. Introduction

The goal of this chapter is to do a brief study on the development of the electricity sector to understand why flexibility markets are necessary. In order to do so, a proper background on the electricity system is needed, to comprehend its challenges, drivers, the latest trends, and the regulatory environment, to have an adequate approach to study the current situation.

The key milestone in recent years was the Paris Agreement, in 2015, where almost two hundred parties acknowledged climate change and sought several lines of action to mitigate it. The main objective of this Agreement was to reduce global warming by limiting the temperature increase to pre-industrial levels (1). One of the solutions to this challenge was changing the way electricity is generated. Therefore, there has been a shift from traditional, carbon intensive, fossil fuels to renewable energy sources, with lower carbon emissions.

This change is especially having an impact throughout Europe, where the European Commission presented the European Green Deal, with the objective to reach carbon neutrality, this is, net zero emissions by the year 2050.

In order to do so, the European Commission asked its members to present a National Energy and Climate Plan (NECP) with several requirements and guidelines to follow on topics like energy efficiency, renewables, greenhouse gas emissions, interconnections, and research and innovation (2). Each country presented a NECP in 2019 for the 2021-2030 period, with their targets, investment policies, and strategic decisions to achieve the European directives. Most of these NECPs have already a reviewed version, which allowed many countries to set even more ambitious goals than four years ago.

Each country has different conditions, that result in distinct approaches on how to reach the European objectives. For instance, in the case of Spain, the Spanish Government plans to rely heavily on renewable energy generation like wind and solar photovoltaic (PV), as it can be seen in *Figure 1*, with more than a 170% increase in wind capacity and 15 times more solar capacity expected in the Spanish national energy plan, compared to 2015 levels.

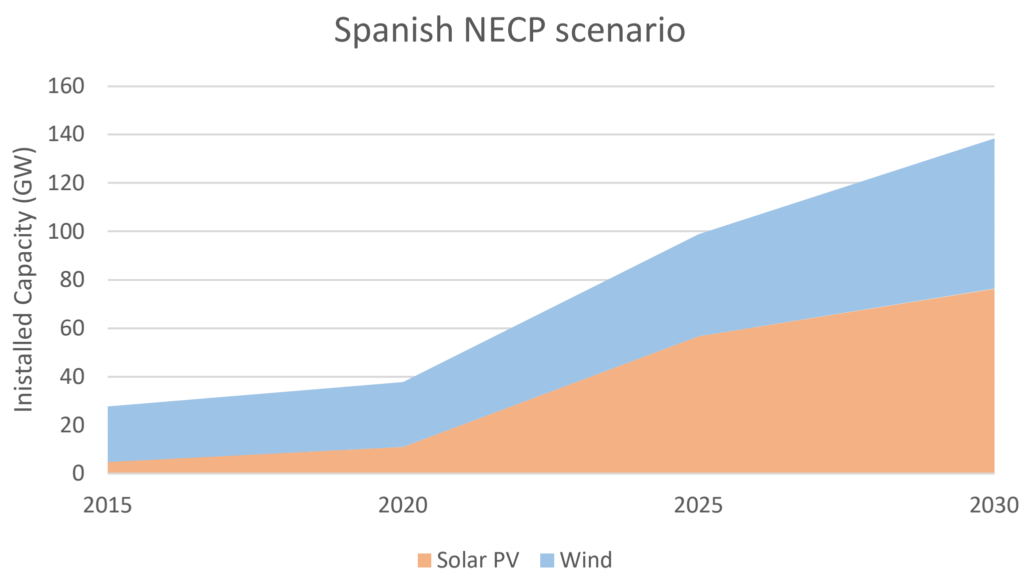

Figure 1. Solar and wind installed capacity in the Spanish NECP scenario. Source: Spanish Ministry for the Ecological Transition and the Demographic challenge, 2023 (3).

In general, new renewable energy sources have considerable technical differences compared to traditional electricity generation facilities. One of the main characteristics of renewable energy sources such as wind and solar is that they are unpredictable and harder to control than conventional fossil-fuel based generation. This means that these types of facilities cannot easily change their output, as they depend on external environmental factors like day-light hours or wind speed.

Another key difference between traditional power plants and solar and wind facilities is the size, which can have many implications. These plants are composed of hundreds of wind turbines and solar panels, with a rated power of 3-5 megawatts (MW) for the wind turbines and 350-400 kilowatts (kW) for the average solar panel (4), (5).

This granularity and smaller size compared to a nuclear power plant or a combined cycle gas turbine, with a rated power ranging between 800-1000 MW (6), allows them to be placed not only in the transmission grid, but also along the distribution network or even at the final delivery point (i.e., final consumers). The location of the sources of energy has an impact on the power-flow direction, changing the way electrical protections need to be set up, and affecting the gid layout itself.

With a high penetration of renewable energy sources these key differences start to make an impact and have consequences. Following with the Spanish case, in the NECP 2023 update, they established an 81% of renewable energy, especially wind and solar in the total electricity generation by 2030 (3). To reach this expected scenario, there has to me a major update or transformation of the grid and new technologies that enable and compliment intermittent renewable energy sources have to be further developed and deployed.

One of the most important standards on which the electricity system is based, is that generation must be equal to demand at any given time. This is not an easy task, and even more so with the high renewable energy source penetration. This is mainly due to the misalignment between the load curve and the time when renewable energy sources can produce electricity.

The load curve follows demand patterns that result from the way and at what times electricity is consumed. This curve is seasonal, with very different patterns in summer than in winter, due to day-light hours, or cooling and heating systems. It also varies depending on the day of the week, where there is an important change from commercial and industrial consumption on the weekdays to more residential consumption on the weekends.

The load curve has a typical shape, which can have some variations depending on the consumption pattern of every country. It usually has two demand peaks, in the early morning and at night, with a valley overnight and a smaller one during the day, as it can be seen in *Figure 2*.

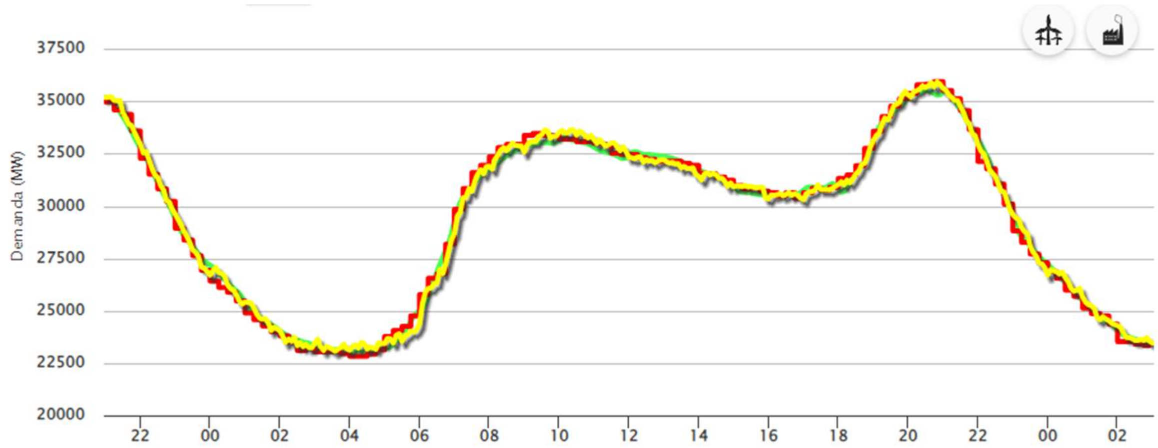

Figure 2. Demand curve for Spain, 21/02/2023. Source: REE (7).

The problem appears when comparing *Figure 2* with the following *Figure 3*, where it can be seen that the main production of solar energy is at the same time as the mid-day valley of electricity. If a country, like Spain, plans to rely on solar PV generation to supply most of the demand of the day, they need to find a way to store the solar energy they harnessed in the day-light hours to supply electricity during the rest of the day, or change the load curve so it adapts, to some extent, to the time when electricity is naturally produced.

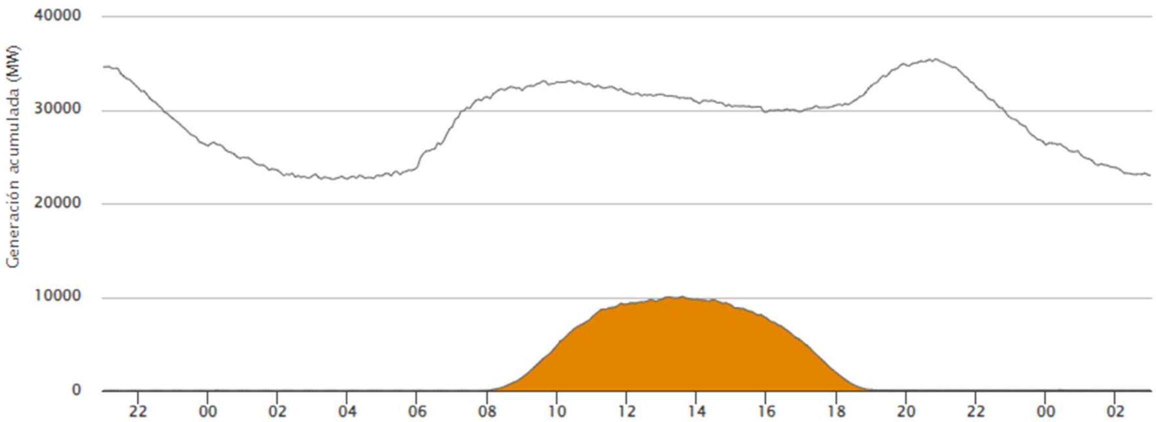

Figure 3. Solar PV generation in Spain, 21/02/2023. Source: REE (7).

Related to energy storage, there has been a massive investment by both, many countries and the European Commission, and several research studies are being carried out to further explore technologies like large-scale Lithium-Ion batteries, hydrogen electrolyzers, and other types of energy storage system, since it is known that they will play a key role to reach the proposed objectives and the *Net Zero* target.

The current plan is to install more than enough capacity of solar PV and wind so that the energy excess there is during windy hours or during the day or when the sun is shining, is stored with the technologies previously mentioned, and can be used during the rest of the time.

Historically, the way it was ensured that generation equals demand at all times, was by adjusting the output of the generation facilities so that they could follow the load-curve. This could be done, mainly, by ramping up and down fossil fuel power plants throughout the day. In the near future situation, with a system powered by hard-to-manage renewable sources, it is impossible to follow the demand, since the generating periods are limited and cannot be changed.

Instead of approach of the past of having a given load curve and making generation facilities follow the demand pattern, the proposed solution is the other way around. This is, changing the demand so it can somehow adapt to the generation pattern, that is now fixed. The way to do that is by enabling demand-side management, that would give the network the flexibility it needs to respond to times of excess and lack of generation.

Demand-side flexibility can come from many different technologies, with a wide size range. They can be for residential customers, with smart meters and appliances that are reactive to different pricing ad can be turned on or off when needed, or electric vehicles, that can act as a small-scale battery for the network, this is, inject power to the grid at times when electricity is scarce. It can also be with rooftop solar PV, that can be curtailed or have a restricted output to adapt to the system's demand.

In a larger setting, with commercial and, especially, industrial customers, it can involve the same technologies as in the previous example, and on top of that, new technologies like power to heat, power to hydrogen or gaining flexibility from improving and optimizing the energy use in many of the industrial processes.

One of the problems this poses, is that residential, commercial or medium-size industrial customers, usually do not have the size to participate in the electricity market at a utility scale. Therefore, an intermediary between the market or system operator and these flexibility providers needs to appear. This figure is the aggregator, and its main function is to group or aggregate different, small, technologies located in the same area and participate in the market presenting one offer with the total added capacity or energy that all of these technologies can provide.

Even though electricity is considered a commodity, it has specific characteristics. All of the circumstances described above, combined together, make the electricity system as a whole in one of the most complex mechanisms. To ensure reliable and accessible energy for all the customers as well as an appealing and profitable scenario for investors and players, the electricity market has to give price incentives for providers and new players and reasonable, affordable prices for the consumers, as energy access is considered a basic need. All this has to be done taking into account a variable demand forecast, the different generating technologies with all their characteristics, and ensuring that the dispatch it can be satisfied without violating any technical constraints of the network or the generators.

This results, in the case of Spain, in a market structure with very different time horizons. In the long term, from months to years, there are futures markets of both, energy and capacity, to ensure liquidity of the market or to hedge the price volatility risk by a bilateral contract with a fixed price. The day-ahead market is an auction that yields the generation dispatch for the following day, since it is a pay as clear model, all units are paid the same price, with some exceptions following regulatory restrictions. An intra-day market that has six auctions running in parallel with a continuous trading market, to ensure that generation is equal to the demand, adjusting the generating units.

There are also re-dispatching and balancing energy markets, where generators can provide a service to the system operator to ensure grid stability at all times. They can have some capacity allocated that can be activated when needed, to restore the frequency of the grid to its natural value, for example.

Regarding flexibility of the network as in demand-side management, a clear market structure has not yet been developed. There are several projects, many funded by the European Commission, that are studying the requirements, regulation, and implications for the current market for the development of a market that enables and incentivizes demand-side management technologies that will provide the network with the flexibility it needs to deploy renewable energy sources at the scale it desires.

The main concern with the development of a new flexibility market is its integration in each country's wholesale market. Several of the most important characteristics to take into account when developing a flexibility market for its integration with other markets are the timing of the market and its relationship with the other existing markets, to ensure there is enough liquidity for fair competition and pricing, and that the technologies that participate in the market comply with the current regulation and technical constraints.

From the numerous projects that have been developed related to flexibility, shown in *Table 1*, this thesis will be focusing in one project in particular, OneNet, in which the Institute for Investigation and Technology from the Comillas Pontifical University plays a key role to develop standardized products that will result in the integration and coordination of all the actors in the electricity network across Europe (8).

In particular, a part of OneNet focuses on the development of a flexibility market in Spain, and other countries, that can be replicable throughout Europe, in countries with similar characteristics, and the integration and coordination of said market in the Spanish electricity market. This project develops a guideline for the best practices to integrate a flexibility market in the Spanish wholesale market and studies its possible coordination with other markets in Spain.

Regarding the coordination of the different markets, this thesis compares and studies the similarity and compatibility of the flexibility market developed in OneNet and the Spanish wholesale electricity markets. In doing so, it yields conclusions on which markets could be a match to forward bids that are not cleared in other markets, and which markets would need further development in key areas to make that possible.

1.2. Motivation and Objectives

It is clear that climate change and the transition from traditional fossil fuels to renewable energy sources that are much cleaner and are less carbon intensive is one of the major challenges society is facing at the current time and it will continue to be so in the near future. In particular, 82% of the Spanish population thinks it is the most important and urgent challenge that the twenty-first century's society is facing, from the survey made by the European Investment Bank, and published in the Spanish NECP (3).

In light of these facts, anything that helps in the decarbonization of the industry and energy sector will be helping, to some extent, to solve one of the biggest problems nowadays. Most of the efforts, including financial, are being focused on this industry, to drive the needed change.

In addition to the changes that the whole energy sector is experiencing, the recent armed conflict between Russia and Ukraine has put, even more so, the energy sector in the spotlight. There has been, and continues to be, an energy crisis throughout Europe, which has resulted in the highest ever electricity prices paid by final consumers. As it can be seen in *Figure 4*, when many countries, including Spain, reached their maximum electricity wholesale price ever recorded.

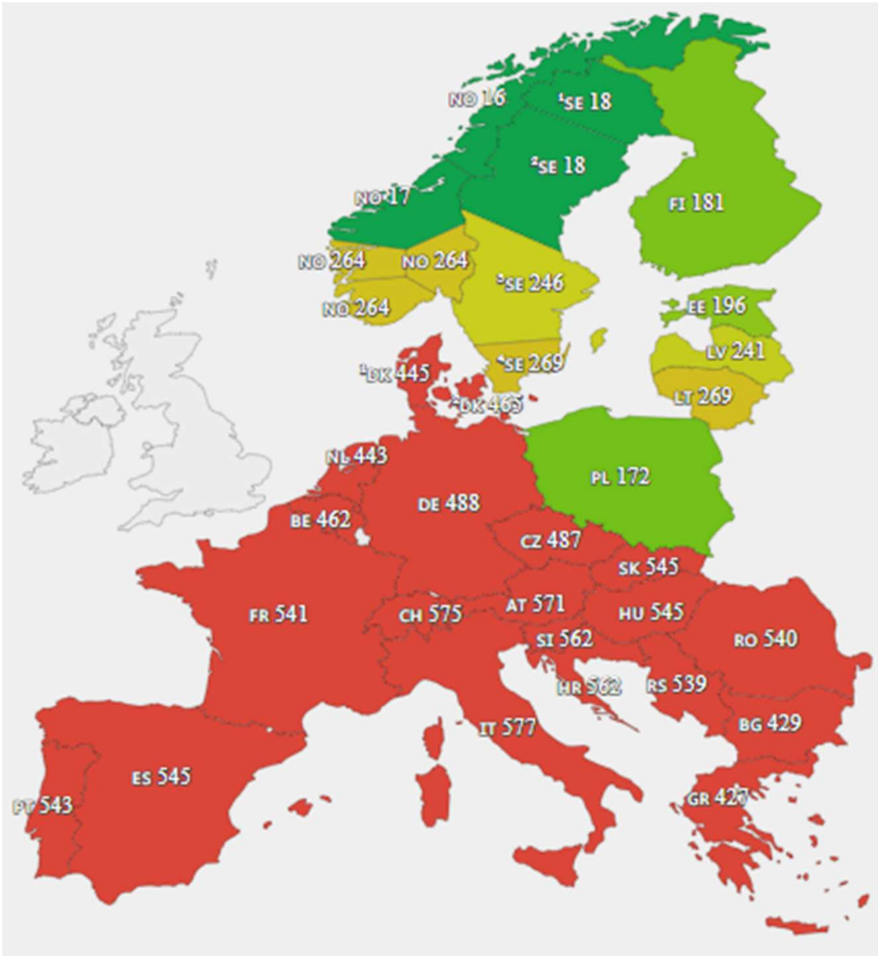

Figure 4. Electricity wholesale prices in Europe, Tuesday 08/03/2022, in EUR/MWh. Source: ENTSO-E (9).

It is even more impressive when the previous *Figure 4*, showing the electricity wholesale price throughout Europe on March 2022, is compared with the electricity price in Europe the same day, one year earlier, as it can be seen in the following *Figure 5*. In the Iberian market (i.e., Portugal and Spain), the price is ten times higher in 2022 than in the previous year, reaching the outrageous amount of 545 EUR/MWh in Spain, as an average price for the whole day.

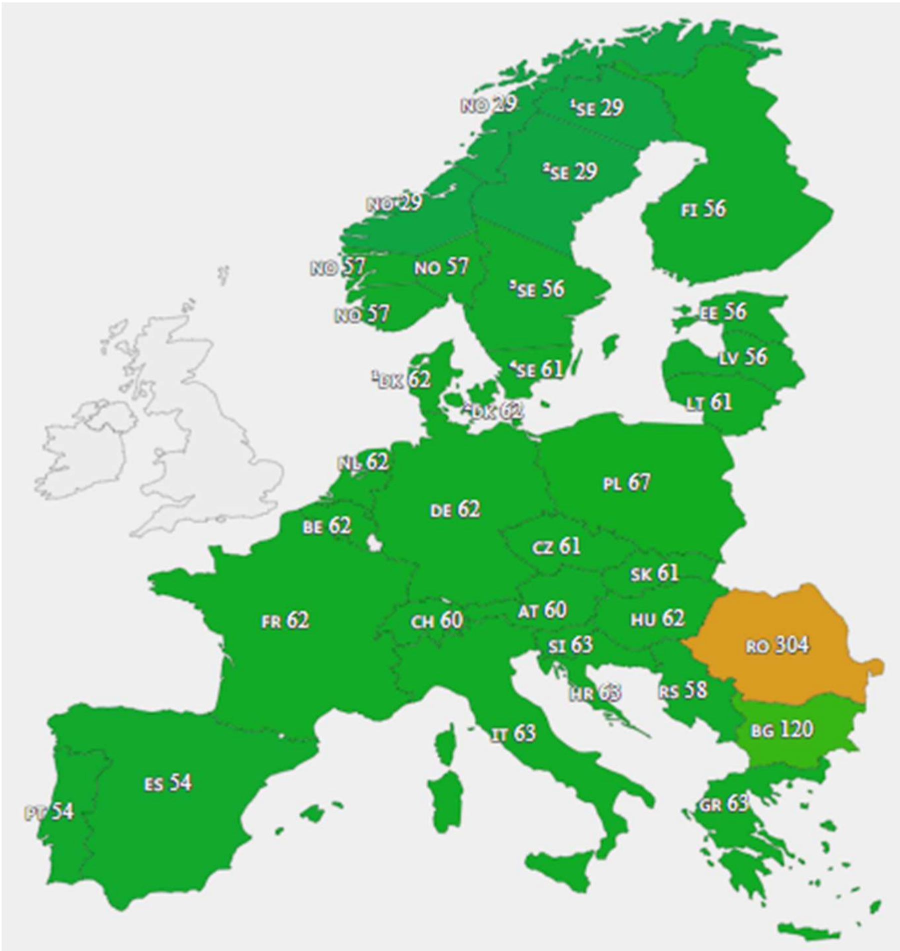

Figure 5. Electricity wholesale prices in Europe, Monday 08/03/2021, in EUR/MWh. Source: ENTSO-E (9).

This dramatical increase in prices that can be observed when comparing *Figure 4* and *Figure 5*, has really had an impact through Europe, especially in highly dependent countries from the Russian gas supply, like it is Germany. This has caused a major uncertainty, leading to trust issues regarding the current wholesale electricity market. Nowadays, there is an open debate discussing the possibility of a structure change of the electricity wholesale market, in an effort to mitigate unexpected rises in the price of electricity, like the one Europe has experienced in the last couple of years.

This project was undertaken due to the need to integrate flexibility markets in the electricity wholesale market and to increase coordination across all European markets to have a unified, standardize electricity system.

With this scenario, it is possible to have a higher penetration of renewable generation since the demand-side would adapt to the changes in generation due to the unpredictability of some renewable sources. In addition, flexibility at both, the generation and the demand side, prevents the costly curtailment of renewables due to the overload of lines and the cost of having to follow the load curve of demand with fossil-fuel based generators.

In addition, the OneNet project's goal is to integrate all the electricity system partakers to optimize the energy system as a whole and develop a new market structure. Therefore, it will create a more robust electricity system across Europe, which will drastically improve the current situation.

The main objectives of this project are as follows:

- Analyze the structure of the Spanish electricity wholesale market, delving deep in the different phases, the architecture of the market, and its regulatory aspects.
- Study the role and key drivers of local flexibility markets, the main challenges that they pose, and their advantages on an electricity system based on intermittent renewable energy sources.
- Focus on the development of the OneNet project, especially in the standardization and harmonization across the current European electricity markets.
- Study the potential coordination between local flexibility markets and wholesale electricity markets, ensure their proper integration across all their different dimensions. The coordination study will be carried out across the following markets:
    - Spanish secondary reserve (automatic frequency restoration reserve - aFRR).
    - Spanish tertiary reserve (manual frequency restoration reserve – mFRR).

- Spanish replacement reserve.
- Spanish day ahead market.
- Spanish intraday market.

- Draw conclusions on which kind of coordination between the different markets is possible and can be designed, and constraint or restrictions in the case that coordination is not feasible in the current situation.

- Develop an overview of best practices in the design of local flexibility markets and their coordination with wholesale electricity markets, increasing the efficiency and reliability of the electricity system as a whole.

Chapter 2. OneNet Project

2.1. Introduction

This chapter's objective is to briefly summarize and explain the OneNet project, on which this thesis is based and elaborates upon. It will provide an overall vision of the objectives, methodology, and structure of the project, as well as expected timelines and scope.

This project arises from the need to adapt the electricity grid to the new generating technologies, dominated by renewable energy sources and, in particular, by wind and solar, with a special focus on distributed generation. Based on this, it has been established that it is of the outmost importance to modernize the electricity sector, changing, or adapting the grid layout, its key players, and the way the market and network operators should proceed.

OneNet's aim is to create a more flexible network, market, and environment, through a more consumer-centric approach. This will be achieved by a standardization and coordination of many aspects of the power sector, including regulations, platforms, and services.

The project, whose motto and final objective is to develop one network for Europe, has seventy-two partners, has a geographical reach of twenty-three countries, and an economic impact of twenty-eight million euros. These seventy-two partners are comprised by market operators, energy agencies, research centers, and distribution and transmission system operators, amongst others. It receives funding from the European Union's Horizon 2020 research and innovation program (10).

Since it is obvious that there has to be a change from a centralized power system to a more decentralized one, the European Union has been founding several research projects that explored possible ways to enable demand side participation, or some other measures that increase the network's flexibility. The OneNet project gathers the findings made in these previous projects, also under the Horizon 2020 objectives (e.g., CoordiNet and INTERFACE) and elaborates upon them to have a mature proposal for Europe's future power systems (10).

Its main objective is to integrate all the actors across the electricity system throughout countries, exploiting the possible synergies between the operation of the network and market. To do so, there is a need to optimize how energy is managed, by enabling consumer participation and developing a fair and open market structure.

These market structure conditions, will allow the development of modern technologies like demand response, distributed generation, or energy storage, giving the electricity network the flexibility it needs for its optimal operation, which will be based on a consumer centric approach.

The whole project is based on three main pillars, all trying to standardize the products through Europe, for a better integration of the players and technologies. These pillars are:

- Establishing a common design for the European markets.
- Defining common interfaces and architecture of the IT assets.
- Verifying the solutions that have been proposed through several testing phases.

2.2. OneNet's characteristics and methodology

Following the rationale of its three pillars, the methodology that OneNet has developed consists of a seven-step process that summarizes their vision, objectives, and how to proceed to develop a set of standardized products for the power sector in Europe. The seven-step process is as follows (10):

- Determine suitable market structures to complement the identified products and services.
- Develop an open IT architecture with scalable data management capabilities to support the market structures.
- Execute the architecture in a reference version to serve as the foundation for European implementation.
- Validate the proposed concepts and solutions through extensive field tests conducted by OneNet.
- Foster a European-level consensus by leveraging the GRIFOn[1] open forum, involving all key stakeholders.
- Promote the adoption of OneNet's outcomes in the standardization process to achieve significant market acceptance.

To complete the seven-step process, OneNet has developed a number of deliverables as a roadmap to achieve its objectives. These deliverables explain in detail all the actions to take, the products that are viable, or guidelines for the exchange of data or for the operation of the network, amongst others.

The main focus of this chapter is to study a reduced set of these deliverables, the ones who highlight the standardized products that have been developed, the overview of the market design options, how to efficiently procure grid services that support these products, and the definition of a fully developed and coordinated flexible market.

Analyzing public deliverables, results in a better understanding of the technical requirements and constraints for the coordination between the different markets, which is the final objective of this thesis

[1] GRIFOn (Grid Forum) is the platform developed as part of the OneNet project to establish a quick and easy communication channel to facilitate a two-way dialogue between the OneNet developers and its stakeholders, to create consensus and enable an efficient standardization process throughout Europe.

2.2.1. Review on markets and platforms in related activities

The goal of this deliverable (8), is to accurately assess the state of the art in the subject, by reviewing the work done in previous projects that could be useful in the OneNet project. As it is common when analyzing previous work, it is considered the starting point for the project, since it is in this deliverable where the key areas for improvement are examined, and the lines of work are laid out to start to build the new concepts and approaches of OneNet.

The projects selected for study in this deliverable are all from the Horizon 2020 list, presented in the following *Table 1*. They all are focused on different areas of expertise, from studies of flexibility and retail market options explored in projects like *Platone* or technology demonstrators like *InterFlex* (11), (12).

INTERRFACE	InterConnect	CROSSBOW
Coordinet	Synergy	TDX-Assist
Platone	EU-SysFlex	InteGrid
EUniversal	Osmose	InterFlex
FARCROSS	Flexitranstore	SmartNet

Table 1. List of the reviewed projects in D2.1 from the Horizon 2020 (8).

The analysis that was conducted from OneNet, was based on a survey made to each of the projects from *Table 1*. The results highlighted some key areas that the OneNet project should focus in, like the delivery of services such as voltage control, congestion management, and frequency control, or the need for further digitalization and standardization of products at a European scale.

Regarding product standardization, which will be deeply analyzed further in this thesis, this deliverable defines the main parameters that should be taken into account while defining a service provided to the grid or market operator.

The attributes that are defined in the OneNet project are the ones that will need to be studied to ensure possible coordination between different markets, as it is discussed in the following chapters. Some of the attributes that should be considered (i.e., the most common attributes used in the different projects) to define a service can be seen and are analyzed in the following section, *A set of standardized products for the system services in the TSO – DSO – consumer value chain*

Of course, the level of importance of these attributes will depend on the specific market or service of interest. Regarding the commodity traded, it is important to understand the different dimensions of this attribute.

First, it can either be to allocate capacity or to activate flexibility. This will depend on the type of service provided, taking into account the reliability preferences of the market and system operator or the time when the service is provided.

Secondly, it can be either reactive or active power, which will mainly depend if the service is related to frequency restoration and management congestion or voltage control. This is due to the nature of each type of power, since frequency is usually controlled with changes on the active power flow and bus voltage can be changed by modifying the reactive power injected (13).

In addition to the characteristics that have been discussed above, the structure of the market that sells these types of services has also a meaningful impact. There are many possibilities to acquire grid services, like flexibility markets, or through bilateral contracts, amongst others. In the following chapters, a study will be conducted regarding the possibility to forward bids from one market to another. The similarities in the market structure, the number of attributes that are alike, and the regulatory aspects are some of the things that will be considered to assess the possibility of coordination between markets.

Another matter to take into account is the party, or parties, in charge of procuring the different grid services. The party that operates the flexibility market can, in some cases, be the same as the one who operates the market of study. When this is not the case, there is a need to study the communication channels between the two, or more, parties, their data sharing policies and regulations, to ensure that effective and on time communication is feasible.

The pricing mechanisms and the procurement timeframe are important characteristics that define certain service. The pricing strategies range from pre-agreed tariffs or fixed contracts that usually result from bilateral contracts to pay as clear or pay as bid methods, which are normally related to a market structure based in auctions. In the procurement timeframe the typical division is between long-term and short-term contracts or services. The timeframe is critical for the definition of the traded commodity, as well as the service it provides since it gives the scope of the procurement process and other characteristics that comprise the service.

OneNet Deliverable 2.1 discusses about demand side response, as it was considered the main challenge to overcome in the near future. There are some barriers that have been identified to the development of demand side response at the transmission and distribution level, which are better explained and discussed in the following chapters. Some of these challenges are the lack of regulation and guidelines concerning aggregation of technologies, or missing information regarding the prequalification process to participate in each market. The absence of a framework at a European level that addresses the development of local congestion markets (8).

To solve most of these problems, some key lines of work have been identified to achieve the objectives proposed in OneNet. While they have a wide range of topics the ones that are of the most interest for this thesis include the need for a regulatory update to standardize some, or most, of the technologies and services to achieve a better and easier operation of the grid, including those services. A set of standardize products will also improve the market competitiveness, with a more profitable scenario regarding investments.

Improvements on digitalization, data management and security, to make more robust communication channels between all actors, including the flexibility providers. The deployment of a smart grid that allows distributed generation based on intermittent renewable energy sources, as well as flexibility from the demand side. Finally, the ability to scale the current technologies, to ensure liquidity in the markets and a more competitive, in terms of costs, scenario.

2.2.2. A set of standardized products for the system services in the TSO – DSO – consumer value chain

The objective of OneNet Deliverable 2.2 (14), is to analyze the products and services that exists or are already in place and then develop some new products, aiming for the maximum standardization.

The review of the products is not only to understand the state of the art in this matter, but also to ensure that these services are up to date and that they are integrated with the new products, to be able to include all the important sources of flexibility services across the network.

The first thing is to understand the use that these services are going to have to the system operator, the different set of attributes of every product, and the value of each of these attributes. To be able to know the use of these products to the system operator, first, it must be considered the different services that the system operator provides, along with their main drivers, and categorize them, to make it easier to harmonize the different products, as they will fall under the same category.

It is also important to distinguish the reason behind the need, as these circumstances affect the way to overcome each problem. The distinction should be if the need comes from a corrective or predictive nature. The corrective needs are the ones that result from circumstances that were not expected or accounted for, some examples could be the trip of a line due to technical problems or an unexpected problem in a generating unit that causes it to stop working. The other group, the predicted events, takes place as a result of a known event that is going to happen either in the long term or in the short term. Some examples could be known maintenance operations in some power plant or substation that causes them to stop production or to cut the power supply.

The main drivers that have been identified regarding the services provided by the system operators are mainly the timeframe of the service and the need they are aiming to address. Looking at the timeframe, it is important to distinguish between long term, short term or operational services. As for the need behind the service they provide, it could be voltage control or congestion management.

Considering these characteristics and distinctions, the clearest and easiest split is between frequency control products and non-frequency control products. Regarding the first group, the frequency control products, with a first analysis, it can be stated that they have a higher margin for harmonization, since these products are not locational based, this is, they do not require locational information.

Therefore, it would be highly beneficial to achieve some type of harmonization, to make it easier to have the same product or service between different bidding zones. It also would be easier to harmonize this type of product because there are some projects like PICASSO[2], MARI[3], or TERRE[4], that are already trying to harmonize to some extent this service.

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[2] PICASSO (Platform for the International Coordination of Automated Frequency restoration and Stable System Operation). It is organized by the ENTSO-E Market Committee to create a platform for the exchange of balancing energy for frequency restoration reserves. It includes twenty-six members and four observers throughout Europe.

[3] MARI (Manually Activated Reserves Initiative). It is organized by the ENTSO-E for the creation, operation, and future development of the European manual frequency restoration reserve (mFRR) platform.

For the non-frequency control products, there are some considerable challenges for harmonization, as this type of service has a locational attribute, making it less applicable for standardization and harmonization than other products that are not location specific. The way to go with these products is to achieve a relative level of harmonization, finding the balance between different products due to locational differences, but that have some common attributes to ease the coordination between the system operator, both for the distribution and transmission systems, and the providers of flexibility to the system.

[4] TERRE (Trans European Replacement Reserves Exchange). It is organized by the ENTSO-E to implement a project for the exchange of replacement reserves throughout Europe.

This thesis focuses on the frequency control services, as they are a more mature technology that are in some cases already harmonized or in place. The frequency control products are used to keep the system's frequency in its established range. In Europe and many other countries around the world, this frequency level is 50 Hz. To maintain stability, there needs to be a constant balance between generation and demand. When there is an imbalance, the frequency can either increase, when the demand is lower than the generation, or decrease, when the generation is lower than the demand.

Other system needs such as adequacy or black start are not discussed in this thesis, as it is not considered applicable to the interest of coordination between markets. There is a possibility to study in the future a possible harmonization of these types of services, that could have common attributes and would benefit from a standardization across some European countries.

There are many services that are needed to ensure that generation is equal to demand at all times. They depend on the type of need and the timeframe, some services having to be completed before the next one can be activated.

Among the different frequency control services that ensure that the frequency stays inside the range around 50 Hz, the most important ones are as follows:

- Frequency Containment Reserves (FCR): It is an automatic function that reacts to disturbances in the high voltage network that create a condition that is off limits regarding the frequency margin. It then stabilizes the frequency to a steady state value, that can be different that 50 Hz, but within a certain margin bandwidth.

- Fast Frequency Reserves (FFR): It is defined as any type of active power input change (i.e., either increase or decrease) in the demand or the injection of power to the grid before a two-second period. This ensures that supply and demand are equal at all times, managing frequency changes.

- Automatic Frequency Restoration Reserve (aFRR): This is an automatic service which restores the frequency from the steady state achieved from the frequency containment reserve to the 50 Hz set point. It replaces the FCR, and therefore, comes after it.

- Manual Frequency Restoration Reserve (mFRR): It is a manually activated service that restores the frequency to the established set point value. It is also in charge of restoring the power exchange or balance between different areas to its initial established set point value.

- Replacement Reserves (RR): It is a complement to the fast frequency reserves, that can be activated either manually or semi-automatically.

This thesis main focus, within the different frequency control technologies will be the last three from above (i.e., automatic frequency restoration reserve, manual frequency restoration reserve, and replacement reserve). It studies their characteristics and main attributes, as well as the market in which it is traded, in order to study the possibility of coordination between them.

In OneNet Deliverable 2.2, another important topic discussed is the definition of a product. It is established what a product is, what are its uses, or what are the most important attributes or characteristics that define a product, amongst others. With this set of characteristic that define a product, it results in a tradable unit that can be procured by the use of a market mechanism.

As it was seen in the previous deliverable, *Review on markets and platforms in related activities*, one of the key aspects to enable harmonization and standardization is to have a well-defined set of attributes for all the products. Having a list of all the characteristics that define a product makes it easier to identify possible services or products that can be coordinated.

The following attributes, listed in the *Table 2*, have been identified as the key characteristics that define a product and that are standard and applicable to most of the services previously described.

ATTRIBUTES	DEFINITION
PRODUCT TRADED	This attribute states if the product traded is energy, in MWh, or capacity, in MW.
TYPE OF POWER	The system operator can trade either active or reactive power.
LOCATIONAL DETAILS	This characteristic determines if the information on the location of the service should be included when submitting the bid.
SYMMETRY	This attribute defines if the bid is symmetric or asymmetric. For a symmetric product, the volume traded has to have an equal amount of upward as downward adjustments, while asymmetric products do not have to have equal volumes. There are some typical cases for asymmetric bids. Only one of the directions (i.e., either upward or downward) is offered, meaning that the other volume is set to value zero. Some services require some rule or relation between the two offers, this is, for instance, the downward volume should be half of the upward volume.
VALIDITY PERIOD	This is the timeframe when the proposed bid can be activated and should deliver all the attributes that it offered.
FULL ACTIVATION TIME	It is the sum of the preparation time and ramping period, that can be included too in the bid. This attribute accounts for the period of time between when the system operator demands that the service is activated and when the flexibility service provider is delivering the amount of power that was requested and offered in the bid.
GATE CLOSURE TIME	This attribute defines the time when no more bids can be submitted to the market.

DELIVERY PERIOD	This is the timeframe in which the flexibility service provider is delivering all the amount of power requested.
RECOVERY PERIOD	This attribute corresponds to the minimum period of time between the deactivation period and the next activation requested by the system operator.
ACTIVATION MODE	This attribute defines the way the service is activated to deliver. It can either be automatic, semi-automatic, or manual.
QUANTITY	This is the maximum or minimum power delivered during a bid. This limit is usually set in the bid itself because of restrictions of the flexibility service provided or by the system or market operators, that would have reached a technical constraint if delivered more or less power.
DIVISIBILITY	This attribute defines if a bid is divisible or indivisible. If a bid is divisible, the system operator can use the part of the bid that it needs, not having to use the whole amount of power in the bid. Usually divisible bids have some level of restrictions or granularity for the divisions. If a bid is indivisible, the system operator must either use the whole bid to its full amount or not make use of the bid at all.
GRANULARITY	This attribute is defined as the smallest unit of volume which the bid can be divided or incremented. It can be related to the divisibility of the bid.
MARKET TIME UNIT	This attribute defines the period where the bids can be bought or sold and where the price is established.
BID STRUCTURE	This attribute defines the level of complexity that a bid can have.

MINIMUM AND MAXIMUM BID SIZE	This is related to a technical restriction of the system or market operators, that have some limitations, usually restricted by minimum size that the bids need to have to be able to participate or enter the market.
MAXIMUM AND MINIMUM BID PRICE	This attribute is related to the price range accepted or set by the market operator. Only bid whose price is within this range can be accepted to participate in the market. Most bids will include an availability price and an activation price.
AVAILABILITY AND ACTIVATION PRICES	This attribute defines the prices set in the bid by the flexibility service provider to deliver said service. The availability price is the price that has to be paid to reserve an amount of flexibility available, it is usually measured in EUR/MW/hour. The activation price is the price that has to be paid to actually deliver the flexibility or power, it is usually measured in EUR/MWh.
AGGREGATION	This attribute defines if there can be a grouping of several bids with similar characteristics via an aggregator. This attribute is closely related with the minimum size of the bid, since if there are many bids that do not meet that requirement, they can maybe be grouped with the help of an aggregator.
PENALTY FOR NON-DELIVERY	This attribute defines the penalty, that can be economic or of another nature, that the flexibility service provider must face if they should fail to deliver to some extent, or fully, the service that was agreed upon.

Table 2. Attributes and its definition for the harmonization of flexibility services (14).

With this set of attributes and characteristics that thoroughly define and apply to most of the services, products can be harmonized and coordinated through other markets by checking that the most restrictive attributes for each product and market are sufficient in the bid that would be forwarded between markets.

While the list in *Table 2* could be thought of as extensive, it is a good balance between thoroughly covering every important aspect that defines a bid and keeping it quite simple so that it can be easier to identify opportunities for the standardization of services. It is important not to have many constraints, or that some of the constraints are not mutually exclusive or related to one another, since the way to forward bids to coordinate the markets will be done through a program, that would work best if kept as simple as possible.

In addition to finding the trade-offs to a better management of the algorithm that will identify the harmonization possibilities, it is of the outmost importance to ensure and facilitate enough market liquidity for the flexibility services. Market liquidity is directly related to having simple bids that can be easily forwarded from one market to another, and also, with less restrictions, more bids would surely participate in the market, gaining liquidity. Therefore, there has to be a trade-off to find the balance between low restrictions to increase liquidity and more complex bids that ensure that the all the technical requirements are met for every procured product or service.

Regarding the extent of harmonized products, and the linguistics behind it, the OneNet project proposes a clear definition of harmonization and standardization, that is the one that applies and will be used throughout the development of this thesis. The distinction between these two terms is basically that standardization is the extreme of harmonization. Harmonization is to increase the similarities or reduce the differences between products or services. Harmonization has a very wide range of possibilities, that can go from minor similarities to highly related products. Standardization is fully harmonized products, this is, products that have exactly the same sets of attributes and characteristics, without any differences between them.

Having most of the products, including those which provide flexibility services to the system has a large number of advantages and benefits for the network, the system and market operators, the flexibility service providers, and, ultimately, for the final consumers, that will benefit from a more robust power supply with a reduced price, amongst others.

Some of the main advantages of having a harmonized system are:

- An increased coordination between transmission and distribution system operators, as well as with flexibility system providers with market and system operators. It would facilitate the interactions between all the actors, by bringing products together and making it easier for flexibility providers to provide a service. With standardized or harmonized products, it will lead to easier communication channels, that would enable coordination between them.

- It will lead to a huge reduction in complexity, that will enable participation and, hence, increase market liquidity. Having a highly liquid market would definitely lead to a cost reduction, since there would be less transaction costs than with a non-harmonized market situation. Having a harmonized system in Europe can facilitate cross-border exchanges and can allow low-cost energy to be shared within countries.

Of course, there are also some challenges or difficulties that harmonization faces throughout some technologies, markets, or countries. There are problems with services that need to have certain locational conditions, that do not apply for a harmonization process. There are many cultural and operational differences between countries or entities, that would make more difficult the communication, and, therefore, complicate the expected coordination.

The most important barrier to harmonization is the legal restrictions and regulations that differ around countries, entities, or through stages of the value chain. It would be crucial and of the outmost importance to develop a regulatory framework that takes into account and addresses all these barriers and that is common throughout all European countries that participate in this project or are expected to participate in the near future. There are some key roles, as the aggregator, that need to be established, with its functions, timeframes, and providers.

2.3. Local congestion management market

With all the different characteristics and attributes described throughout this chapter, the OneNet project has developed, amongst others, a market that will be used for local congestion management, and that is expected to coordinate with several other markets, which will be discussed in the following chapters for the case of Spain.

Congestion occurs in a grid if the power flows obtained from the market results cannot be safely accommodated by the network due to some technical, economical or operational constraints. The steps taken by the system operator to manage congestion in the grid is called congestion management. Mostly, it involves re-dispatching the units in the congested area such that the congestion is resolved.

The expected relation and coordination with the different markets is depicted in the following *Figure 6,* extracted from the Deliverable 3.1 from the OneNet Project, where it can be seen a process where bids are forwarded from one market to another through the local flexibility market.

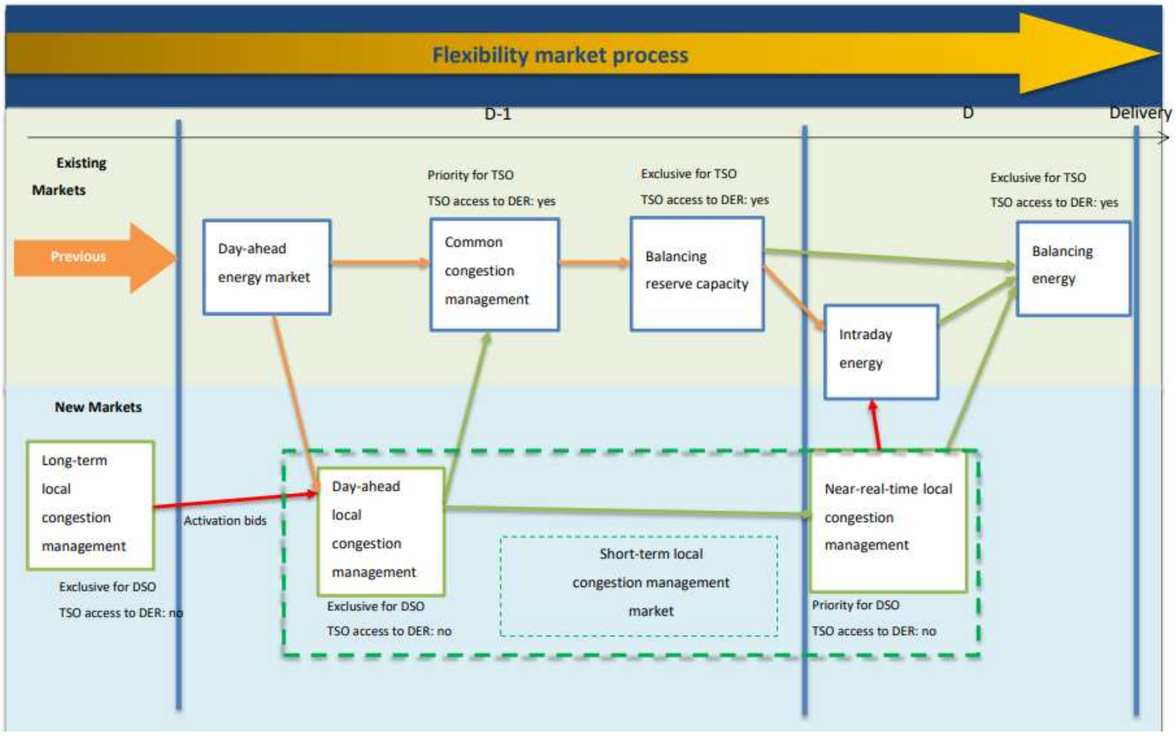

Figure 6. Example of the relation and coordination between the existing markets and the new markets proposed by the OneNet Project. Source: Deliverable 3.1, OneNet (15).

Chapter 3. Coordination of OneNet with the Spanish markets

3.1. Introduction

This chapter develops the main study of this thesis, the possible coordination between the OneNet project and several of the markets that comprise the whole Spanish electricity market. Specifically, the study that will be carried out is to analyze and compare OneNet local congestion management with the Spanish day-ahead, secondary, tertiary, and replacement reserve markets.

To do so, given the attribute and characteristics described above in *Chapter 2*, both markets (i.e., OneNet's local congestion management and each of the Spanish markets) are compared between each other, and then, the compatibility and the possibility for bid forwarding between markets is analyzed.

Before making a deep dive into the different Spanish markets and the analysis, it is necessary to see the big picture of the project that is being undertaken. There is a description of the bid forwarding process, explaining why it is needed and how it works. Then, prior to study the integration of the OneNet project in the Spanish market, there needs to be a brief review of how the Spanish electricity market works, who are its key players and stakeholders, and how each of the markets is integrated and related with every other.

As it has been explained in previous chapters, the coordination between markets, especially for flexibility markets, is crucial for its development and to be economically viable. To help with the renewable energy deployment, it is of the outmost importance to have a well-developed market that is able to integrate all of this generation, both utility scale and distributed energy resources.

One of the easiest methods to increase market liquidity, which is extremely important to ensure that the market actually works and is profitable, is through harmonization and standardization of certain services or products. The benefit of having some level of harmonization is that it allows and enables bid forwarding between markets.

3.2. Bid forwarding

The concept of bid forwarding is to exploit and make the most out of the resources in the power sector. Many of the bids that are submitted to the electricity markets (i.e., intra-day, day ahead, or balancing markets) are rejected for some reason. These reasons can vary, for instance, not fulfilling the product requirements, like the size of the bid, technical constraints of the generating unit, or due to infeasibility because of time constraints, like full activation time or ramp up period. Other reason could be economic, meaning that they are out of the market.

With a bid forwarding concept, the bids that are rejected in one market, for whatever reason, can be then forwarded to another market with similar or compatible conditions regarding delivery time, size of the bid, or other technological constraints. This way, market liquidity has a huge increase, as it increases the supply of services that can be delivered. A simplified example of how this process works can be seen in the following *Figure 7*.

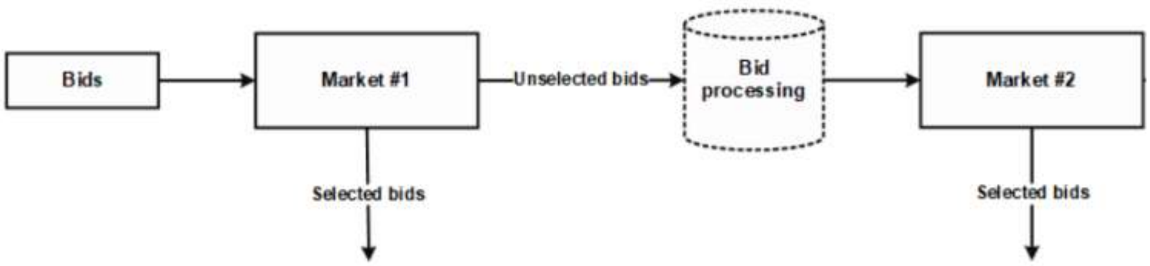

Figure 7. Simplified example of bid forwarding process. Source: Bid Forwarding as a way to connect sequential markets: opportunities and barriers (16).

To make bid forwarding possible, there has to be an analysis and definition of compatible markets and create a platform that can detect if a bid that has been rejected in one market has the opportunity to enter another market. In order to do this market compatibility analysis that will be carried out further along this chapter, there has to be a high level of harmonization between the services or products that are traded or procured, since it would be impossible to find compatible bids that have totally different attributes and characteristics.

A situation where bid forwarding exists and is in place is beneficial to most of the players and actors across the whole power sector. It increases the opportunities for flexibility service providers to participate in the market, since there is an increase in demand due to the fact that they now can participate in several other markets. It makes a more robust network, since it increases the flexibility supply, with all the advantages and positive impacts that it has for the system operator and the power network as a whole.

The final consumers will also benefit from this situation, as there will be a subsequent price reduction due to the increase in supply of flexibility services. In addition, there will be less need for power facilities that are only built to operate to adjust generation to demand, as it is the case for many combined cycle gas turbines (CCGTs) in Spain.

These facilities usually have extremely low capacity factors, which means that they are idle most of the time throughout the year. While this is necessary to ensure power supply for the Spanish customers, it is very costly for the system, and therefore, for the final consumers. Having a reliable flexibility and demand side management system, will definitely reduce the use and further construction of these types of facilities, thus, reducing by a considerable amount the final price paid by the customers.

Regarding the operation and agent responsible for the bid forwarding process, European framework (17), dictates that the party responsible for the operation of local markets can be the system operator or a third party market operator, who must comply with the required regulation. One of the responsibilities of the responsible agent is to group or aggregate bids in case it is needed to comply with the requirements of the markets to which the bids are being forwarded, always following the aggregation rules established by the system operator and the national regulation.

3.3. Methodology for the comparison

To enable a bid forwarding process, that appears in *Figure 7*, it needs to be verified the compatibility between markets, by checking each of the attributes described in *Table 2,* individually. This means that compatibility of markets is defined attribute by attributed, isolating them and comparing them together. When comparing these characteristics, they can be differenced by their importance, resulting in *necessary conditions* and *conditional conditions* to ensure that the bid forwarding process takes place, as demonstrated in (16).

When looking at the features of the market, the *necessary conditions* are the ones where the two markets involved in the bid forwarding process need to strictly comply with it. It can be seen as binary, either they comply, or they do not. If they do comply, there is possibility for bid forwarding, pending on checking the other attributes, but if they do not comply with a necessary condition, it is not possible to introduce a bid forwarding process between those two markets.

A *conditional condition*, however, is a feature where full compatibility is not required, and the bid forwarding process can take place given that the bids undergo a bid processing process, where they are filtered, slightly altered or grouped to make them fit for the market structure of the market they are being forwarded to.

These conditions can be seen in the following *Table 3*, from (16). Here the attributes described previously in *Table 2*, are defined as conditional or necessary conditions for the bid forwarding process, as well as the process they need to undergo in order to achieve compatibility.

Regarding the third column of the following *Table 3*, it mentions the bid processing stage of the bids for bid forwarding compatibility. As it can be seen in *Figure 7*, the bid processing process occurs when there is not full compatibility between two markets. Bid processing needs to be on the same level as the compatibility comparison, this is, attribute by attribute.

If two attributes have a conditional condition, they can undergo a process where they are somehow changed so that they are fit for the market. This falls under the responsibility of the agent in charge of the bid forwarding process and can include all the measures listed in the following *Table 3*.

Design feature	Type	Required bid processing stage
Technical requirements	Conditional	Only allow bids that comply with the technological requirements.
Gate closure time	Necessary	No possibility for bid forwarding
Market time unit	Conditional	Split divisible products or merge divisible and indivisible products to meet the required conditions.
Local granularity	Conditional	Only allow bids that contain the required locational information. Enable bids to place additional locational information even when is not required.
Type of product	Conditional	Establish conditions for the conversion between capacity and energy bids.
Allowed technologies	Conditional	Only allow bids that comply with the technologies allowed.
Aggregation condition	Conditional	Regroup sets of bids or assets to comply with the required aggregation conditions.
Minimum bid size	Conditional	Aggregate the bids to achieve the minimum bid size and granularities required.
Bid structure	Conditional	Allow bids that comply with the bid structure requirements.

Table 3. Features and conditions for the bid forwarding process. (16)

The process of bid forwarding follows certain methodology to properly assess the potential that two markets have between them. This methodology involves the following process:

First of all, there is a need to identify possible markets that have potential, a priori, for bid forwarding within the national electricity markets. Then, there needs to be an analysis as the one that has been described above, where there is an individual analysis of the characteristics, identifying the compatible features and the barriers to the bid forwarding process, that can then be solved with a proposed bid processing stage. Finally, there needs to be a set of recommendations and steps that need to be taken to successfully address the barriers that have been identified.

These steps included in the methodology are the ones that are followed throughout this thesis when comparing the selected Spanish markets (i.e., following the first step of the methodology) with the local congestion management market from OneNet.

3.4. Spanish electricity market

The electricity market in Spain is a dynamic and complex ecosystem that plays a crucial role in the country's energy landscape. Spain has made significant strides in transitioning its electricity sector towards cleaner and more sustainable sources, as it can be seen in the National Energy and Climate Plan (NECP) updated in June 2023, where it set an objective of having eighty-one percent (81%) of renewable energy share in the final electricity generation (3).

The electricity market is comprised by several markets and timeframes, to ensure an efficient generation, consumption and distribution of electricity. There is a forward energy market that procures energy in the long and medium term, enabling the different participants to manage risk and pan their future consumption and generation. Then, there is a day ahead market, which as is indicated by its name, it takes place the day before the energy is delivered. It sets the foundation for electricity pricing and after the market is matched, it results in the generation schedule for the units for the following day.

In addition to those two markets, near real time operation there is an intraday market that offers flexibility and re-scheduling of units, close to delivery time, to adapt to changes and circumstances that were unforeseen in the day ahead market. This market has two parallel markets at the same time, one that is a continuous trading market and another one that is an auction market organized as six discrete sessions that take place throughout the day. Furthermore, there are several balancing energy markets that provide services for the system operator, needed to ensure the optimal operation of the power grid.

These services are known, in Spain, as primary regulation (FCR), secondary regulation (aFRR), tertiary regulation (mFRR), and replacement reserve (RR). They have very different characteristics, some of the services are mandatory and without remuneration, while in others participation is voluntary and is paid in accordance with the energy injected to the grid or capacity allocated.

This are the main markets for when the traded good is energy. There are also other markets that trade capacity, both in the long and medium term through the capacity market and by reserving capacity, and closer to real time operation through the re-dispatching markets.

This is a very complex market structure, with a lot of restrictions and relations between markets, all to ensure the robustness and reliability of the power system, achieving a fair price for consumers to pay, while maintaining incentives and an attractive rate of return for generator or other parties to be a part of the market.

The main focus of this thesis will be to analyze the technical restrictions and constraints of some of the markets mentioned above and compare them with local congestion management market proposed in the OneNet project. To do so, following the first step of the methodology described in the previous section, it will be necessary to study the characteristics of the markets that will be subject to the analysis, that are:

- Secondary regulation – automatic frequency restoration reserve (aFRR)
- Tertiary regulation – manual frequency restoration reserve (mFRR)

- Replacement reserve (RR)
- Day ahead market
- Intraday market

In the following sections, there will be a deep dive into each of these markets, to have a better understanding of how they work and then compare their compatibility for coordination with the local congestion management market that has been proposed in OneNet.

3.4.1. Secondary Regulation – Automatic Frequency Restoration Reserve (aFRR)

The secondary regulation is a service provided by certain generators to the system operator for the correct operation of the network. It is used for two main reasons:

- To restore the frequency to its set point value (i.e., in Spain this value is 50 Hz).
- To restore the value of the power exchange between different areas to its set power exchange value, which is zero. This is, to cancel any deviation in the exchange programs at all times.

It is an optional and remunerated service, provided by certain units that are previously approved by the system operator. It is regulated through the operating procedures established by the system operator (i.e., Red Eléctrica de España – REE). Specifically, by the Operating Procedure 7.2 Secondary Regulation.

The secondary regulation service has been historically provided by thermal generators that can change their output easily, by modifying the amount of fuel they consume. With the current trend towards renewable energy sources, there have been many debates about whether green generators are, or not, able to provide said service. There are currently many studies analyzing the potential of renewable generators, mainly wind, to provide this service.

Regarding the response time and delivery period of this service, it goes from two seconds after any contingency or for whatever reason it must be used and has to ensure power delivery until fifteen minutes after.

The characteristics of this market as a whole are listed in the following *Table 4*.

MARKET ARCHITECTURE	**TYPE OF MARKET**	**AUCTION**
	Market time unit	15 minutes
	Locational granularity	Zonal
PRODUCT	Type of product traded	Capacity
	Technical requirements	FAT – 5 minutes
	Technical prequalification conditions	Yes
TIMING	Gate opening time	Day ahead – 14:45 h
	Gate closure time	Day ahead – 16:00 h
	Publication of results	Day ahead – 16:30 h
PARTICIPANTS	Market operator	System operator – REE
	Allowed technologies	Generation, demand, and storage
	Aggregation conditions	Aggregation allowed
BIDDING	Minimum size bid	10 MW
	Divisibility	Bids should be divisible. Only one bid presented per block can be indivisible
	Symmetry	The bids must follow some rules regarding upwards and downwards reserve

Table 4. List of attributes of the Secondary Regulation service in Spain. Source: Operation Procedure 7.2 Secondary Regulation. REE (18).

Elaborating on the symmetry restrictions of the bid, there are two different levels, depending on the size, aggregation, and number of bids, where there are rules to follow regarding the upwards and downwards reserves. The first of these levels results from the aggregation of bids placed by the same, or different generators, that are in the same area. The result of this group of bids is called a block of bids. These blocks are also aggregated over the whole area that is covered by those participants of the secondary market.

As for each of the individual blocks of bids that are presented in a given area, the sum of the upwards and downwards reserve must comply with the maximum and minimum limits presented by the system operator. If the bids and blocks of bids do not follow the following equations for each of the periods, they will be automatically discarded.

$$SORes_{Max} > Res_{Up} + Res_{Down}$$

$$SORes_{Min} < Res_{Up} + Res_{Down}$$

Where $SORes_{Min/Max}$ means the maximum and minimum limits presented by the system operator and $Res_{Up/Down}$ means the upwards and downwards reserve of each bid.

For the whole reserve of a bidding area, which is the aggregation of each of the blocks, should be in between a ten percent (10%) interval of the established reserve set point. This must be for both, the upwards and the downwards reserve, as it can be seen in the following equations that rule this process.

$$0.9 \cdot SetPointRes_{Up} < \sum Res_{Up} < 1.1 \cdot SetPointRes_{Up}$$

$$0.9 \cdot SetPointRes_{Down} < \sum Res_{Down} < 1.1 \cdot SetPointRes_{Down}$$

Where $SetPointRes_{Down/Up}$ means the maximum and minimum setpoint limits of the interval and $Res_{Up/Down}$ means the upwards and downwards reserve of each bid.

Notice that these restrictions apply to a combination or block of bids, not to specific, individual bids. This means that there can be an assignment of a bid with just one direction, this is, upwards or downwards, but not both. Only the block needs to comply with these regulatory constraints but can be made up of several smaller bids with no symmetry restrictions whatsoever. This can be done through a third party, called aggregator, that will be discussed more thoroughly in the following chapters.

3.4.2. Tertiary Regulation – Manual Frequency Restoration Reserve (mFRR)

The tertiary regulation is a paid adjustment service, closely related to the previously discussed secondary regulation. It is a service which main functions are:

- Maintain the balance between generation and demand in the case of a contingency or any power deviation.
- Restore the secondary regulation reserve that had been previously used.

It is mandatory for certain generators and pumped hydro storage to place the bids for the tertiary regulation market, as tertiary regulation of one unit is described as the maximum upwards and downwards power variations. On an all-system level, the tertiary reserve is the aggregation of all the tertiary reserves available in the whole system.

Its timeframe goes from fifteen minutes after any contingency or whatever reason to be needed to two hours of providing the service. It comes into action after the secondary regulation has finished, obviously, so it can restore its power.

The main characteristics of this adjustment service are listed in the following *Table 5*.

MARKET ARCHITECTURE	**TYPE OF MARKET**	**AUCTION**
	Market time unit	15 minutes
	Locational granularity	Zonal
PRODUCT	Type of product traded	Capacity
	Technical requirements	FAT – 15 minutes
	Technical prequalification conditions	Yes
TIMING	Gate opening time	Day ahead – 21:00 h
	Gate closure time	Day ahead – 23:00 h
	Publication of results	25 minutes before the next programming horizon
PARTICIPANTS	Market operator	System operator – REE
	Allowed technologies	Generation, demand, and storage
	Aggregation conditions	Aggregation allowed
BIDDING	Minimum size bid	10 MW
	Divisibility	Can be fully and partly divisible, or indivisible bids
	Symmetry	No symmetry needed

Table 5. List of attributes of the Tertiary Regulation service in Spain. Source: Operation Procedure 7.3 Tertiary Regulation. REE (19).

3.4.3. Replacement Reserve (RR)

The replacement reserve service, in Spain previously known as power-deviation management, is a balancing service managed at a European level, which has the main following objectives:

- Maintain the balance between generation and demand in the case of a contingency or any power deviation after the closure of the intraday market.
- Restore both the secondary and tertiary power reserves that have been previously used.

Following European guidelines, there should be hourly periods where the replacement reserve can be activated. With this, the period in which the service should be provided can vary between fifteen, thirty, forty-five, or sixty minutes, with quarterly-hour resolutions.

The main characteristics of this adjustment service are presented in the following *Table 6*.

MARKET ARCHITECTURE	**TYPE OF MARKET**	**AUCTION**
	Market time unit	15 minutes
	Locational granularity	Zonal
PRODUCT	Type of product traded	Capacity
	Technical requirements	FAT – 30 minutes
	Technical prequalification conditions	Yes
TIMING	Gate opening time	Day ahead
	Gate closure time	48 minutes before the next programming horizon
	Publication of results	30 minutes before the next programming horizon
PARTICIPANTS	Market operator	System operator – REE
	Allowed technologies	Generation, demand, and storage
	Aggregation conditions	Aggregation allowed
BIDDING	Minimum size bid	1 MW
	Divisibility	Can be fully and partly divisible, or indivisible bids
	Symmetry	No symmetry needed

Table 6. List of attributes of the Replacement Reserve service in Spain. Source: Operation Procedure 3.3 Replacement Reserve. REE (18).

3.4.4. Day ahead market

The day ahead market in Spain is the main market where generating units are dispatched with the work of the market and the system operator. The unit dispatch works in the following way:

The generating units place their bids for each hour period of the next day. The system operator makes a demand forecast for each of the hours of the following day, in addition to the demand bids that are placed. The selling bids are placed in increasing price order, while the buying bids are placed in decreasing price order, as it can be seen in the following *Figure 8*. These curves are called the aggregated curve of supply and demand, respectively.

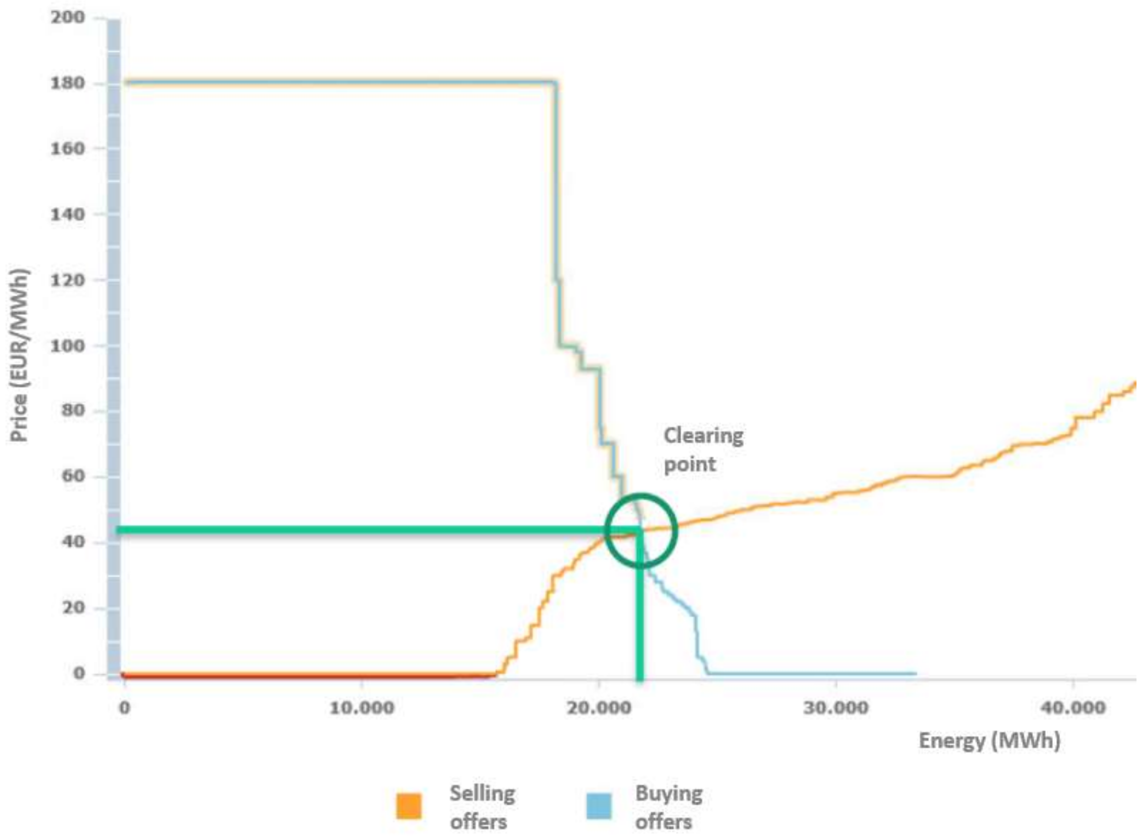

Figure 8. Aggregated curves of supply and demand in the day ahead market that establish the clearing market price and energy Source: (13).

As a result of placing the bids in ascending, for supply, and descending, for demand, order, a merit-order is formed. The aggregated supply and demand curves intersect at one point, yielding the market clearing point. The result of this is the energy that is going to be generated and consumed in that hour and the price for that energy. Since it is a marginalist market scenario, all of the generating units will be paid the clearing price, independently of the price the offered in their bid, and all the demand will pay the same price, independently of the price they were willing to pay.

In these market conditions, all the generators that enter the market will be paid more than the initial price they offered, while all the demand will pay a lower price than the one they were initially willing to pay, except the clearing unit and the clearing demand, that will be paid and pay exactly the price they offered. In the case of the example in *Figure 8*, the cleared price was of 44 EUR/MWh and a cleared energy of 22,000 MWh.

This results in generating units always placing bids with a price equal to their marginal costs, to ensure that they enter the market, while probably making a profit, since they will get paid the marginal price. That is why there are many selling offers at a price of 0 EUR/MWh in the example in *Figure 8*.

The main characteristics of this market are presented in the following *Table 7*.

MARKET ARCHITECTURE	**TYPE OF MARKET**	**AUCTION**
	Market time unit	1 hour
	Locational granularity	Zonal
PRODUCT	Type of product traded	Energy
	Technical requirements	No
	Technical prequalification conditions	No
TIMING	Gate opening time	Day ahead
	Gate closure time	Day ahead – 12:00 h
	Publication of results	Day ahead – 13:00 h
PARTICIPANTS	Market operator	Market operator – OMIE
	Allowed technologies	Generation, demand, and storage
	Aggregation conditions	Generation and demand cannot be aggregated. Thermic units can be aggregated in the same bid.
BIDDING	Minimum size bid	0.1 MW
	Divisibility	No restrictions
	Symmetry	No symmetry needed

Table 7. List of attributes of the Day Ahead Market in Spain (20).

3.4.5. Intraday market

The intraday market in Spain is an energy market that has two different markets running in parallel, the continuous market and the auction based market, which consist of six auctions throughout the day.

Its main goal is to adjust and reduce the differences between the dispatch made based on the forecast and the actual demand and generation. It is a market used to correct the day ahead market, near delivery time when there are fewer forecast errors.

On the one hand, each of the auctions follows a similar procedure as the one described in the previous section, and it can only trade with Spain's neighbors, excluding France. On the other hand, the continuous market trading sessions are connected with the rest of Europe, and trading is allowed up to two hours before the delivery period.

The main characteristics of this market are presented in the following *Table 8*.

MARKET ARCHITECTURE	**TYPE OF MARKET**	**AUCTION**
	Market time unit	1 hour
	Locational granularity	Zonal
PRODUCT	Type of product traded	Energy
	Technical requirements	No
	Technical prequalification conditions	No
TIMING	Gate opening time	Day ahead – 14:00, 17:00, 21:00 Delivery day – 01:00, 04:00, 09:00
	Gate closure time	Day ahead – 15:00, 17:50, 21:50 Delivery day – 01:50, 04:50, 09:50
	Publication of results	Day ahead – 15:07, 17:57, 21:57 Delivery day – 01:57, 04:57, 09:57
PARTICIPANTS	Market operator	Market operator – OMIE
	Allowed technologies	Generation, demand, and storage
	Aggregation conditions	Generation and demand cannot be aggregated together
BIDDING	Minimum size bid	0.1 MW

	Divisibility	Can be fully and partly divisible, or indivisible bids
	Symmetry	No symmetry needed

Table 8. List of attributes of the Intraday market in Spain (20).

3.5. OneNet local congestion management market

The OneNet local congestion management is a part of the Spanish demo in the OneNet project. The different characteristics of this market, in line with the attributes described in the previous sections, are expressed in the following *Table 9*.

MARKET ARCHITECTURE	**TYPE OF MARKET**	**AUCTION**
	Market time unit	15 minutes
	Locational granularity	Nodal
PRODUCT	Type of product traded	Energy / Capacity
	Technical requirements	FAT < 1 hour
	Technical prequalification conditions	Yes
TIMING	Gate opening time	Day ahead – 12:00 h
	Gate closure time	Day ahead – 14:45 h
	Publication of results	After gate closure time (Day ahead – 14:45 h)
PARTICIPANTS	Market operator	Independent market operator – OMIE
	Allowed technologies	No restrictions
	Aggregation conditions	Aggregation allowed
BIDDING	Minimum size bid	0.01 MW - DSO
	Divisibility	No restrictions
	Symmetry	Both symmetric and non-symmetric products are allowed

Table 9. Listo f attributes of the local congestion management market proposed by OneNet. (14).

This list of attributes presented in the *Table 9,* sets the guidelines for the comparison for possible coordination with the rest of the Spanish markets, as it is discussed in the following chapters.

3.6. Coordination between the markets

Having already described and analyzed the characteristics of each of the markets and services that are important for this thesis, this section compares each of them with the flexibility market from the OneNet project.

By doing this comparison, it is possible to identify the possible markets that allow bid forwarding, as well as the constraints or the ways to move forward when it is not possible, at the present time, to forward and coordinate bids between them.

To study the possible coordination, certain compatibility and similarity in the characteristics described in *Table 4, Table 5, Table 6, Table 7, Table 8,* and *Table 9* is needed. Of course, it is not necessary to have exactly the same attributes in each market (i.e., complete standardization), but it is important to have a certain degree of harmonization. There are some cases that although there are differences between some of the attributes, but as discussed in the previous section, they are only conditional conditions, which allows bid forward as long as there is a thorough bid processing process to ensure that all the bids are a fit for the market.

In each of the following sub-sections, as well as in the following chapters, the results of each comparison are thoroughly analyzed, proposing, when necessary, some solutions that can enable the coordination between them, like more regulatory constraints or the addition of a third party as an intermediary.

3.6.1. OneNet's local congestion management market and Spain's automatic frequency restoration reserve

In this section the comparison between the flexibility market from the OneNet Project, whose characteristics are described in *Table 9* and the secondary regulation market in Spain, whose attributes are listed in *Table 4*, is carried out.

In the following *Table 10*, the attributes of both markets are combined, to have a direct understanding of how each of the attributes relates to one another. The congestion management market is red-colored, while the secondary regulation or automatic frequency restoration reserve is blue-colored.

Shaded in light orange are the attributes that categorize as conditional conditions, and that, therefore, need some kind of bid processing, in line with the methodology described in previous sections. The attributes that appear with no shading are fully compatible with a bid forwarding process, and therefore, do not need processing.

LOCAL CONGESTION MANAGEMENT AND AUTOMATIC FREQUENCY RESTORATION RESERVE				
LOCAL CONGESTION MANAGEMENT			SECONDARY REGULATION	
Market Architecture	**Product**	**Timing**	**Participants**	**Bidding**
Type of market Auction Auction	Type of product traded Energy / Capacity Capacity	Gate opening time Day ahead – 12:00 h Day ahead – 14:45 h	Market operator Independent market operator – OMIE System operator – REE	Minimum size bid 0.01 MW – DSO 10 MW
Market time unit 15 minutes 15 minutes	Technical requirements FAT < 1 hour FAT < 5 minutes	Gate closure time Day ahead – 14:45 h Day ahead – 16:00 h	Allowed technologies No restrictions Generation, demand, and storage	Divisibility No restrictions Bids should be divisible, only one bid presented per block can be indivisible

Locational granularity	Technical prequalification conditions	Publication of results	Aggregation conditions	Symmetry
Nodal	Yes	After gate closure time – day ahead 14:45 h	Aggregation allowed	No restrictions
Zonal	Yes	Day ahead – 16:30 h	Aggregation allowed	Bids and groups of bids must follow some symmetry restrictions

Table 10. Comparison between the Local Congestion Management Market in OneNet and the Secondary Regulation (aFRR) service in Spain.

As it can be seen comparing all the attributes in *Table 10*, the flexibility market from OneNet is much less restrictive than the secondary regulation market in Spain, as it might be expected. Therefore, it will be much easier, in the early stages at least, to forward bids from the aFRR Spanish market to the local congestion management from OneNet if the gate closure time of the local congestion management is closer to the real-time. Moving GCT close to the real-time can also increase the prediction accuracy of renewables and demand-response systems. In order to forward bids in the other direction (i.e., form OneNet's flexibility market to the Spanish aFRR market), there must be implemented some kind of filter or prequalification to know which bids can and which cannot be forwarded to the secondary regulation market.

Following the methodology explained in previous sections, the way to proceed after having selected the markets that are compared and the attributes that are analyzed, the next step is to compare one by one, each of the attributes from the previous *Table 10*. As it has been mentioned before, the characteristics that are conditional conditions have been highlighted in light orange, while the characteristics that are compatible for bid forwarding are unshaded.

In the case of the market architecture, it can be seen that both markets are auction based and with a time unit of 15 minutes, which will pose no problem. Regarding the locational granularity, the local congestion management has a more exhaustive granularity than the aFRR, being nodal and zonal, respectively.

This means that in order to forward bids from the secondary regulation market to the local congestion management, there must be a bid processing process that determines if a bid complies with the necessary locational characteristics. In the other direction, granularity is not expected to be an issue as it secondary regulation requires is a zonal market (lesser granularity than the local markets). All the bids must comply with the locational characteristics, which in this case is belonging to certain area, amongst others.

Both markets have technical prequalification conditions. In order to be able to participate in the aFRR service in Spain, as it is stated in the Operation Procedure 7.2, each unit must pass all the tests established by the Energy State Department in Spain, as well as being assigned to the control center responsible for its regulation area. Regarding the product that it is traded, there needs to be assured that both the technical prequalification conditions and the technical requirements are met in both cases.

The full activation time of the secondary regulation market is more restrictive than the one in the local congestion management market, 1 hour compared to 5 minutes. This means that there needs to be a filter that only allows the technologies whose full activation time is under 5 minutes from the flexibility market to enter the aFRR market. This probably limits, in many cases, the possibility for bid forwarding.

Regarding the gate closure time, as it has been seen in *Table 3*, a necessary condition, poses no problem when forwarding bids from local markets to secondary regulation, since the local congestion management's gate closure time precedes the one form the secondary regulation market. The other time-related attributes follow the same line since they are closely related to one another. Therefore, this set of characteristics has full bid forwarding potential from OneNet flexibility market to the aFRR market in Spain.

The operator of both markets is different since the balancing services are managed by the system operator in Spain. This might not be a problem, as there are solid communication channels and relations between the Spanish market and system operator.

As for the technologies that are allowed, there are some restrictions in the aFRR market, while there are none in the flexibility market. Therefore, there has to be a filter that only selects the bids that comply with those characteristics to be forwarded to the secondary regulation market.

There are no special aggregation conditions in any of the markets, thus, there is full compatibility for bid forwarding, and it is not necessary to process the bids that will be forwarded from one market to another.

Regarding the bid size, there are considerable differences between the minimum bid size in both markets. This attribute is conditional, as it can be easily solved through aggregation of smaller bids, in order to comply with the required minimum to enter the secondary regulation market. The aggregation will be done by the bid forwarding agent, along with the other bid processing duties.

The divisibility of the bids should not be a major problem, but there is also need for bid processing. In general, only divisible bids are allowed in the aFRR market, therefore, the bid processing agent must separate the bids that are divisible from the ones that are not.

In case of symmetry, the secondary regulation market has some rules that can affect the number of bids that could be forwarded. Since there are no restrictions from the local congestion management side, there should be a bid processing stage. To do this, there are two options: the first one is to directly filter the bids from the flexibility market and only allow those that comply with the requirements form the secondary regulation market. The second option, is to aggregate the bids in a way that, combined together, follow the aFRR requirements, without having to be symmetric one by one, but just as a group.

This, of course, has its advantages and drawbacks. It is easier to just filter bids that are symmetric, without doing any more processing. However, this might result in very low compatibility and reduce bid forwarding possibilities. On the other hand, aggregating the bids in a way that they achieve symmetry as a whole is a complex process, but can mean much more bids being forwarded from one market to another. In light of this, it should be considered the aggregating measure as the optimal, since the other would be very limiting.

3.6.2. OneNet's local congestion management market and Spain's manual frequency restoration reserve

In this section the comparison between the flexibility market from the OneNet Project, whose characteristics are described in *Table 9*, and the tertiary regulation market in Spain, whose attributes are listed in *Table 5*, is carried out.

In the following *Table 11*, the attributes of both markets are combined, to have a direct understanding of how each of the attributes relates to one another. The congestion management market is red-colored, while the tertiary regulation or manual frequency restoration reserve is blue-colored.

Shaded in light orange are the attributes that categorize as conditional conditions, and that, therefore, need some kind of bid processing, in line with the methodology described in previous sections. The attributes that appear with no shading are fully compatible with a bid forwarding process, and therefore, do not need processing.

LOCAL CONGESTION MANAGEMENT AND MANUAL FREQUENCY RESTORATION RESERVE				
LOCAL CONGESTION MANAGEMENT			TERTIARY REGULATION	
Market Architecture	**Product**	**Timing**	**Participants**	**Bidding**
Type of market Auction Auction	Type of product traded Energy / Capacity Capacity	Gate opening time Day ahead – 12:00 h Day ahead – 21:00 h	Market operator Independent market operator – OMIE System operator – REE	Minimum size bid 0.01 MW – DSO 10 MW
Market time unit 15 minutes 15 minutes	Technical requirements FAT < 1 hour FAT < 5 minutes	Gate closure time Day ahead – 14:45 h Day ahead – 23:00 h	Allowed technologies No restrictions Generation, demand, and storage	Divisibility No restrictions Can be fully and partly divisible, or completely indivisible bids

Locational granularity	Technical prequalification conditions	Publication of results	Aggregation conditions	Symmetry
Nodal	Yes	After gate closure time – day ahead 14:45 h	Aggregation allowed	No restrictions
Zonal	Yes	25 minutes before the next programming horizon	Aggregation allowed	No symmetry needed

Table 11. Comparison between the Local Congestion Management Market in OneNet and the Tertiary Regulation (mFRR) service in Spain.

As it can be seen when comparing the *Table 10*, from the previous section, and the *Table 11*, they both look very much alike, and both, the secondary and tertiary markets, have more or less the same characteristics and restrictions compared to the local congestion management market in OneNet. Therefore, this section has similar findings and results as the previous section, *OneNet's local congestion management market and Spain's automatic frequency restoration* reserve.

Again, the manual frequency restoration reserve is a much more restrictive market that the flexibility market from OneNet, but making a broader comparison, the tertiary regulation service has less restrictions than the secondary regulation service.

Following the same methodology as before, the attributes are compared one by one, in order to identify barriers and opportunities for bid forwarding between the markets. Since they are very similar markets, both balancing energy services, the results will be very alike.

In the case of the market architecture, it can be seen that both markets are auction based and with a time unit of 15 minutes, which will pose no problem. Regarding the locational granularity, the local congestion management is more granular than the mFRR, being nodal and zonal, respectively. This means that the market operator (OMIE) should do a small processing to ensure that they are compatible, similar to the previous case.

Regarding the product that it is traded, there needs to be assured that both the technical prequalification conditions and the technical requirements are met in both cases. The full activation time of the tertiary regulation market is more restrictive than the one in the local congestion management market, 1 hour compared to 15 minutes. This means that there needs to be a filter in the bid processing that only allows the technologies whose full activation time is under 15 minutes to enter the mFRR market.

Both markets have technical prequalification conditions. In this case, the bid processing agent must ensure that only the technologies that comply with the other market requirements are forwarded. This probably limits, in many cases, the possibility for bid forwarding.

Regarding the gate closure time, is not a problem since the local congestion management's gate closure time precedes the one form the tertiary regulation market. The other time-related attributes follow the same line since they are closely related to one another. Therefore, this set of characteristics has full bid forwarding potential from OneNet flexibility market to the mFRR market.

The operator of both markets is different since the balancing services are managed by the system operator in Spain. This might be a problem, although there are solid communication channels and relations between the Spanish market and system operator.

As for the technologies that are allowed, there are some restrictions in the mFRR market, while there are none in the flexibility market. Therefore, there has to be a filter that only selects the bids that are either demand, storage or generation to be forwarded to the tertiary regulation market.

There are no special aggregation conditions in any of the markets, thus, there is full compatibility for bid forwarding, and it is not necessary to process the bids that will be forwarded from one market to another.

Regarding the bid size, there are considerable differences between the minimum bid size in both markets. This attribute is conditional, as it can be easily solved through aggregation of smaller bids, in order to comply with the required minimum to enter the secondary regulation market. The aggregation will be done by the bid forwarding agent, along with the other bid processing duties.

In this case, there are no divisibility nor symmetry restrictions in the mFRR market, therefore, there is full compatibility without the need for bid processing in this two attributes.

3.6.3. OneNet's local congestion management market and Spain's replacement reserve

In this section the comparison between the flexibility market from the OneNet Project, whose characteristics are described in *Table 9*, and the tertiary regulation market in Spain, whose attributes are listed in *Table 6*, is carried out.

In the following *Table 12* the attributes of both markets are combined, to have a direct understanding of how each of the attributes relates to one another. The congestion management market is red-colored, while the replacement reserve balancing energy service is blue-colored

Shaded in light orange are the attributes that categorize as conditional conditions, and that, therefore, need some kind of bid processing, in line with the methodology described in previous sections. The attributes that appear with no shading are fully compatible with a bid forwarding process, and therefore, do not need processing.

LOCAL CONGESTION MANAGEMENT AND REPLACEMENT RESERVE				
LOCAL CONGESTION MANAGEMENT		REPLACEMENT RESERVE		
Market Architecture	**Product**	**Timing**	**Participants**	**Bidding**
Type of market Auction Auction	Type of product traded Energy / Capacity Capacity	Gate opening time Day ahead – 12:00 h Day ahead	Market operator Independent market operator – OMIE System operator – REE	Minimum size bid 0.01 MW – DSO 1 MW
Market time unit 15 minutes 15 minutes	Technical requirements FAT < 1 hour FAT < 30 minutes	Gate closure time Day ahead – 14:45 h 48 minutes before the next programming horizon	Allowed technologies No restrictions Generation, demand, and storage	Divisibility No restrictions Can be fully and partly divisible, or completely indivisible bids

Locational granularity	Technical prequalification conditions	Publication of results	Aggregation conditions	Symmetry
Nodal	Yes	After gate closure time – day ahead 14:45 h	Aggregation allowed	No restrictions
Zonal	Yes	30 minutes before the next programming horizon	Aggregation allowed	No symmetry needed

Table 12. Comparison between the Local Congestion Management Market in OneNet and the Replacement Reserve service in Spain.

When analyzing *Table 12*, it can be seen that it is in line with the results that have been obtained in the two previous analysis, from *Table 10* and *Table 11*. This specific market, as it has been descripted in the previous section, *Replacement Reserve (RR)*, it is a market that is used mainly to replace the tertiary and secondary reserves, as well as to balance generation and demand.

If the replacement reserve market is compared with the secondary or tertiary markets, it can be seen that it is a much less restrictive market, making the possibility for coordination and bid forwarding from the local congestion management market from OneNet easier.

In the case of the market architecture, both markets are auction based and with a time unit of 15 minutes, as in the previous cases. Regarding the locational granularity, the local congestion management market is more granular than the RR market, being nodal and zonal, respectively. The unselected bids have to go through a bid processing stage to ensure that they are compatible, as it happened in the previous cases.

Regarding the product that it is traded, there needs to be assured that both the technical prequalification conditions and the technical requirements are met in both cases. The full activation time of the replacement reserve market is more restrictive than the one in the local congestion management market, 1 hour compared to 30 minutes. This means that there needs to be a filter in the bid processing that only allows the technologies whose full activation time is under 30 minutes to enter the RR market.

Both markets have technical prequalification conditions. In this case, the bid processing agent must ensure that only the technologies that comply with the other market requirements are forwarded. This probably limits, in many cases, the possibility for bid forwarding. However, easing the prequalification requirements, such as prequalifying as an aggregated group instead of individual unit, simplifying the prequalification and reducing the redundancy in prequalification processes can increase the number of prequalified units available.

The gate closure time is not a problem since the local congestion management's gate closure time precedes the GCT of the replacement reserve market. It would be most useful when the beginning of the next programming horizon is close in time, but always after the gate closure time of the flexibility market. The other time-related attributes follow the same line since they are closely related to one another. Therefore, this set of characteristics has full bid forwarding potential from OneNet flexibility market to the RR market.

The operator of both markets is different since the balancing services are managed by the system operator in Spain. This might be a problem, although there are solid communication channels and relations between the Spanish market and system operator.

As for the technologies that are allowed, there are some restrictions in the RR market, while there are none in the flexibility market. Therefore, there has to be a filter that only selects the bids that are either demand, storage or generation to be forwarded to the replacement reserve market.

There are no special aggregation conditions in any of the markets, thus, there is full compatibility for bid forwarding, and it is not necessary to process the bids that will be forwarded from one market to another.

Regarding the bid size, there are considerable differences between the minimum bid size in both markets. This attribute is conditional, as it can be easily solved through aggregation of smaller bids, in order to comply with the required minimum to enter the secondary regulation market. The aggregation will be done by the bid forwarding agent, along with the other bid processing duties. In this case, the minimum bid size is smaller than in the other balancing energy markets (i.e., secondary and tertiary regulation), thus, it will be easier to achieve the minimum bid size than in the previous cases.

Again, there are no divisibility nor symmetry restrictions in the RR market, enabling full compatibility without the need for bid processing in this two attributes.

3.6.4. OneNet's local congestion management market and Spain's day ahead market

In this section the comparison between the flexibility market from the OneNet Project, whose characteristics are described in *Table 9*, and the day ahead market in Spain, whose attributes are listed in *Table 7*, is carried out.

In the following *Table 13*, the attributes of both markets are combined, to have a direct understanding of how each of the attributes relates to one another. The congestion management market is red-colored, while the day ahead market is blue-colored.

Shaded in light orange are the attributes that categorize as conditional conditions, and that, therefore, need some kind of bid processing, in line with the methodology described in previous sections. The attributes that appear with no shading are fully compatible with a bid forwarding process, and therefore, do not need processing. The attributes that are shaded in grey are the ones violating one necessary condition.

LOCAL CONGESTION MANAGEMENT AND DAY AHEAD MARKET				
LOCAL CONGESTION MANAGEMENT			DAY AHEAD	
Market Architecture	**Product**	**Timing**	**Participants**	**Bidding**
Type of market Auction Auction	Type of product traded Energy / Capacity Energy	Gate opening time Day ahead – 12:00 h Day ahead	Market operator Independent market operator – OMIE Market operator – OMIE	Minimum size bid 0.01 MW – DSO 0.1 MW
Market time unit 15 minutes 1 hour	Technical requirements FAT < 1 hour No	Gate closure time Day ahead – 14:45 h Day ahead – 12:00 h	Allowed technologies No restrictions Generation, demand, and storage	Divisibility No restrictions No restrictions

Locational granularity	Technical prequalification conditions	Publication of results	Aggregation conditions	Symmetry
Nodal	Yes	After gate closure time – day ahead 14:45 h	Aggregation allowed	No restrictions
Zonal	No	Day ahead – 13:00 h	Generation and demand cannot be aggregated.	No symmetry needed

Table 13. Comparison between the Local Congestion Management Market in OneNet and the Day Ahead Market in Spain.

Taking a look at *Table 13*, it can be seen that it is considerably different that the three previous analyses that have been made. First of all, the product traded is different, since it is not capacity, as in the secondary or tertiary regulation, but energy, expressed in MWh. This changes the way that bids can be forwarded between one market and the others, since there is no need to "transform" an energy bid into a capacity bid, and a capacity bid into and energy one for a given time period.

In the case of the market architecture, the day ahead Spanish market has a time unit of 1 hour, while the local congestion management has a time period of 15 minutes. This makes it possible to forward bids from the flexibility market to the day ahead market by converting quarterly to hourly bids, after a bid processing stage. Regarding the locational granularity, it is the same as in the balancing energy examples, the local congestion management has a more exhaustive granularity than the day ahead, being nodal and zonal, respectively. Having to go through a bid processing stage to ensure that they are compatible, but not being a major issue to overcome.

In this case, the day ahead market does not have any technical prequalification conditions or technical requirements, while the flexibility market does. It will be easy to forward bids from the local congestion management market since they will not need to undergo any bid processing. The other way around will require a bid processing stage to filter the technologies that do comply with the technical requirements of the flexibility market.

Regarding the gate closure time, in this case it is a problem when trying to froward bids from the local congestion management market to the day ahead market in Spain since the gate closure time of the flexibility market takes place after the gate closure time of the day ahead market. This creates a situation where it is not possible to forward bids to the day ahead market. In order to overcome this barrier, it would be necessary to change the whole timing of the local congestion management market, so that the gate closure time would be before the day ahead market one.

It might not be worth it to make bid forwarding possible from the local congestion management market to the day ahead market. The goal of introducing flexibility resources into the network is to deal with intermittency and to ensure the security of the system. If local flexibility markets are conducted much before the real-time delivery, the accuracy of predictions made by renewables and demand response systems will be low. This will create a situation in which further flexibility is required to manage the prediction errors in the system. Therefore, moving the GCT of local markets before day-ahead market is not a suitable option, especially considering the availability of intraday markets for bid forwarding in the intraday timeframe.

Regarding the gate closure time, but from the other perspective, it is possible to forward bids from the day ahead market to the local congestion management market, since the gate closure time is, in this case, after. However, only bids from the units that are located in the area covered by the local market can participate in the local congestion management market. Additionally, as the local markets require granular locational information, the bids should be updated accordingly.

In this case, the market operator is the same for both markets, making it easier for communicating than in the previous cases. As for the technologies that are allowed, there are some restrictions in the day ahead market, while there are none in the flexibility market. Therefore, there is not needed a bid processing stage to forward bids from the day ahead market to the local flexibility market since it is less restrictive.

The only requirement of the day ahead market regarding aggregation is that demand and generation cannot be aggregated together, while there are no restrictions in the local congestion management market. This will, again, make it possible to forward bids to the local flexibility market from the day ahead market without the need of a bid processing stage.

Regarding the bid size, even though there are differences, it is much lower compared to the previous cases. When forwarding bids from the day ahead market, there are no restrictions since the bid size is smaller in the local congestion management market and, therefore, there is no need for aggregation.

Again, there are no divisibility nor symmetry restrictions in the day ahead market, enabling full compatibility without the need for bid processing in this two attributes.

3.6.1. OneNet's local congestion management market and Spain's intraday market

In this section the comparison between the flexibility market from the OneNet Project, whose characteristics are described in *Table 9,* and the day ahead market in Spain, whose attributes are listed in *Table 8*, is carried out.

In the following *Table 14*, the attributes of both markets are combined, to have a direct understanding of how each of the attributes relates to one another. The congestion management market is red-colored, while the day ahead market is blue-colored.

Shaded in light orange are the attributes that categorize as conditional conditions, and that, therefore, need some kind of bid processing, in line with the methodology described in previous sections. The attributes that appear with no shading are fully compatible with a bid forwarding process, and therefore, do not need processing.

LOCAL CONGESTION MANAGEMENT AND INTRADAY MARKET				
LOCAL CONGESTION MANAGEMENT			**INTRADAY**	
Market Architecture	**Product**	**Timing**	**Participants**	**Bidding**
Type of market Auction Auction / continuous	Type of product traded Energy Energy	Gate opening time Day ahead – 12:00 h Day ahead – 14:00, 17:00, 21:00 Delivery day – 01:00, 04:00, 09:00	Market operator Independent market operator – OMIE Market operator – OMIE	Minimum size bid 0.01 MW – DSO 0.1 MW

Market time unit 15 minutes 1 hour	Technical requirements FAT < 1 hour No	Gate closure time Day ahead – 14:45 h Day ahead – 15:00, 17:50, 21:50 Delivery day – 01:50, 04:50, 09:50	Allowed technologies No restrictions Generation, demand, and storage	Divisibility No restrictions No restrictions
Locational granularity Nodal Zonal	Technical prequalification conditions Yes No	Publication of results After gate closure time – day ahead 14:45 h Day ahead – 15:07, 17:57, 21:57 Delivery day – 01:57, 04:57, 09:57	Aggregation conditions Aggregation allowed Generation and demand cannot be aggregated.	Symmetry No restrictions No symmetry needed

Table 14. Comparison between the Local Congestion Management Market in OneNet and the Intraday Market in Spain.

Taking a look at *Table 14*, it can be seen that it is considerably different that the four previous analyses that have been made, especially because of the several gate closure times. First of all, the product traded is energy, as in the day ahead market. As it has been explained before, it has both a continuous trading market and an auction based market with six auctions throughout the day, in either case, it is compatible with the local congestion management market.

In the case of the market architecture, the intraday market has a time unit of 1 hour, while the local congestion management has a time period of 15 minutes, as it happened in the previous case. This makes it possible to forward bids from the flexibility market to the day ahead market by converting quarterly to hourly bids, after a bid processing stage.

Regarding the locational granularity, it is the same as in the balancing energy examples, the local congestion management has a more exhaustive granularity than the day ahead, being nodal and zonal, respectively. Having to go through a bid processing stage to ensure that they are compatible, but not being a major issue to overcome.

In this case, the intraday market does not have any technical prequalification conditions or technical requirements, while the flexibility market does. It will be easy to forward bids from the local congestion management market since they will not need to undergo any bid processing. The other way around will require a bid processing stage to filter the technologies that do comply with the technical requirements of the flexibility market.

Regarding the gate closure time, it is not a problem when trying to forward bids from the local congestion management to the intraday market, since all the auctions that is has take place after the gate closure time of the flexibility market. Therefore, it is possible to forward bids from the local flexibility market to the intraday market.

Unlike in the previous example, in the case of the intraday market it does make sense to have bids forwarded from the local congestion management market, since it is a market made to correct the errors in forecasting and the deviations of demand and generation throughout the day, where local flexibility resources would prove very useful to provide the service.

In this case, again, the market operator is the same for both markets, making it easier for communicating than in the balancing energy examples. As for the technologies that are allowed, there are some restrictions in the intraday market, while there are none in the flexibility market. In order to have bids forwarded from the local flexibility market to the intraday market, there must be a bid processing stage to ensure that the only technologies allowed are storage, generation, and demand.

The only requirement of the intraday market regarding aggregation is that demand and generation cannot be aggregated together, while there are no restrictions in the local congestion management market. This will require another bid processing stage, to filter or limit some of the technologies, but will not be an issue.

Regarding the bid size, there are very small differences between the minimum bid size of these two markets. With this said, it will still be necessary to process, in this case aggregate, the smaller bids from the local congestion management market to be eligible to participate in the intraday market.

Again, there are no divisibility nor symmetry restrictions in the intraday market, enabling full compatibility without the need for bid processing in this two attributes.

Chapter 4. Analysis of results

The objective of this chapter is to discuss and analyze the results that have been obtained during this project as a whole. This thesis has obtained results for the different parts that it has studied, but is mainly focused on the previous chapter, where there has been done a study of the coordination of the different Spanish markets with the local congestion management market proposed in OneNet.

This coordination comparison has only been possible after having studied the different characteristics and format of the OneNet project in *Chapter 2*, were the main guidelines were set as to which attributes should be taken into account when looking at the possibility for harmonization of services and markets. In particular, the market focus of this chapter was the local congestion management market proposed by the OneNet Project.

In addition, there was a study on the relationship between markets, and the possible ways to enable coordination, and has been defined as the bid forwarding process. It has been clearly stated how it works, the main parties involved, and the areas where it should focus, as well as how to identify the main barriers and how to overcome them.

Related to this, there has been a thorough study of the methodology to follow for the correct study of coordination between two markets, identifying its three main steps:

- Selection of markets for the compatibility study.
- Study of the design features and the identification of potential barriers to the bid forwarding process.
- Development of recommendations to overcome the defined barriers.

Then, in *Chapter 3*, there was a study of five different markets and services in the Spanish electricity market, that are: the secondary regulation market (aFRR), the tertiary regulation market (mFRR), the replacement reserve market (RR), the day ahead market, and the intraday market. This coordination study followed the methodology stated above.

Following the first step of the methodology process, the markets that have been compared are chosen. The five markets, previously stated, are the main wholesale electricity markets (i.e., day ahead and intraday markets), and the balancing energy markets (i.e., secondary regulation, tertiary regulation, and replacement reserve). These markets have been chosen for the study due to the fact that they are the most significant electricity markets in Spain.

Then, the second step consists of the definition of the attributes that are analyzed and the comparison between each market, where every feature is compared individually to ensure that the correct process is followed. After carefully reviewing the coordination potential between each of the markets, the main barriers and compatible features have been identified.

The results of the analysis made in the previous section, *Coordination between the markets*, are clear as for which markets there is coordination potential and for which there is not, as well as the main recommendations that need to be followed to make the bid forwarding process possible (step three of the methodology).

There is bid forwarding potential from the OneNet local congestion management market to the following Spanish markets:

- Secondary regulation (aFRR)
- Tertiary regulation (mFRR)
- Replacement reserve (RR)
- Intraday market

In all of these cases, there is potential for coordination, meaning that there are several conditional conditions that need to be addressed to achieve the optimal bid forwarding process.

In the case of the day ahead market, it has been established that there is no possibility to forward bids from the local congestion management market to the day ahead market, due to the violation of a necessary condition, this is, the gate closure time of both markets makes it impossible to forward bids in that direction. This could be seen as a potential barrier, since the rest of the features are aligned or are just conditional conditions, but the day ahead market would not benefit as much receiving new flexible bids.

This is because it is the main electricity market in Spain and does not require the services that flexibility resources provide, like adapting to the intermittency of the generation. It is not the goal of this electricity market to follow the changes in generation, there are already other markets and services in place (i.e., intraday market and balancing energy markets) that manage those situations. It is better to introduce the flexibility resources into those markets, rather than in the day ahead market.

Even though bid forwarding is not possible in the flexibility market to the day ahead market, it is possible to forward bids in the other direction since there is a coordination potential, once the several conditional conditions are resolved.

When analyzing the barriers or conditional constraints in the markets where there is potential for bid forwarding, it can be seen that there are some common issues across the different markets, especially between the balancing energy markets. In light of these facts, the main issues will be address, in order to overcome those barriers. The main barriers found are:

- Technical prequalification conditions
- Technical requirements
- Minimum bid size

These are the most restrictive attributes, that are the most challenging to resolve. There are some other minor restrictions, that should be taken into account but will not pose any problem whatsoever, like the locational granularity, the different market and system operator, or the light aggregation restrictions.

Regarding the major barriers, the first two (i.e., the technical prequalification conditions and the technical requirements) could be treated similarly since it involves the technical characteristics of a bid. This can be solved by placing a filter and only allowing the bids that comply with those two technical restrictions to enter the market they are being forwarded to.

Regarding the minimum size required for the bids, it has a simple solution, a priori. This can be solved through aggregation of bids, grouping smaller bids that have qualified to create a larger bid that complies with the minimum bid size of each market.

As it has been mentioned in the previous sections, this aggregation should be done by the agent in charge of the operation of the bid forwarding process, which in this case is the market operator – OMIE. There is not a clear regulatory framework that defines the responsibilities and procedures regarding aggregation, and the little there is, is established at a national level, which can arise issues in the future, when trying to coordinate between different countries and lacking harmonization (17). This regulatory framework should be further developed, establishing clear roles and responsibilities in this process, and, if possible, it should be done at a European level to have a harmonized or standard structure in the future.

With this in mind, the general approach to overcome the barriers should be a bid processing stage composed by two, or three, different levels. The first, should be a filter that distinguishes the bids that meet the technical requirements and the prequalification conditions, called the "Technical constraints filter". Then, after the bids that have passed the filter can be aggregated when they do not meet the minimum bid size, in the "Aggregation" phase. If necessary, there could be an intermediate filter that takes into account the other minor constraints, called "Other constraints", this is not necessary in all the cases. This bid processing stage can be seen in the following *Figure 9*.

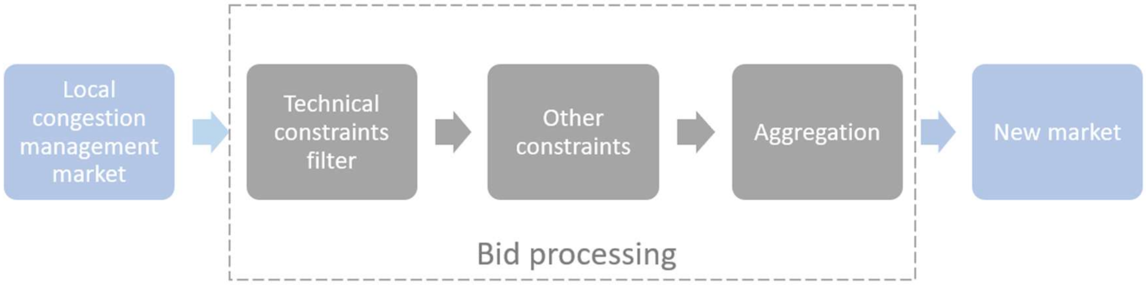

Figure 9. Description of the general bid processing stage developed.

Taking into account the characteristics of all the markets, even though all of the balancing energy services are compatible and coordination between them should be developed, it can be concluded that the market that would benefit the most from the bid forwarding process would be the intraday market. This is due to the main uses and objectives of this market, along with no technological constraints. In addition, the continuous trading market as well as the numerous auctions enable the deployment of plenty flexibility resources.

Chapter 5. Conclusions

After having done a review of the OneNet Project, with an especial focus on the concepts of harmonization, standardization, and coordination as well as analyzing the attributes and characteristics that define these concepts, a solid base has been obtained on the criteria to be followed in the coordination of markets in the electricity sector, ensuring at all times compliance with all the requirements that apply.

In addition, there has been a thorough analysis of the bid forwarding process, identifying its main stakeholders, and responsibilities, amongst others. Then, the methodology to follow in order to study the coordination potential between two markets has been analyzed. This includes the definition of attributes and features that are necessary to assess the bid forwarding process.

Once that the OneNet project and its objectives have been defined, there has been a deep dive in one of its markets, that is of particular interest for the development of this thesis, the local congestion management market, that will be used to study the possible coordination with other markets in Spain that are already in place.

Then, after doing a thorough study of the OneNet Project, the focus has been shifted to the electricity sector in Spain, where there has been done an analysis of the five markets that have been selected to study the compatibility with the flexibility market from OneNet. These five markets have been: the secondary regulation market, the tertiary regulation market, the replacement reserve market, the day ahead market, and the intraday market. These are three of the main markets that comprise the balancing energy services in Spain, as well as the day ahead and intraday markets, that are the main Spanish energy markets.

During this process, there has been a qualitative assessment on the importance of local flexibility markets, their benefits, and the reasons behind their increase in popularity and confidence. In this case, the local flexibility market from OneNet, is expected to enable flexibility resources and integrate them in several markets, like ancillary services or the wholesale electricity market. It can be thought of as the first stages of the integration of flexibility resources in the electricity sector. This will be crucial to deal with the intermittency of renewable energy sources, as well as to ensure the correct operation of the system.

The main objective of this thesis was to study the coordination potential between local flexibility markets and wholesale electricity markets, in this case, of Spain. This is a starting point that should then be expanded to more markets and more countries in Europe, to create a harmonized electricity market that takes into account all the participants across the whole sector in Europe.

This thesis has developed a guideline and an overview of good practices and methodology in the development and study of coordination between different markets, that can be further developed and put into place to study coordination of electricity markets that enable flexibility in other countries.

In the case of Spain, four of the five markets that have been studied can be considered suitable for coordination with the flexibility market proposed in OneNet, in the direction local congestion management to Spanish market. The day ahead market has not been considered optimal for coordination in that direction but can surely have bids forwarded to the local congestion management market.

In addition, during the coordination study, some potential barriers to the bid forwarding process have been identified. The major barriers are that the bids need to comply with the technical requirements of the market they are being forwarded to, as well as the minimum bid size. In order to solve these issues, a bid processing stage that takes into account these main factors, and others, has been proposed, as it can be seen in *Figure 9*. With this process, bids can be, first filtered and then aggregated, so that they can comply with all the requirements of the market.

As it can be expected in every developing sector or new technology that is being integrated in a market, there is a lack of regulation concerning flexibility sources in Spain and in Europe. In order to make coordination possible, it is of the outmost importance to have harmonized and regulated products across the whole energy sector, first within countries, and then across borders. This is especially important when defining the role of the aggregator, that plays a key role in the whole bid forwarding process.

The lack of regulatory framework is twofold, there needs to be more regulation concerning the possibility for market coordination, the relationship between the parties involved, both existing and new, and the development and integration of new technologies that are essential to enable coordination. In addition to having more regulation, it is indispensable that this regulation is standardized throughout the whole energy sector, for all the actors involved, and across international borders within Europe, since standard products are the base of flexibility implementation and coordination.

Furthermore, some regulations and constraints that are currently in place should be relaxed, to enable the participation of other providers of the service, without compromising the quality of the service procured.

In conclusion, taking into account all these factors, it can be ensured that this thesis has achieved all of its goals, since it has clearly developed a guideline of good practices and methodology to enable coordination between markets in the electricity sector, with an especial focus in the OneNet project, selecting its most important attributes. It has successfully studied the coordination potential of the flexibility market from OneNet with several Spanish electricity markets, regarding its timeframes, or architecture of the market, amongst other important features.

In addition, it has identified the point where there could be potential problems and how to solve them, regarding timeframes and technical constraints of some of the services, developing a bid processing scheme that will enable bid forwarding between markets. Furthermore, it has underlined the most important regulatory measures that should be taken to ensure that all the work done here is feasible and applicable, and that can be easily escalated to other countries and regions, especially at a European level.

Chapter 6. Future projects

As it has been mentioned during the previous chapters, the objective of this thesis is just a starting point for the development of flexibility and its integration in the whole electricity system. In light of these facts, it is safe to assume that there are infinite possibilities for future projects that elaborate on this one.

Most of these potential future projects could be just to escalate and replicate what has been done in this thesis to other markets and other geographies but maintaining the same methodology in terms of procedures or regulatory framework. All of these projects combined together hopefully can result in a fully integrated and coordinated flexibility system across Europe.

6.1. Coordination within clusters – Western cluster

As explained before, one of the possibilities of a future project, that is included in the goals of the OneNet Project is the expansion to other nationalities, while ensuring the same coordination methodology. The OneNet Project has created certain divisions between areas that will work at the early stages together before trying to merge the whole European system.

In doing this, the European countries that are participating in this project have been divided into four groups that will works closely together to achieve the integration of flexibility services in the network and coordination between the different countries. In the following *Figure 10*, it can be seen how these groups or clusters are organized. In the case of Spain, it will work along its neighbors, France and Portugal, forming the so called Western Cluster.

Figure 10. Organized clusters in the OneNet Project. Source: Deliverable 3.1. OneNet (15).

In order to achieve a correct integration between countries, it is of the outmost importance to have extremely well defined communication channels between the different countries and parties, integrating TSO to TSO communication and TSO from one country with the DSO from another, as well as market and system operators.

In addition to having good communication channels between all the involved parties, it is imperative to have a common platform where all the flexibility providers can place their bids and all the other actors can participate, independently of their countries.

This is expected to be a long process, but the ultimate goal is to replicate the analysis that has been done in this thesis in the other countries (i.e., Portugal and France, but can include participants form other clusters like Slovenia, Slovakia or Poland). When there is already coordination between the different markets of interest within one country, communication and coordination between different countries can take place.

It is important that the same methodology is followed across borders from the early stages of this process, so it can then be easier to interconnect the different countries together, beginning with the organized clusters, and then grouping those clusters together.

6.2. Development of the bid forwarding algorithm

Other possible future project is to develop the bid forwarding algorithm that has been mentioned in the previous chapters. This algorithm, at the beginning should only be focused on the markets that it will be directly working with, while working close with the different market operators, so that it can be fed all the bids that are offered, independently if they are selected to enter the corresponding market or not, that in the future should be done by this same, but upgraded, algorithm.

It should take into account all of the technical constraints that were described in the previous sections, with all the timeframes and relationships between the markets, as well as a different criteria for selecting the optimal bids for each market.

In addition, it would be beneficial if it could act as an aggregator too. As it has been seen, flexibility services are usually very small in size and, therefore, there is almost at all times the need for aggregation of bids to comply with the minimum bid size that is regulated in each of the markets. Even though it could be advantageous in some cases to have the aggregation process incorporated, it can also have its drawbacks.

It would be very beneficial in the cases where there are not many bids that need to be grouped, like the cases when bids are "recycled" from one market to another but must follow some minimum bid size rule. It should be fairly easy to group a relatively small number of bids.

It would not be beneficial, and maybe even feasible, to try to aggregate all of the flexibility, for instance, from demand-side response, to create a bid composed of thousands of smaller bids. This might be too much to process, while having to manage and do the same for several other markets.

It can have both, allowed aggregation so that it can have the flexibility to group bids whenever it is convenient and useful for the system, but have a third party aggregating the bids that directly enter the market in the form of flexibility, establishing a low minimum bid size to be able to enter the local congestion management market.

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Chapter 8. Annexes

ANNEX I. SUSTAINABILITY DEVELOPMENT GOALS

The following are the sustainable development objectives, proposed by the United Nations for global economic, environmental, and social improvement, on which this work will have the greatest impact (19).

- SDG 7: This objective is set to achieve affordable, reliable, and clean energy to all. By further developing the electricity market, it will increase its reliability, efficiency, and will result in lower electricity prices for all. In addition, since flexibility markets are aligned with higher renewable penetration, it will allow more sustainable energy generation.

- SDG 8: Since this project's target is to create a better electricity market scenario, it will result in sustained and sustainable economic growth. As a side effect, during its course, it will help create decent employment.

- SDG 9: This is a highly innovative project that will build a resilient market infrastructure throughout Europe and help increase industrialization across several countries.

- SDG 11: This project will create more sustainable cities and communities by enabling higher renewable energy use and optimizing the energy system.

- SDG 13: By making it easier to increase green energy production, this project will help reduce the carbon emissions from traditional fossil fuel facilities, which will mitigate climate change, reducing its impacts.