LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
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Master's thesis

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Evaluation of the technical and market requirements unlocking demand response independent aggregators in selected European countries

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Prof. Samuli Honkapuro
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Dr. Gonçalo Mendes

ABSTRACT

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In respect of the climate change matters, countries are doubling the efforts to reach the EU renewable energy targets. This motivation has already been highlighted in 2019, as the share of RES in the energy consumption reached approximately 18.9% closely aligning with the 20% target. In light of a sustainable electricity market transition, forecasting continuously demand and supply due to the intermittency nature of RES becomes complex. In this context, the role of balancing market is considered vital ensuring reliability and security of operations. As a response to these changes, demand response emerged as key enabler supporting the integration of RES by providing balancing services the market. In parallel, European Commission guidelines acknowledged the fundamental role of demand response (DR) aggregation explicitly unlocking the access of independent aggregators. As a matter of fact, these market players shifted the status of customers to prosumers actively participating in the balance management of the electricity system.

This thesis presents a comparative framework identifying the technical and market requirements allowing the access of independent DR aggregators in selected EU and UK balancing markets. At the moment, Finland and the UK are leading the transition by enabling third-party aggregators in their balancing markets. The Netherlands is undergoing noticeable changes by regulating the status of these market players in the primary response. However, an agreement with balance responsible party (BRP) is still mandated in the secondary and tertiary reserves. Iberian market remains locked for DR aggregation and third-party aggregators status not yet recognized. Although advancements are gradually implemented, results reflected existing challenges at the technical and market levels. Lessons learned from targeted pilots highlighted the compensation challenge between involved market players. The analysis of selected countries reflects on the opportunities and factors influencing the integration of DR aggregation in a long-term prospect.

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My gratefulness goes to my parents for their constant moral support during my studies and my personal life.

NOMENCLATURE

aFRR	Automatic Frequency Reserve
BM	Balancing Markets
BSP	Balancing Service Providers
BRP	Balancing Responsible Party
CHP	Combined Heat and Power
CPP	Critical Peak Pricing
DER	Distributed Energy Resources.
DSO	Distribution System Operator
DSR	Demand Side Response
DR	Demand Response
DSM	Demand Side Management
DTU	Demand Turn-Up
EC	European Commission
EFR	Enhanced Frequency Response
EU	European Union
FAT	Full Activation Time
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal Operations
FRR	Frequency Restoration Reserve
GHG	Greenhouse Gas
ICT	Information and Communication Technology
MARI	Manually Activated Reserves Initiative
mFRR	Manual Frequency Reserve
mFRRDA	Manual Frequency Reserve directly activated
mFRRSA	Manual Frequency Reserve scheduled activated
OFGM	Office of Gas and Electricity Markets
PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
TERRE	Trans European Replacement Reserves Exchange
TOU	Time Of Use
TSO	Transmission System Operator
REE	Red Eléctrica de España

REN	Redes Energéticas Nacionais
RR	Restoration Reserve
SEL	Stable Export Limit
STOR	Short Term Operating Reserve
UK	United Kingdom
USEF	Universal Smart Energy Framework
VLP	Virtual Lead Party
VPP	Virtual Power Plant

TABLE OF CONTENTS

1. Introduction....5
1.1. Overview of the electricity markets structure....5
1.2. Problem formulation....6
1.3. Research objectives....8
1.4. Structure of the report....9
1.4. Assumptions....10
2. Flexibility in electricity markets....12
3. Overview of balancing markets....16
3.1. Definition of balancing markets....17
3.2. Balancing market services....18
3.3. Current development and challenges in design of balancing markets....24
3.4. Market behavior in electricity balancing market: Roles of market participants....25
3.5. Identification of design principles of balancing markets....29
4. Demand response....35
4.1. Implicit demand response....36
4.2. Explicit demand response....36
4.3. Benefits and challenges in demand response services....38
5. Independent aggregators as new market players....40
5.1. Aggregators as demand response enablers in the balancing market....41
5.2. Fundamentals of aggregation....42
5.3. Current types of aggregators....44
5.3.1. Combined aggregators....45
5.3.2. Independent aggregator models....46
5.4. Compensation challenge....47
5.5. Value proposition of the aggregator in the balancing markets....50
6. Methodology and framework development....53
6.1. Methodology and selection of comparison features....53
6.2. Definition of components of the framework....54
6.2.1. Technical product requirements....54
6.2.2. Market and regulatory requirements....56
7. Comparative analysis of selected case countries....59
7.1. Finland....59
7.1.1. Overview of the balancing market in Finland....59

7.1.2. Status of demand response in Finland ... 63
7.1.3. Independent aggregators as market players in Finland ... 65
7.1.4. Relevant Finnish pilots ... 67
7.2. Netherlands ... 69
7.2.1 Overview of the balancing market in the Netherlands ... 69
7.2.2. Status of demand response in the Netherlands ... 73
7.2.3. Independent aggregators as market players ... 75
7.2.3. Relevant Dutch pilots ... 79
7.3. United Kingdom ... 80
7.3.1. Overview of the British balancing market ... 80
7.3.2. Status of demand response in the UK ... 86
7.3.3. Independent aggregators as market players ... 89
7.3.4. Relevant pilots in the UK ... 94
7.4. Iberian countries ... 95
7.4.1 Structure of Iberian balancing market ... 95
7.4.2. Overview of demand response status in Iberian market ... 99
7.4.3. Status of demand response aggregation in balancing market. ... 102
7.4.4. Development toward demand response aggregation ... 105
8. Discussion ... 108
9. Conclusion ... 115
References ... 119

APPENDIX I. Flow chart of the technical and market barriers and enablers.

APPENDIX II. Technical and market requirement of the balancing reserves in Finland.

APPENDIX III. Technical and market requirements of the balancing reserves in the Netherlands.
APPENTIX IV. Technical and market requirements on the FCR reserves in UK.

APPENDIX V. Technical and market requirements of the balancing reserves (aFRR and RR) in the UK.

DEFINITIONS

Aggregator: In the context of this thesis, demand response aggregator is defined as an entity aggregating the flexibility of the customers by changing their consumption trends. The DR aggregator can sell the flexibility to other market participants or trade it in the electricity markets. In the balancing markets, the DR aggregators provides balancing services as form or energy or capacity.

Balancing capacity: The TSO is charged of procuring the required volume of capacity from the balancing service providers to the reserves to maintain the nominal frequency value of the system.

Balancing energy: The balancing energy refers to the energy used by the TSO to balance the supply and demand. It is offered by the balancing service provider.

Balancing market: The balancing market is part of the electricity markets in which precoders offers their balancing services to stabilize the levels of supply and demand. The balancing markets are composed of energy balancing markets procured close to real-tine, and reserves markets procured generally ahead of time.

Balancing reserves: The balancing reserves are part of the balancing markets used to maintain a stable system frequency. The balancing reserves are defined as the frequency containment reserves, frequency restoration reserves, replacement reserve commonly referred at consecutively primary, secondary, and tertiary reserves.

Balancing services: The balancing services refer to the energy and capacity services offered by the balance service providers in the balancing markets.

Balancing Service Provider: The BSP is an active market participant in the balancing market providing energy and capacity balancing services to the TSO.

Balancing Responsible Party: The BSP is a market participant in the balancing market and is responsible for the imbalances of its portfolio.

Demand Response: DR is part of Demand Side Management and it consists of changing the consumption behavior in response to the market changes. Demand Response is divided as explicit demand response referred to it as incentive based or market-based DR, and implicit demand response that offers dynamic pricing to the customers.

Demand Side Management: DSM is defined as actions to optimize the use of energy through energy efficiency of demand response. Energy efficiency as a DSM concepts targets the use of limited amount of energy while improving of the services. Demand response refers to the change of costumer´s consumption implicitly or explicitly.

Imbalance: In the balancing market, an imbalance when the physical volume of the balance responsible party differs from its position. The physical volume equals the allocated volume that is injected or withdrawn in the balancing markets. The imbalances are to be adjusted by the BRP.

Imbalance settlement: The imbalance settlement consists of financially settle the imbalances caused by the BRP. Depending on the TSO calculations, the BRP could either be compensated or charged for their imbalances.

Independent aggregators: The DR independent aggregator is a market participant considered as a third-party service provider aggregation the demand response resources from its customer to sell or trade the flexibility in the balancing markets for instance. The independent aggregator has no agreement with the customer´s supplier or the BRP.

Frequency containment reserve: The FCR reserves are used to continuously maintain the system frequency in its nominal and constant value (50Hz in the European Union). The FCR are activated within 30 seconds and automatically.

Frequency restoration reserve: The FRR are used to restore the system frequency in case of deviation and to replace the FCR is case the deviation lasts more than 30 seconds. The FCR is usually activated in 30 seconds and up to 15 minutes. The FRR is categorized depending on its activation methods including the aFRR activated automatically and mFRR activated manually.

Replacement Reserve: Part of the balancing reserves, the RR is used to restore the system frequency and provide the system with support the FRR in case of additional system frequency deviations. The RR are activated within a range of 15 minutes up to several hours.

Transmission System Operator: The TSOs are legal entities responsible for maintaining and securing the transmission of electricity at the national level, and interconnections internationally if applicable. The main goal of the TSO is to ensure a reliable transmission system at the long-term. In the balancing markets, the TSO contracts the balancing services from the balancing service providers, request the delivery of these services, and defines the technical and regulatory requirements for market participants

1. Introduction

1.1. Overview of the electricity markets structure

The restructuring of the power sector following the Electricity Directive 96/92/EC in unbundling of transmission, distribution, generation, and supply resulted in massive changes. In a traditional and vertically integrated electricity system, utility approach consisted of dealing with system imbalances when they occur. Today, electricity markets are designed to meet power balance, sustainability with respect to environmental constraints, and cost efficiency (Erbach, 2016). The restructuring of the electricity market is considered as the main driver in introducing fair competition in the internal electricity market targeting the liberalization of trading and the supply from monopoly. The design of the electricity market remains a complex subject as it could be classified depending on various features. The electricity system is based on four pillars including the generation, transmission, distribution, and selling in an organized electricity market. From an economical perspective, this market is considered as a system allowing the trade (buying or purchasing) electricity in various marketplaces via long or short terms contracts. On that premise, the market includes financial and physical features. The trade of the electricity depends defensibly on the forecasting of the demand and supply. Thus, to hedge the forecasting probability errors, the electricity is traded accordingly to the procurement time to satisfy the current demand.

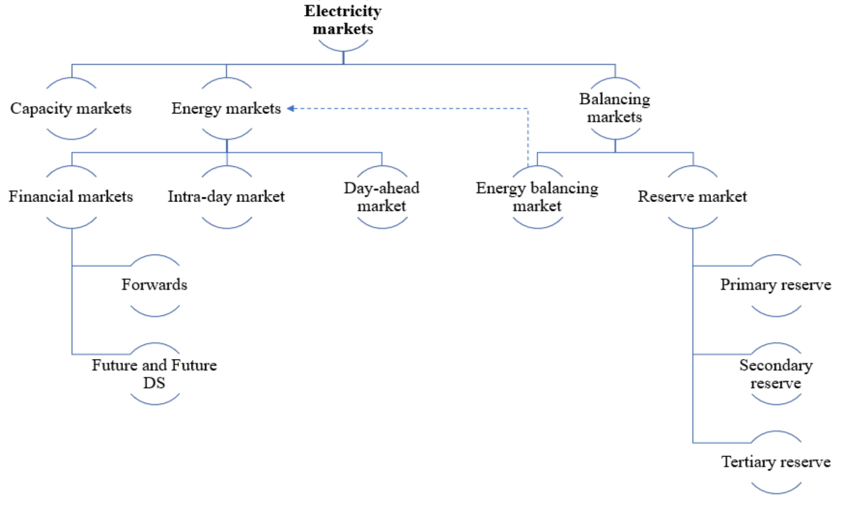

Figure 1. Electricity market general structure.

In a long-term perspective, forwards and future markets as the name indicates, are procured months, or even years ahead of the delivery time. The main purpose of these markets is to reduce the risks of the operations and secure fair price development. In addition, they are used to secure the needed capacity ahead of time. The future and forward markets are considered financial markets as the electricity is not delivered physically. The wholesale markets are composed of day-ahead and intra-days markets. These markets are defined as physical markets in which the electricity is delivered physically (Partanen, et al., 2019). In the day-ahead markets, electricity is traded on an hourly basis. Essentially, providers such as large-scale generating units, suppliers, and other market participants submit bids a day before the delivery. The day-ahead as a fundamental procurement role in the electricity market, enables the buy and sell of energy for the following 24 hours (NordPool, 2020) .

As a matter of fact, in 2017, 70% of electricity consumed in Finland was procured from day-ahead markets (Pearce & Forsman, 2018). After the closure gate of the day-ahead market, the electricity is traded in the intra-day in order to efficiently secure the balancing between the demand and supply. Within the concept of balancing, one can distinguish between the energy and ancillary balancing markets. These markets are also referred to as TSO or reserves markets as they are used to continuously maintain the nominal value of the system frequency, and to restore back the previous reserves activated. The TSO provides balancing bids through the balancing reserves including the FCR, aFRR and mFRR. However, the structure of the balancing markets differs from country to country and will be discussed on further details in the Chapter 3. The reserves are usually procured ahead of time through contractual agreement with the TSO and the service provider. The balancing energy market is provisioned after the gate closure of the intra-day market to further secure the system balance. Contrarily to the ancillary services, the balancing energy markets procure the energy bids in real-time. It is important to mention that the reserve market can also be open for balancing energy provision, as in happens in countries such as Finland.

1.2. Problem formulation

Today, the EU electricity system is driven by a strong penetration of high intermittent energy resources. EU member states are doubling the efforts to meet the RES target set to 2030. Following the climate and energy framework implemented for 2021-2030, European countries are required to include at least 32% of renewable energy in their share of electricity generation, improve the energy efficiency by at least 32,5%, and reduce the GHG emissions by 45% (EU Europa, 2020). Currently, progress toward meeting these targets can clearly be observed. In fact, the share of renewable energies in the energy consumption increased significantly from 8.5% 2004 to 2018 by reaching a percentage of 18.9% (EC Europa, 2018).

Figure 2. Development of percentage share of RES in European gross final consumption (EEA, 2019).

Highlighting the nature intermittently of renewable energies, and the constant need for a balance between production and generation, balancing markets are designed to offer security and stability to the electrical system. The issue of security of supply does not only emerge from RES resources, but also from electricity imports, as a current challenge that various European countries are relying on to meet demand (Europa, 2019). This dependency is a considered as a major vulnerability for the European electricity supply, which raises questions about whether the traditional balancing market is adaptable to not. The EC has long understood the benefits of demand response as a flexibility enabler, having implemented since then various directive unlocking the balancing markets in that direction. With a first mention in the European Energy Efficiency Directive, the role of demand response was recognized as an important enabler, part of the balancing markets and promoted in the implementation guidelines of an internal electricity market design (Europa, 2012).

With the development of the smart metering systems, customers are now able to monitor and change their consumption trends to respond to price changes, which refers to implicit demand response (DR). To actively participate in the trade of electricity, more specifically in the balancing market, aggregators emerged as market agent creating a portfolio of pooled customers consumption change as a flexibility response and trade it in the electricity market in exchange of a compensation through a bilateral contract (Babar, et al., 2013). However, demand response aggregator models traditionally requires an agreement with the customer´s supplier or balance responsible party. In response to these dependency, DR independent aggregators emerged as business players also known as Virtual Power Plants (VPP) to alleviate the technical requirements such as pre-qualification processes and enable prosumers to meet the minimum bid required. In theory, independent aggregators are able to participate in the wholesale markets, as well as in the FCR, aFRR, and mFRR, and RR, referring to reserve balancing markets along with the real-time energy balancing market. However, the current balancing energy and reserve markets are mainly designed for large scale generating units (Akrami, et al., 2019). Third-party aggregators are facing complexities at the technical and market levels, such as high minimum bids or a lack of a regulated framework defining the role of aggregators. Although recent EU regulation promotes the transparent and equitable participation of flexible resources in all electricity markets, TSOs are still preventing access or requiring agreements with BRPs which goes against the core business models of independent aggregators.

1.3. Research objectives

The aim of this thesis consists on implementing a comparative framework of balancing market requirements characterizing the participation of DR independent aggregators. The main targeted countries are Finland, the Netherlands, the Iberian countries Portugal and Spain, and the UK. For this purpose, the selected balancing markets are analyzed, determining at first the regulatory framework defining the status of DR aggregation. To do so, this thesis analyses the key design features of the balancing market.

The comparative framework is built in two levels highlighting the barriers and enablers of third-party aggregators at a technical and market level, encompassing both regulatory and economic characteristics. Because explicit demand response is a core aspect of this thesis, the requirements go in parallel with specific features of DR- The comparative framework is mainly based on national reports and balancing reserves' market manuals, published by the respective TSOs. With the results obtained from the analysis, this thesis determines whether the selected markets align with the EU regulation unlocking the access of independent DA or not. Furthermore, this thesis presents the market and economic values of DR aggregation. To achieve that, the different DR aggregator models currently present in the market are defined with an emphasis on their operating process, relationship with the different market players, along with the compensation models suitable for the DR independent aggregator model. To support the countries' case analysis, relevant pilots are investigated, to retrieve enabling drivers and barriers encountered as well as answer questions related to compensation challenges.

This thesis answers the following research questions:

1) What are the technical and market requirements for independent aggregators to access the balancing markets in the selected countries?
2) How can the balancing market design features influence the access of aggregated demand response resources?

This master´s thesis is conducted part of the FlexUnity project with the collaboration of Virtual Power Solutions S.A, Lappeenranta-Lahti University of Technology, Electric Corby CIC, Simples Energia de Espana SL, and Centro de Investigação em Energia, REN- State Grid, S.A.The main objective of this project is to develop a commercial concept of energy communities by integrating flexibility aggregation in selected balancing markets. In order to address to the current challenges, the project aims to mainly implement AI algorithm in the VPP platform to optimize the flexibility of the prosumers, design innovative flexibility business models, and, undertake pilots in the UK and Iberian market to demonstrate the key results of the project.

1.4. Structure of the report

The main objective of this thesis is to propose a framework for comparing different types of barriers and enablers to DR independent aggregators in Finland, the Netherlands, UK, and Iberian markets. As theoretical background, the first chapter presents an overview of the electricity market supporting the chapter 3. It defines the different market and products and their position time-wise, as well as their respective goals. Chapter 2 introduces the concept of flexibility in the context of modern electricity markets, accentuating on the different flexibility options applicable in the traditional and modern electricity market.

Chapter 3 defines balancing markets in more depth, stressing their needs in the current energy system context. This encompasses the energy and capacity balancing services and existing balancing markets, including the balancing energy and reserves markets. As a support for Chapter 7, sub-section 3.1.3 provides an analysis of the role of the different market players in the balancing markets, while Section 3.2 analyses their fundamental design criteria. In addition, this section describes the undergoing changes influencing the balancing markets with respect to the European guidelines and Network Codes.

Demand response, as core of this thesis, is defined and categorized in chapter 4 along with analyzing the current status of DR in the selected countries. The characteristics of explicit demand response are partially used to retrieve the technical barriers in section 6.2.1.

Chapter 5 focuses on DR aggregators, by defining the fundamentals of aggregation and the applicable types of DR aggregators; its final objective is to differentiate between combined and independent aggregator models. Furthermore, it describes the compensation challenge raised between the DA and BRP/supplier. Focusing on the independent aggregators, the section 5.4 provides different compensation models applicable to this market players. In addition, the values brought by DR aggregation are presented at a market and economic levels.

Chapter 6 defines the comparative framework components based on the technical and market requirements of balancing markets. This chapter relies on the fundamentals of balancing markets defined in chapter 3 including the procurement, time bidding horizons and balancing responsibility.

Chapter 7 focuses on the selected countries, and proposes a comparative framework composed of technical and market requirements, selected from literature review. Prior, to the comparative analysis, the structure of the case countries balancing markets is discussed for each selected country underlying the demand response status. Chapter 7 intends to analyses the access of independent aggregators in balancing markets following a requirements template designed in chapter 6. Based on the findings, specific barriers and enablers are highlighted, and supported with relevant ongoing and forthgoing pilots. Results from the pilots are used to point out case countries development toward unlocking the access of independent aggregators and answering questions related to compensation challenges.

The results obtained from the comparative analysis in chapter 7 are discussed in more depth in the chapter 8. With the aim to position the role of DR independent aggregator in the selected balancing markets, the discussion provides insights about the current technical barriers, and potential advancements. In addition, French balancing market is used as an example to support the transition to a flexible balancing market.

1.4. Assumptions

In this thesis, it is assumed that the balancing markets in Spain are composed of secondary, tertiary, and slow down reserve. The primary reserve is not included in the scope as it is not used in the imbalance settlement process of the Spanish TSO. However, a brief description of the technical requirements of the primary reserve is included. Further explanation of its role is referred to in Chapter 3. The same is applies to the Netherlands, as the participation in the FCR is as well mandatory for the connected generation units. The analysis of the

Iberian balancing market is relatively complex due to the lack of information on the structure of its Portuguese counterpart. Considering that Spain and Portugal share the MIBEL, Spanish balancing market is taken into a baseline in the analysis of the Iberian balancing market with a highlight of the differences between the two countries, if applicable. In the Chapter 5, the thesis introduces the different business models of used by existing aggregators in the market. The independent aggregator is considered as a service provider. In addition, the aggregator-DSO variant of aggregation is discarded. Chapter 7 introduces different pilot where the potential of independent aggregators in balancing markets is being tested. Finland is taken as the reference example to illustrate the issue of the compensation challenge between the BSP/BRP/TSO.

2. Flexibility in electricity markets

The foundation of the power system is encountering changes oriented towards a sustainable transition. In a world where climate change is a pressing matter, European countries are doubling the efforts to adapt to the new market design by engaging gradually flexibility targeting industrial loads and distrusted generators (Phillippa & Pinto-Bello, 2019). In fact, in June 2019, the UK has taken a step toward change by avoiding burning coal for power generation purposes for 432 hours (National Grid, 2019). The penetration of the high share of renewables in the electricity system requires measures and actions to counterbalance the intermittency and the volatility of energy production due to the weather conditions (O. George, et al., 2010). The transition comes with risks affecting the power balance. In addition to the uncertainty of the forecast, power plants are subject to potential outages (Goutte & Vassilopoulos, 2019). Electricity is characterized by its complexity to be stored, the lack of elasticity in the demand side and need to hedge the volatile electricity prices. Following the new electricity system trends, researchers and industries have given strong attention to power flexibility, in order to understand how it should be implemented and what are the mechanisms behind it. Various definitions have been given to flexibility and its value in the power systems. However, it is complex to accurately define flexibility, due to the intersection of many variables. Flexibility entails multiples components, and its assessment is mainly based on time. The lead time defines when the flexibility should be requested and delivered. The duration of flexibility depends on the long, short, medium-term needs (Linkenheil, Küchle, Kurt and Huneke, 2017). In the short terms, aspects such as the power quality, voltage and frequency become a priority. In the medium term, demand should be covered taking into account the balance between supply and consumption. In the long-term, transmission capacity should be able to ensure grid security, while avoiding grid congestion in case of high energy feed-in. In addition, production capacity is required to meet the demand considering load curtailment if needed (ESMAP, 2019).

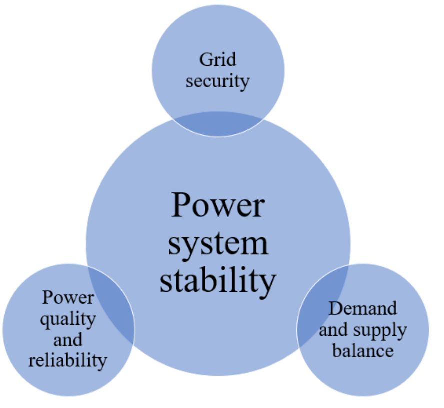

Figure 3. Main parameters affecting power system stability in a medium and long terms.

Considering the intermittency nature of renewable energy generations, the net load concept is defined as the load needed to be met by conventional generating units including fossil based power plants to meet the forecasted demand (P. S. Catalão, 2015) .The figure 4 highlights the importance of flexibility in a power system in which wind participates in the generation. The yellow area describes the varying demand, and the net load is represented in orange. The conventional generator needs to adapt their production to the changes of both wind generation and load. Steeper ramps result from the limited generation of wind power. Therefore, to meet the demand in a short period of time, conventional power plants increase their production regardless of the cost efficiency of the process. The low turn down phenomena occurs when wind generation is high, and demand is low. In this situation, conventional generators lower their production but should be ready to adjust it back, in case of intermittency (Cochran et al., 2014).

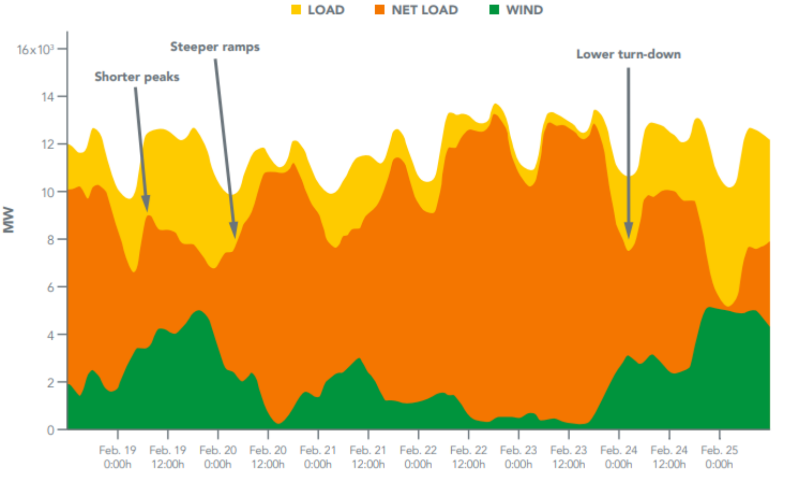

Figure 4. Wind output variation impact (Cochran et al., 2014)

With knowledge of the need of flexibility, the Dutch TSO TenneT stated on the 30th of April 2018 that supply and demand were in an imbalanced state, further emitting an emergency alert (Duijnmayer, 2018). In fact, the forecasts of the market parties' transactions showed that the expected consumption and production were far from the norm, and that a deficit was evident (Juffermans, 2018) The deficit on that day is due to the unpredictability of the electricity generated from renewable energy, essentially wind and solar.

Overall, the definition of flexibility encompasses the ability for managing power system resources in a cost-efficient manner, while meeting supply and demand. In the context of this thesis, flexibility is considered as a resource for adjusting system stability. At the operational level, flexibility, referring to demand response, is capacity responding to the changes in demand and supply, in ways that avoid the increase of operational costs associated with balancing markets. In more depth, flexibility can be categorized as structural and physical (S. Goutte and P.Vassilopoulos, 2019). The physical flexibility refers to the resources responding to variations in demand and generation. It is the actual use of demand side resources and considers the extension of the grid and interconnection capacities. A fundamental example of physical flexibility remains the conventional generating units such as power plants. The structural flexibility is complementary to the physical one as it targets market change improvements, mainly through the development of market design and operations (Akrami, et al., 2019). For instance, widening the balancing markets and integrating demand side resources is considered as a structural flexibility.

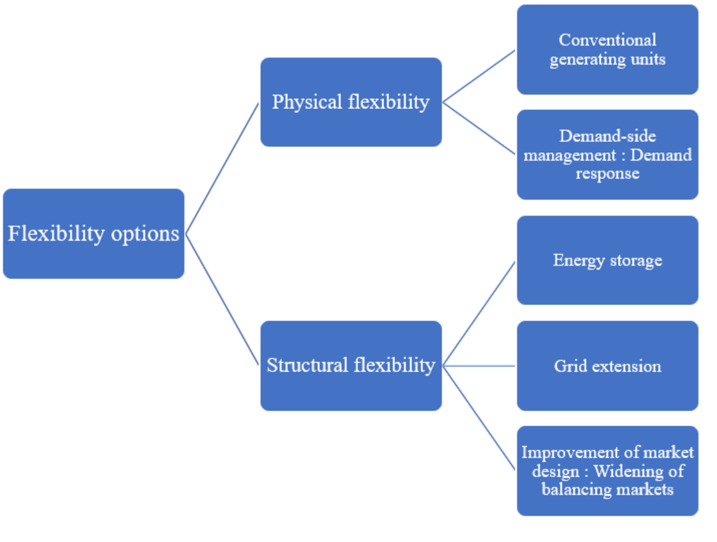

Figure 5. Physical and structure flexibility options.

Conventional power plants are commonly a source of flexibility in the power system, by helping achieving a balance between supply and demand and hedging against the intermittency of RES. The traditional flexibility definition is closely related to the technical aspects of power plants. Considering power plants an efficient means to secure supply, it encompasses the ramping rates including the magnitude and speed of the power plants. Power plants can change and adapt their power output depending on the demand load curve, as well as rapidly switch on and off, without causing a shutdown situation. According to IEA, the flexibility of these conventional generating units can be enhanced by:

- Taking actions to change the plant operations;
- Investments in integration of modern technologies, such as installation of Battery Energy Storage Station in a power plant to enhance the flexibility and economy.

In a modern market design, flexibility is needed both on the supply and demand side, in order to ensure a proper balance between these two. On the supply side, the flexibility can be achieved through power plants, as they play a major role in flexibility, allowing the control of their generation output at various response times. Over and above, flexibility in the current energy system can be brought by energy storage, power-to-X technologies, and interconnected transmissions systems (Klitkou et al., 2019).Demand-side management is a form of flexibility encompassing explicit demand response involving a direct participation of the customer and it is the core topic of this thesis.

3. Overview of balancing markets

Balancing markets are vital to balance the supply and demand in a close to real-time basis. Due to its natural characteristics, electricity cannot be stored partially highlighting the need for a balancing system. Balancing markets are considered as the adequate cost-efficient solution adapting to the current changes. Customer profile is the first variable defining the need for balancing markets. Forecasting demand profiles is complex, meeting the planned demand in real time is even harder. Theoretically, maintaining balanced production and the consumption aligns with the schedules and the forecasts. However, the procurement of energy is done beforehand. In an analysis of the balancing markets, Morales et al. (2014) raised the need of balancing market to hedge against the bottlenecks and congestion issues partly caused by grid frequency deviation from the norm. In fact, alteration would damage the grid infrastructure and the equipment due to technical deficiencies. In these circumstances, the balancing market can be used as a real-time solution (Bergman, et al., 1999). Integrating renewable energy is among the biggest challenges in the electricity market, creating a real need for balancing markets. In the traditional centralized energy system, the electricity was generated from fossil fuels-based generator transmitting electricity from high voltage level to lower voltage levels to be distributed to the end customers (Coster, 2010). The simplicity of the system with the great economies of scale created a “three level” or “vertically-operated” electricity market.

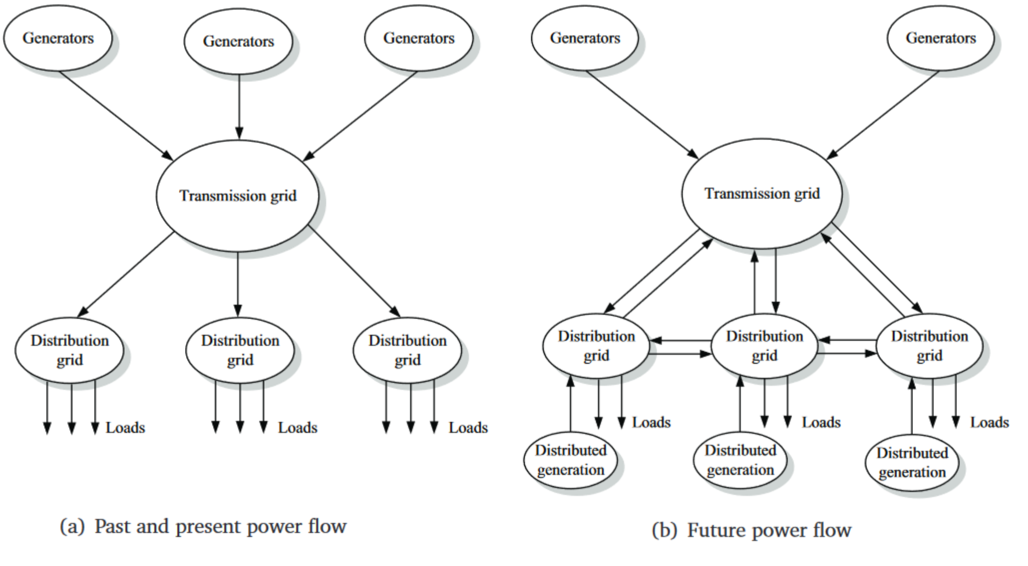

Figure 6. Traditional versus modern power flow models (Coster, 2010).

Renewable energies by nature as DES are closer to the customer reducing the transmission losses as an advantage. In this thesis, DES sources refers to demand response, energy storage, and distributed generation. Various studies engaged in finding an optimum solution to integrate the distributed generation in the grid including (Akrami, et al., 2019) (Calvillo, et al., 2016). In addition to the change in market behavior, renewable energy generation output is heavily dependent on the weather variable increasing the complexity of forecasting in real-time the demand and supply. Therefore, balancing markets are presented as a pre-conditional solution to hedge against RES fluctuations.

3.1. Definition of balancing markets

The good functioning and design adequacy of balancing markets does not only give TSOs the opportunity to access balancing services in real-time, but also ensures a smooth integration of renewable energy resources enabling new market players to enter a fair competitive electricity market. Balancing market is usually referred to as a last resort marketplace. In the EC regulation 2017/2195, balancing market is defined as "*institutional, commercial and operational arrangements that establish market-based management of balancing*" (Comission Regulation (EC), 2017). Typically, balancing markets are structured differently across the European countries, as TSO approaches are may vary. Balancing markets are single period markets, close to the delivery time by minutes. According to (van der Veen & Hakvoort, 2016), balancing is a set of actions managed by the respective national TSO, ensuring a continuous balance and equality between the production and the consumption of electricity maintaining the system frequency in the 50Hz European standard. To illustrate the principle, the electricity system is based on two pillars. Quality voltage**,** and the system frequency that exhibits the withdrawals including the transmission losses considered as loads and injections of generated or imported electricity (Abbasy,2012). It is important to mention that the voltage quality is considered at the local level, while in the frequency of the system is required at the interconnected power system level.
A deeper understanding of the balancing market requires the distinction between active and passive balancing (Mazzi, et al., 2018). As a matter of fact, balancing markets appear to have common fundamentals with an energy market and ancillary markets. However, the approaches are different.

The foundation of balancing markets is distinguished by its complexity implying the use of different approaches. One of the fundamentals reside in the methods deployed to hedge the contingencies and grid overload at the transmission level. N-1 approach applies the fundamentals of a system operation characterized with preventive security margins (Abbasy, 2012). N-1 principle requires that the power dispatch and transmission remain stable in case of power system failure. The N-1 principle might translate into an economic burden for countries with long transmission lines, such as Russia. In this situation, the power system must be equipped with parallel solutions to protect the grid. In a N-1 system, balancing resources need to be scheduled, and providers are demanded to meet the N-1 criteria. Thus, planning of load losses and the eventual deployment of reserves is required leading to additional operational costs (de Haan, 2016). A system without preventive security margins implies that failures are allowed and expected, and the power system is designed as such.

3.2. Balancing market services

The balancing operations should align with the system requirements defined in Article 127 of the EU regulation 2017/1485 establishing the frequency quality for an efficient transmission. Because, balancing should be maintained in real-time, two types of balancing services are integrated and managed by the TSO and they are referred to it as energy and reserve balancing markets. As the consensus is the security of supply, TSOs should design adequate technical requirements and product standards in a clear manner to have access to balancing services.

Although the general structure of balancing markets might seem uniform among EU countries following the regulation, clear differences exist, depending on the activation of the reserves and their main purposes. According to (Steyn de Haan, 2020), balancing market approaches can be categorized as active and passive partially referring to the extent of the respective TSO participation. Active balancing requires the use of forecasts and preventive action to hedge future imbalances. For instance, the activation of Replacement Reserve is considered as pro-active balancing as they can also be activated to prevent the future use of FRR. The active TSO, uses forecasts, and manual activated reserves. In addition, time control is differentiating TSOs approaches. Active TSOs can trigger balancing operations one hour prior to real time, and prioritize gathering balancing resources.

Passive balancing consists of using reserves to restore system imbalances such as the activation of mFRR. The objective of both active and passive TSOs is to achieve balancing cost efficiency. The passive TSO would rather minimize the volume of balancing energy used, by compelling the market participants via incentives, contrarily to the active TSO, who would rather minimize the average balancing energy costs (Rigard Ceriso, et al., 2016).

After the unbundling of the electricity markets, the TSO acquired the role of balancing the generation and consumption of power in real time and closely monitor the system's frequency. To fulfill this responsibility, the TSO needs to procure balancing services, including energy and capacity services, from providers restoring the system balance. In this context, the TSO needs access to additional resources to respond to frequency changes. The balancing services consist of up and down regulatory bids, categorized as energy and capacity balancing services. In a free market system, the providers are responsible to decide on the amount of capacity bids accordingly to their generation.

The modus operandi of the balancing services differs across the countries. Therefore, an accurate categorization is not representative of their definition. However, they are directed by technical requirements and criteria including the type of activation (manual/automatic), the response time, or availability or the generators. In the balancing energy markets, the bids are traded in a MW volume and priced in €/MWh. The TSO is charged to activate the up and down regulatory bids according to type of shortages. For instance, if the generation does not match the consumption, then up regulatory bids are activated. The down regulatory bids are activated if a surplus of generation situation occurs. Therefore, the balancing energy markets are mainly used by the TSO to ensure a real-time balancing of the electricity systems.

The balancing energy market is a real time market used to clear the imbalances of the BRP. As mentioned earlier, this type of market has a repetitive cycle trend. The Balancing Service Providers can offer their up and down regulatory bids after the gate closure of the intra-day market to clear the imbalances. Depending on the direction needed (up-or down), the cheapest bids are activated first by the TSO. In the balancing energy market, a pricing mechanism proper to its design is used to compensate the participation of the BSP. The pricing mechanism is categorized as pay-as bid and marginal pricing methods. The pay-as bid is defined simply as the offer price of the balancing service provider for its accepted bid. The marginal pricing rarely referred to it the pay-as cleared method reflects the price of the highest price of the bids accepted by the TSO in the energy balancing market during the Program Time Unit which stands for the imbalance period in which the TSO clears the imbalances (van der Veen & Hakvoort, 2016).

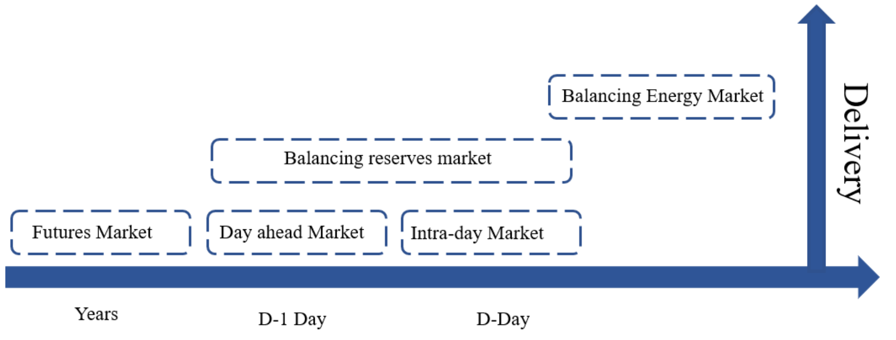

Figure 7. Time-wise categorization of electricity markets.

The balancing markets include the reserve capacity market where providers can offer capacity bids of MW volumes and priced in €/MW. As the opposite of the balancing energy markets, the capacity providers are to follow reserve technical and regulatory requirements and can participate yearly, monthly, daily, or hourly following the design of the reserves. However, not specifically in real time. Accordingly, the reserve capacity markets are products that offer system security prior to real-time. To illustrate this, the capacity market is seen as reservation or a guarantee procured beforehand by the TSO to ensure a continuous balancing.

The structure of the balancing markets differs across Europe. The compensation in the participation of the reserve illustrates this difference. For instance, according to the respective TSOs REE, and TenneT, the participation on the primary control reserve is mandatory for generators in the Netherlands and Spain and are not compensated due to the absence of a competitive mechanism. In contrast, Fingrid, the Finnish TSO, procures the obligatory share of FCR from contracted power plants on a competitive basis (Fingrid, n.d.). In addition to that, Germany procures the Primary control reserve directly through the capacity markets. Therefore, the energy balancing markets might not be incorporated (Abbasy,2012). The providers in the balancing capacity market are remunerated via capacity or availability payments.

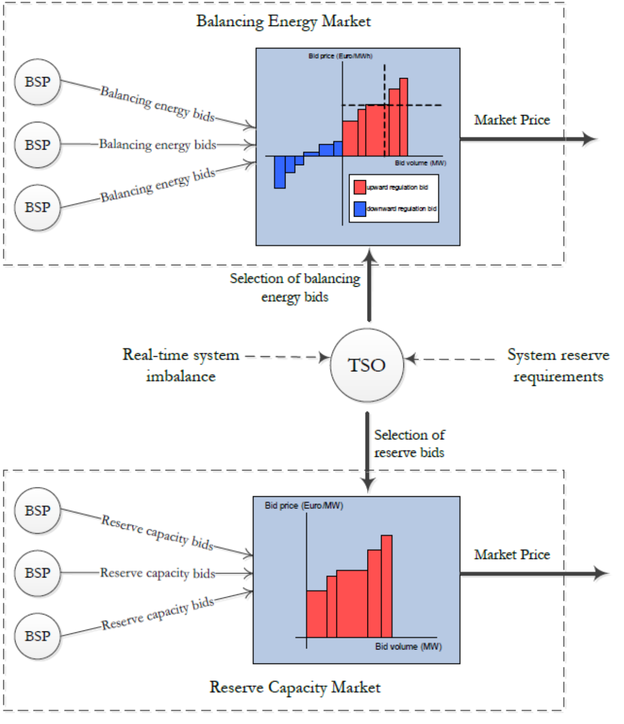

Figure 8. Correlation between energy and reserve capacity balancing markets (Abbasy,2012).

To summarize, respective TSOs procure two types of balancing products in the reserves: Up-ward and down-ward regulating bids. This symmetry allows the restoration of negative and positive imbalances. The balancing capacity can be derived from generation or consumption and is procured in advance. The energy balancing is used in real-time to balance supply and demand.

In the context of this thesis, the procurement is an important parameter as it measures the extent of participation of the DR aggregators in the balancing markets. Therefore, an understanding of the different types of balancing services provided is required. The balancing services are defined as the balancing capacity and balancing energy. For a comprehensive overview, this section considers three marketplaces including primary, secondary, and tertiary reserves also referred to as operating reserves. Each of these marketplaces can be either a capacity and/or an energy market. However, exemptions are applied depending on the countries that will be analyzed in the following chapters.

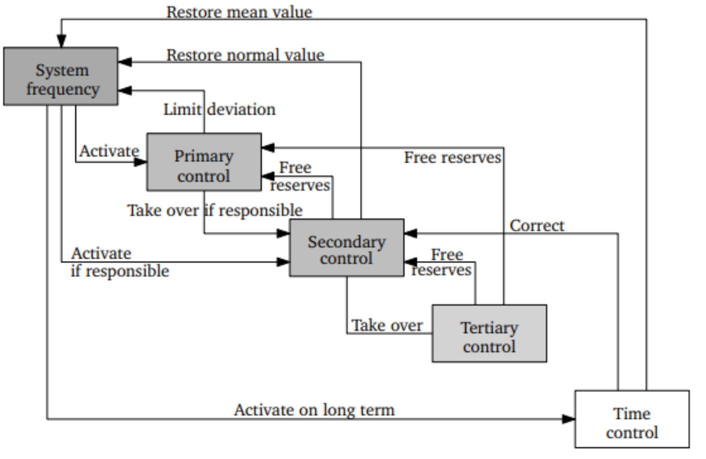

Figure 9. Function relationship between the balancing reserve markets (Frunt, 2011).

Commonly, FCR is the fastest reserve activated, as a deviation of frequency can heavily damage the grid and cause blackouts (Frunt,2011). Thus, TSOs are required to constantly contract FCR capacity available as an active power is widely known as the primary reserves. Its name is due to its fact activation. In fact, FCR is mainly used to regulate the frequency deviation from its nominal value within 30 seconds of change. The FCR is activated to maintain in the balance in the synchronous system. This means that the area operating within the same frequency range and interconnected can active the FCR. For instance, Finland is part of the Nordic synchronous area. The same is applicable with the Netherlands that procure the FCR in a common market with Austria, Belgium, France, Germany, and the Switzerland. The Frequency Containment Reserve in the European balancing market is defined as an operational reserve used to maintain the constant frequency value 50 Hz, and thus achieve a constant power balance (Röben, 2018). FCR are used to maintain and re-establish the regular frequency nominal value internationally for all the connected grid.

The resources with accepted FCR bids are automatically activated by the TSO as soon as the deviation is detected based on the frequency measurements, and the bids are provided from various sources including generation, storages, and demand response. The Balance Responsible Party along with the TSO decide on the settled balancing energy to be activated in the FCR. The activation of balancing capacity follows a structured strategy based on system frequency. With a homogenous activation within the EU countries, the procurement, pricing, and products differ from countries. Considering FCR as a balancing market place, two sub-markets have been identified underlying the different approaches. The categorization of the frequency containment reserve differs depending on the architecture of the balancing market. For instance, Finland accounts an FCR for normal operations and an FCR for disturbances.

In the European Code on System Operation, the frequency restoration reserve (FRR) is referred to it as the secondary reserve. Technically, the FRR is used to restore the system frequency back it its nominal value in the synchronous area. The synchronous area refers to the area managed by interconnected TSOs operating under the same nominal frequency. In this context, the secondary reserve operates in the system and interconnected area to resolve their imbalances. According to the EC Electricity Balancing Network Code, the Frequency Restoration Reserve are operating reserves that can be activated either manually or automatically. In general, the activation time can reach up to 15 minutes. However, the requirement of the reserve is depending on the synchronous area. To achieve a system balance in 15 minutes, the regulating balancing services are ordered up/down-ward symmetry to change the total production or consumption. In this context, the FRR is the second fasted reserve to be activated after the FCR. As its name indicates, the FRR is used to replace the FCR if the frequency deviation duration exceeds 30 seconds. The frequency restoration reserves are activated either automatically in the aFRR or manually in the mFRR. While the aFRR is automatically and continuously activated, the mFRR is activated manually in a discrete manner by the TSO in circumstances when the deviation is consonant. In Europe, the technical requirements, and the pre-qualification assessment of providers to the FRR are set in the Network Code on System Operation published in 2017 setting guidelines for the TSOs. In the same year, guidelines for implementing a common FRR platform for exchanging balancing energy were designed. This measure encouraged the uniformization of the technical requirements across Europe in both the aFRR (PICASSO platform) and mFRR (MARI platform).

The Network Code on System Operation defines Replacement Reserves as active power hold available by the TSO to restore the level of FRR and be activated for future imbalances. Replacement Reserve highlight the differences in balancing market structure upon European countries. In fact, only 16 EU countries included the replacement reserve in their balancing reserve market including Finland, the Netherlands, UK, and the Iberian market. Replacement reserve can be used for multiple purposes including avoiding the activation of the FRR, settling the congestions (Faria & Vale, 2018). The Network Code on System Operation published by the European Commission (EC) stated that BRP providing the RR should be able to provide the connecting TSO with real-time measurements. In general, the RR is activated from 15 minutes to hours and is usually used as pro-active measure to not only restore the FCR, and FRR but also prepare for eventual future imbalances.

3.3. Current development and challenges in design of balancing markets

The restructuring of the electricity markets in 1996 impacted significantly on the balancing markets. In fact, the Electricity Directive 96/92/EC promoted the supplier competition and allowed the customer to freely chose and change their supplier at any moment. Therefore, the limitations to integrate small scale DR in balancing markets gradually disengage from customer unwillingness. Additionally, the transmission of electricity rotated from internal to external. Changes in the balancing markets are partially triggered by the introduction of information and communication technologies ICTs such as smart meters enabling the explicit demand response. However, the growing integration of RES plays a major role in the increase of flexibility. The entry of new market players such as independent aggregators and the access of aggregated demand response in balancing markets requires a change in the fundamental design coordinating the operations between the participants. In addition, regulations are introducing a wider and flexible balancing market across Europe promoting international exchange on energy bids. The EU regulation "2017/2195 of 23 November 2017 establishing a guideline on electricity balancing has been focusing on the harmonization of the services (Röben, 2018) . The establishment of the ENTSO-E, European Network of Transmission System Operator could be considered as a disruptive change, as the organization gathers the EU TSOs and allows different sources to participate in the balancing markets. Thus, the balancing market across Europe are being integrated exchanging balancing capacities during the imbalance settlement period.

The Manually Activated Reserve Initiative involves 19 European countries and targets designing a mFRR platform of balancing energy exchange. MARI common platform is also used by TSOs as a congestion management mean the countertrading and re-dispatching needs (Entso-E, 2017). The interconnection between the balancing markets is creating new challenges leading to internal market congestion (Doorman, et al., 2018). In fact, as the size of the participants is extensive, time between the operations and the activation of bids is limited leading to congestion in the transmission due to overload In addition, the location of balancing bids is stated as an important factor in creating congestion as some countries such as Germany use portfolio based bidding system not taking into account the exact location of bids which affect the decision making on bid availability to the European balancing exchange platform. PICASSO standing for the Platform of the International Coordination of Automated Frequency Restoration and Stable System Operation was created to allow the exchange of balancing energy commonly within the EU parties (Ensto-E, 2018) .The Trans European Replacement Reserve Exchange project consists of exchanging Replacement Reserves between 9 countries including Spain, Portugal, and the UK (Elexon.b, n.d.). Following the directive and the ENSTO-E recommendations, the integrated European Balancing market promoted the coordination and the harmonization of the balancing product between the EU countries to facilitate the exchange.

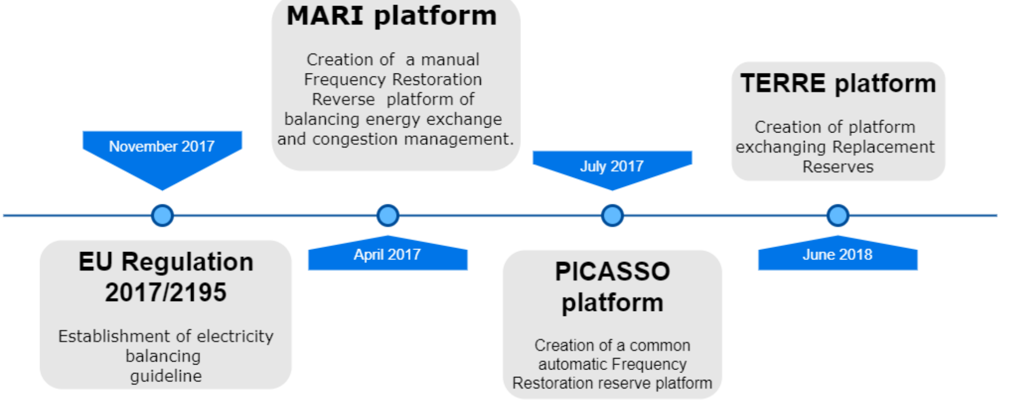

Figure 10. Timeline evolution of the balancing services EU exchange platforms.

Implementing common balancing platform requires a strong harmonization. Design aspects such as targeted market integration, coordination between the technical product requirements, and cross borders transmission rules should be taken into account. Balancing markets are now capturing the attention of regulators. In point of fact, their foundation and design aspects are key enablers for the integration of DER and thus the transition for a more sustainable and flexible balancing market.

3.4. Market behavior in electricity balancing market: Roles of market participants

The Network Code in electricity Balancing underlings the roles of the TSO, BSP, and BRP in the balancing markets and their cooperation. The role of the TSO in balancing is defined concisely in the Network Code of Electricity Balancing entered in force in November 2017. TSO tasks encompass managing the balancing of the system and procurement of energy and capacity balancing services from Balancing Services operators while TSOs can be classified according to their activation methods: active, and passive balancing approaches (Fransen, et al., 2016). TSO manually activate the balancing reserves in order to adjust the power system imbalances. It plays a key role in the market as it actively procures reserve capacity. At the opposite of the passive TSO approach, the active might be able to activate the reserve prior to interruptions or disturbance. The proactive TSO is fully responsible for restoring the system balance. It procures high balancing capacities and activate the reserves on an hourly basis based on the historical experience. The UK, for instance, is considered as a proactive TSO. On the other hand, the passive TSO activates the capacity reserves after disturbances and support the market parties to contribute to the balance of their portfolio. Dutch TSO is considered as a reactive TSO. Passive balancing is a term included in the reactive role of a TSO. Rewarding the market parties for changing their energy portfolio to balance the system (Steyn de Haan, 2020). Another category of TSO can be underlined related to the procurement of the balancing services. A connecting TSO holds contractual arrangement of a BSP located in a different scheduling area. Whereas the requesting TSO is the party that mainly calls the delivery of the balancing services.

Table 1. Summary of the TSO´s responsibilities in the balancing market.

Country	**TSO**	**Type of approach**
Finland	Fingrid	Active balancing
The Netherlands	TenneT	Passive balancing
Spain	Red Eléctrica de España	Active balancing
Portugal	Redes Energéticas Nacionais	Active balancing
UK	National Grid Operator	Active balancing

The Framework Guidelines on Electricity Balancing published in 2012 is designed to the related stakeholders including the routes to becoming a BSP or a BRP. While coordinating the balancing services between the responsible players, TSOs are required to implement financial terms and condition taking into account the balancing services pricing, balancing charges and the imbalance settlement costs. As a major market player in the balancing markets, TSOs should ensure transparency and ensure fair competition.

The technical requirements to access the balancing market are defined by the TSO including the minimum size of the bids, product symmetry and others that would be discussed in further details. As part of its role, the TSO oversees activating the capacity reserves manually or automatically. Due to the complexity of balancing, reporting and monitoring the quality performance of the balancing operations becomes important in the control. For instance, tracking the balancing energy prices as well as the reserve capacity procured. All the operations undertaken by the TSO should remain cost-efficient. In addition, the knowledge flow and data exchange must be taken into account as they are decisive in the current balancing market structure.

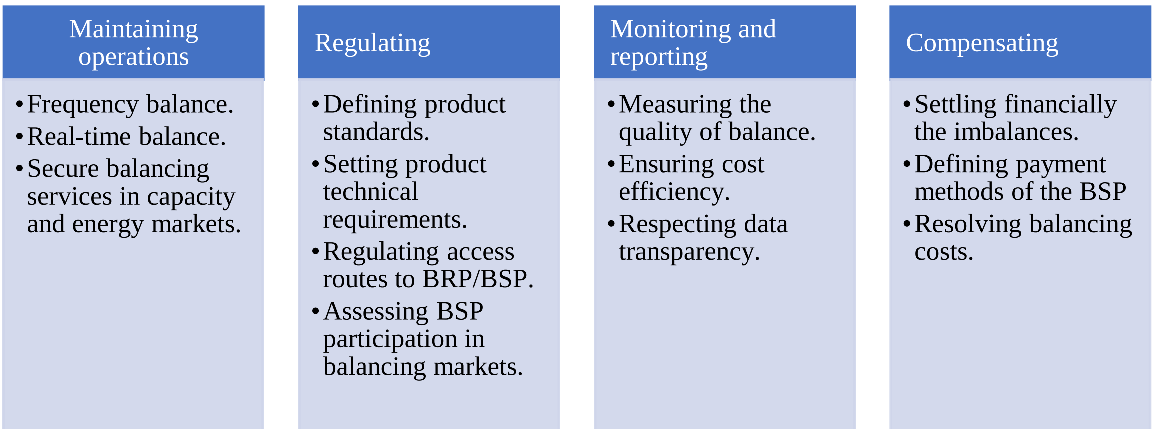

Figure 11. Summary of the TSO´s responsibilities in the balancing market.

Role of the Balancing Responsible Party

The balance responsible party latest definition is stated in the Commission Regulation (EU) 2017/2195 part of the establishment of electricity balancing. The party can enter the market as a market participation or as body responsible for the balance portfolio for one or multiple units in such that their imbalances are under the control of the BRP. It means that the providers or the market participants can designate a BRP or can be themselves responsible for their own imbalances. In general, as market participants in the balancing market, the balance responsible party can be generators, or third-parties including large-scale electricity users. In the balancing energy markets, the balance responsible party interferes directly at the levels of the balancing responsibility and indirectly at the imbalance’s settlement. As part of its obligation, the BRP is allowed to make the necessary changes to their schedule used to assess their position prior to the cross zonal intraday gate closure.

Figure 12. Summary of the BRP´s responsibilities in the balancing market.

Role of Balancing Service Provider:

The Balancing Service Provider is an important market player in the procurement design phase. It is defined as a market participant providing balancing services in the energy and capacity markets to the TSO. The BSP can be either a unit or a group referred to it as an aggregator. Prior to market entry, the balancing service provider is required to pass pre-qualification tests and fulfill the technical and regulatory requirement set by the connecting TSO or by the requesting TSO if the TSO-BSP model is applied. The nature of the electricity markets requests a real-time balancing; therefore, the balancing service provider are demanded to submit balance services to the TSO under the responsibility of one or two balance responsible parties. For transparency and information flow purposes, the BSP shall include the schedule of the volumes or bids submitted, the type of products and their direction and other requirements included in the balancing capacity contract. In a national balancing market, the BSP is requested to belong to the same scheduling area of its balancing responsible party(ies).

Role of the Distributor system operator:

The role of the DSO in the balancing market is indirect and seen as has a collaborator status (de Heer, H. & Van der Lan, M., 2017). The European directive for the establishment of internal balancing market regulation ensures that an effective and efficient balancing is achieve through the collaboration of the TSO, DSO, BRPs and BSPs. With this said, the

TSO in hand with the connected DSO are charged for allocating the costs of the DSO actions. If necessary, the DSO contributes to the establishment of the technical and regulatory requirements for market participants to access the balancing market. For instance, the pre-qualification or routes to access to the reserves including the FCR, FRR, and RR can be developed with the connecting DSOs. Aiming to a harmonized balancing market, the regulation grants the right to the DSO to set and express certain limits including the delivery of power in the reserves if for instance due to the geographical location of the BSPs or concerning the activation of the active power of the reserves. However, the activation of reserves remains exclusive to the TSO such as in Spain in which the activation of the interruptible load program can strictly be order by the TSO.

At the market level aggregator or suppliers offer flexibility to the market to participate to the balancing portfolio. The DSO under contracts can request flexibility for grid reliability purposes along with controlling the security of operations.
Following the restructuring of the power market, the DSOs are required to supply the customers in their operating area fairly, charging them the same tariffs and without discrimination.

3.5. Identification of design principles of balancing markets

The balancing market could be represented as a repetitive cycle. In fact, the balance settlement reflects the imbalances from the BRP schedules (balancing responsibility) and the need for balancing services procurement. The main participants in the balancing market are the BSP, BRP, and TSO that interfere at all the design levels.

The procurement and settlement of balancing markets are fundamentals recognized in the commission regulation EU 2017/2195, and their harmonization is vital to establish an interconnected balancing markets platform such as TERRE. The imbalances can occur not only due to the mismatch of the generation and demand but also due to real-time differences between the actual delivery and the schedules of the market parties submitted to the TSO. In this phase, it is also important to take into account the intermittency nature of the renewable power. In this thesis, four main balancing design criteria are taken into account including the balancing planning referred to it as the balancing responsibility, the procurement of the balancing services, their delivery, and finally the balance settlement. The design criteria are applicable for both energy and capacity balancing market with an exception of the imbalances settlement that involve only the energy balancing market.

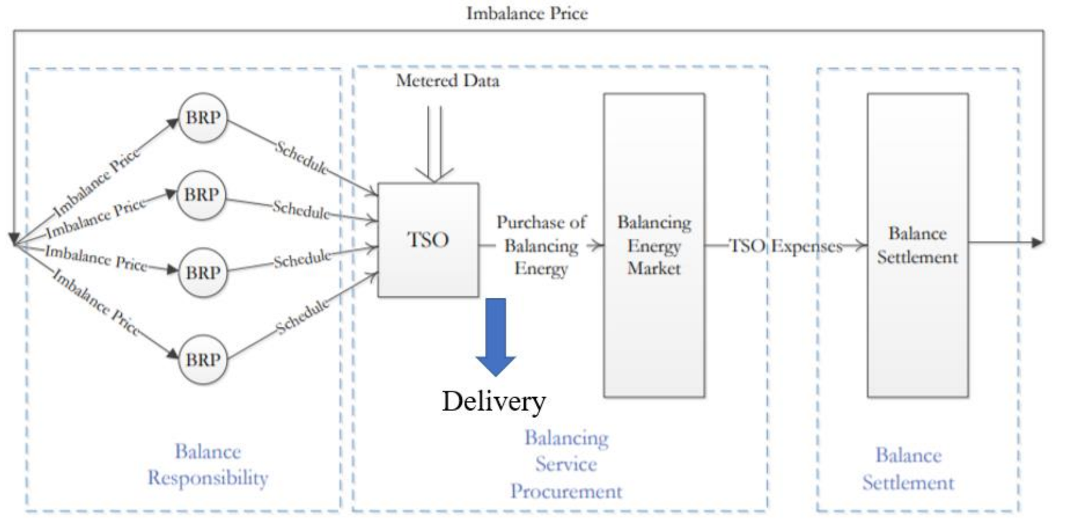

Figure 13. Components of balancing market (Abbasy,2012)

Balancing responsibility:

The balancing planning requires the balancing responsible parties to schedule their production, consumption and trading in order to detect their deviations. Because, they are held financially accountable for their imbalances, the balancing planning is also referred to it as balancing responsibility. The energy schedules are defined as Program Time Unit or Schedule Time Unit, depending on the terminology used, in which the imbalances have to be solved. The duration of the PTU differs, in Finland PTU is referred to it as the imbalance unit time It is defined as a timeline basis used in the balancing markets pointing the balancing responsibility of the TSO and the BRP. It is closely related to the imbalance settlement as the schedules (forecasts) of the providers as well as a real time basis planning of their generation, trading, and consumption. After assessment, TSO decides on real time energy balancing through the balancing energy market. Thus, in this phase two market players are involved counting the BSP and the TSO. As the balancing responsibility is considered as the first pillar of the balancing markets, it is important to highlight that it includes sub-criteria such as the technical and regulatory regulations defining the roles and the routes to become a BRP. The Commission Regulation (EU) 2019/943 on the internal market for electricity included balancing responsibility as an important feature in the market design.

Balancing procurement:

The procurement or provision of the balancing markets involves the participation of the Balancing Service Providers, and its activation is principally directed by the TSO.The procurement of the balancing services including energy and capacity reserves are management solely by the national TSO. Procurement is usually conducted by bilateral contracts and auctions. Balancing services used in reserves are procured ahead of time of use. Thus, the balancing services are procured by the balancing service providers and activated by the TSO for restoration purposes (Abbasy, 2012). In this design phase, it is important to distinguish between balancing energy expressed in MWh and procured in real-time and balancing capacity, expressed in MW, which is procured accordingly to the reserve requirements and types of contracts and activated either automatically or manually by the TSO to solve the frequency deviations.

The mechanism followed by the TSO for the procurement in the balancing market differ mainly at the level of the reserves. In fact, the participation in the Dutch and Spanish primary reserve FCR remains obligatory for the connected units. Thus, there is no compensation nor competition mechanism at the opposite of the secondary and tertiary reserve. In a commonplace, procurement is done via generation. However, the load is increasing its share through demand response programs. Prior to the procurement, balance planning is conducted. Balance Responsible Parties provide to the System Operator with their energy portfolio or the transaction of each unit. This includes the generation and production forecasts. In the European balancing markets, the TSOs are the one charged in procuring balancing services. In a general context, the Balancing Services Providers deliver to the System Operators (including TSOS) the balancing energy bids to ensure the system balance. The balance delivery is not widely recognized part of the design parameters of the balancing market as this might be considered part of the procurement or as a requirement.

The delivery of the balancing services necessitates an understanding of the exchange models consisting of the TSO-TSO and TSO-BSP. In regards of the establishment of a European Platform of exchanging balancing energy in RR, it is important to define the roles of the TSOs for an efficient cross border procurement. The first model entails the balance service provider has an exclusive contract connecting TSO. It is considered as the basic model for the procurement and delivery of the balancing services as it has been agreed that TERRE platform would apply a multilateral TSO-TSO model. In addition, the regulation for establishment a balancing market stated that the exchange of the balancing capacity is intended to be based on the TSO-TSO model four years after its entry in force.

The TSO-BSP model involves both connecting and requesting TSOs and is more complex than the standard model. In fact, the BSP is allowed to have a contract agreement with a TSO other than its connecting one. In other words, the BSP will provide the balancing services to its connecting TSO and then to the requesting TSO. One benefit of the TSO-BSP model includes the possibility of the providers to participate in products in cross boundaries TSOs in case the connecting TSO does not offer those products.

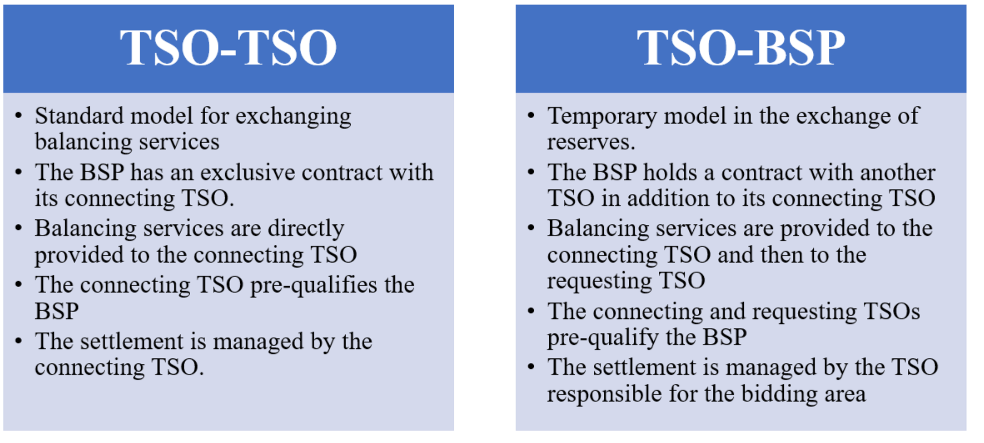

Figure 14. Main differences between TSO-TSO and TSO-BSP models.

In this thesis, the provision of the balancing markets is an important criterion as it encompasses pre-requirements for the participants to enter the markets. For instance, the BSP are affected by the frequency of bidding, and method of procurement specifically to the reserves (daily bids, bilateral contracts or other forms), the routes to become a recognized balancing service provider, and the compensation schemes. The technical and regulatory requires are further explained in the chapter 6.

Balance settlement:

Accuracy in forecasting the generated, consumed, and traded of electricity is a complex process especially with an integration of intermittent resources. In a general context, the customers related to the supplier might consume more or less electricity than what the supplier had purchased. The same is applicable to the trader or a unit with what it generated or sold. For that reason, the balance settlement is a mandatory design criterion to counter balance the nature of electricity.

The imbalance settlement is defined as a financial mechanism in view of its end objective. This design phase consists of financially settle the BRP imbalances either by paying or charging them for the deviations of their schedules referred to it as imbalances. This settlement is conducted during the imbalance settlement period. The balance settlement can also be defined as the attribution of the costs issued due to the activation of the balancing energy bids by the TSO in order to balance the deviation of the BRP from their schedules. The imbalances can be either positive or negative.

The Balance Responsible Unit or BSP are required to manage the balance of the portfolio in a time specified by the TSO usually on hourly basis such as Finland. In this context, the BRP is held financially accountable for its deviation from the allocated volumes and its final position. The position in the electricity balancing market is a term employed during the measurement of the imbalance settlement. The BRP communicates the total energy volumes which points to its position including the sum of all the injections, withdrawals and the trading. The imbalance price is categorized as positive or negative depending on the imbalance direction and is calculated for each imbalance settlement period and area. The pricing of the imbalance bids activated are pricing based on the balancing pricing mechanism used by the national TSO. In other words, due to the imbalances in the BRP deviations, the TSO activated the balancing energy bids. Based on the price the bids were purchased, the TSO attributes imbalances pricing to the BRP. It should be pointed out that the imbalance prices are applicable in the energy balancing markets as the balancing are continuously needed for maintaining the system frequency. The settlement of the balancing energy market is highlighted in the establishment of a harmonious balancing market regulation and points out the FCR, FRR, and RR market places.

Table 2. Payment approaches in the balancing energy market based on the Electricity balancing Code Commission Regulation (EU) 2017/2195.

	Positive balancing energy price payment direction	**Negative balancing energy price payment directing**
Positive balancing energy	TSO to BSP	BSP to TSO
Negative balancing energy	BSP to TSO	TSO to BSP

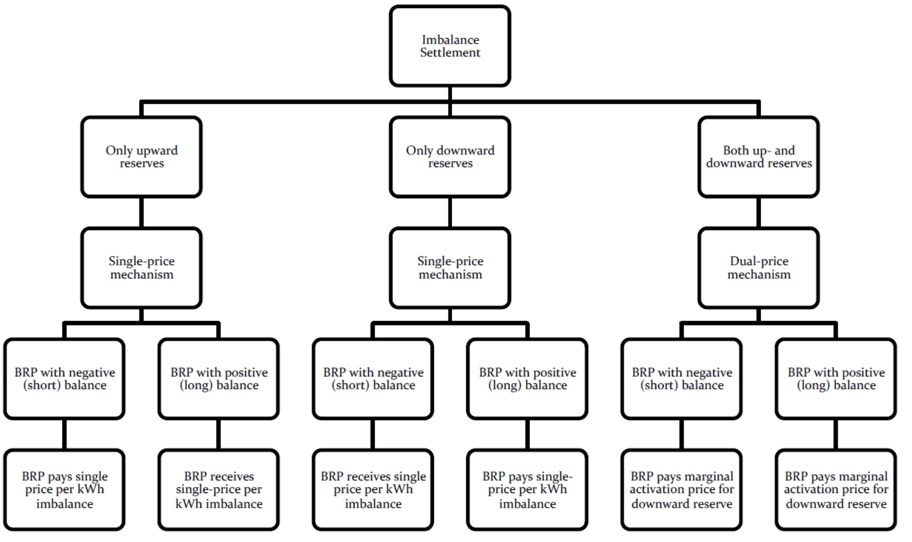

Figure 15. Pricing methods applied in the imbalance settlement (Schäfers & Röben, 2018).

The imbalance price formation is in reality more complex and encompasses additional parameters. Although the balance settlement is an important parameter in the balancing market design, it is not the direct scope of this thesis. However, examples of the imbalances settlement in selected countries are given to illustrate the design process. The imbalance settlement in the UK according to Elexon is conducted on a half hourly basis for each trading period. The TSO implemented two energy imbalance price system in order to clear the imbalances. The system sell price is attributed to the parties with a surplus in the imbalance settlement. The opposite is applicable to the system buy price. This method of price clearing is practiced by the UK to balance the position of the parties (Elexon, n.d.). In Finland, the TSO uses a hierarchic model in its balancing settlement. In fact, Fingrid applies the principle that each participant in the balancing market is attached to an open supplier. Thus, the highest level is occupied by Fingrid´s Balance Service Unit denoted to as the open supplier of the BRP eSETT Oy.

4. Demand response

In a general context, demand-side management is defined as actions taken to introduce flexibility in a system through controlling the consumption, energy and cost-efficiency. As defined earlier, flexibility is the use of the current system resources to respond and subsist changes in the demand. At the early stages of the electricity market, demand-side management has been defined as "*the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape"* (Gellings, 1985). Within the smart grid context, the concept of demand-side management was expanded to include energy efficiency as well. Briefly, energy efficiency includes the programs promoting to use less energy while maintaining the similar level of services the customer is receiving (Tem, n.d.). While demand response interferes actively at the market level, energy efficiency is considered as measure complementing the demand response ensuring cost-effectiveness to the customers.

The restructuring of electricity markets required the power network companies and system operators to change their operation architecture. Demand response has been integrated to provide new provision resources and participate in the limitation of the fluctuations offering security, and cost efficiency. It is important to outline the main drivers of demand response in actual context of the electricity market and more specifically in the balancing markets. The development of the Information and Communication Technology including smart meters plays a major role in enabling demand response (Joung & Kim, 2013). In fact, smart meters add new value to demand response, by enabling an hourly metering, needed for instance in the direct load programs. As part of the demand-side management, demand response enables load management and shifting in accordance with the supply operations. Demand response can be used in order to response to price changes, or as an incentive payment (Conchado, et al., 2016). In addition, it can be used to provide marketplaces such as balancing markets with additional capacity or to clear real-time imbalances. Demand response has been closely analyzed by literature proposing classifications. On a broad context, demand response is categorized as implicit and explicit DR. This thesis focuses mainly on explicit demand response.

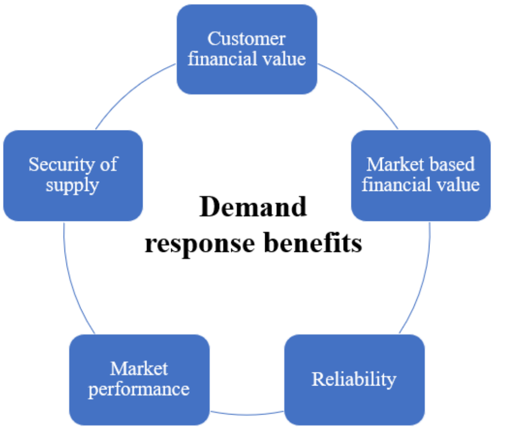

Figure 16. Summary of the DR benefits.

4.1. Implicit demand response

Implicit demand response is defined as a price-based programs offering customers the opportunity to select time-varying pricing methods based on their consumption. Thus, implicit demand response is a sort of dynamic pricing offering, that is reflected on the price of electricity in different times of the day, depending on generation and consumption constraints. In parallel to that, the customer is free to react to these changes without any commitment or obligation. It is important to highlight that customers are allowed to participate in both implicit and explicit demand response without restriction. The main programs in implicit demand response are time of use tariffs, critical peak pricing, and real time pricing (Alkemade & Niesten, 2016). The time to use tariff (TOU) consists of considering two periods in which the customer is priced according to on or off-peak prices. On the other hand, the critical peak pricing (CPP) is characterized with high prices when the electricity grid is endangered in terms of high deviations of supply and demand for instance in order to adjust the peak demand. The real-time pricing permits the customers to adjust their consumption as they are notified prior with the tariffs.

4.2. Explicit demand response

Explicit demand response is also called incentive or market-based demand response. Explicit demand response bids are traded and sold in wholesale markets, capacity and balancing markets, being usually established and regulated by the grid operator (Weck, et al., 2016).

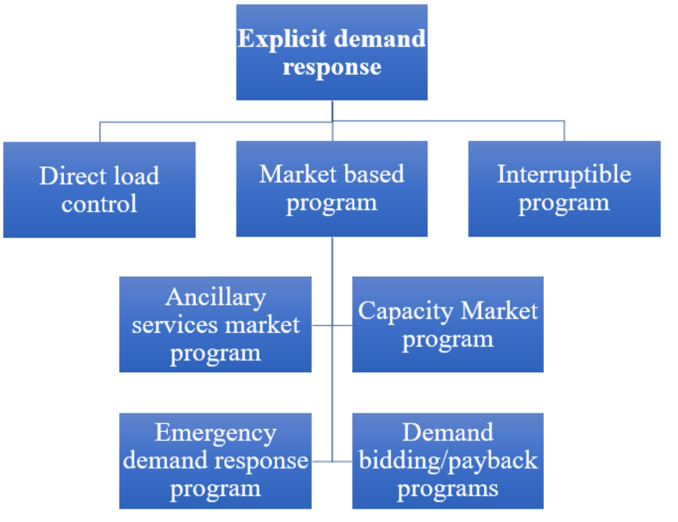

Figure 17. Categorization of explicit demand response.

Various programs exist classifying as implicit demand response, including direct load control, interruptible services, and market-based DR programs. In this thesis, the categorization of explicit demand response is based on the US department of Energy report (US Department of Energy, 2006) .The demand bidding or payback programs are out of scope for this thesis as the customers participating in this program place load reduction bids in the wholesale market in exchange of compensation. In this approach, the bids submitted accepted should be lower than the market place. Thus, the customers not fulfilling their delivery requirements face penalties. The demand bidding is traditionally reserved for large industry customers.

The interruptible or curtailable service is generally implemented by the TSO as a parallel solution offering additional support in the balancing market. Depending on the technical requirements for participation, large industrial customers are encouraged to reduce their consumption within a predefined range. The participants are rewarded for their load reduction. The interruptible load program is used in Spain and Portugal and is activated in the Replacement Reserve to offer a certain security in case of unexpected frequency deviations. However, penalties for failing to deliver the contracted load are often a burden on top of the strict technical requirements. Despite the TSO contract capacity from providers, the program is not always activated due to the low need, or number of participants.
The market-based demand response program offers market players the possibility to sell their flexibility ion the electricity markets in exchange of utilization or availability prices

expressed respectively in €/MWh or €/MW. This approach includes many sub-programs such as the ancillary services market in which the market players can participate in the operational reserves.

In direct load control, the customers engage in a contract allowing the program controller to manage their consumption by reducing the load. This is done by shutting down in a short notice the equipment such as air conditioner or water heater. Thus, this program is more directed to small-scale customers and/or the residential sector, rather than to large industrial customers. In the Netherlands, for instance, the direct load controller can be represented by the customer supplier or an aggregator instead of the TSO TenneT (de España Zaforteza, 2019). Part of the market-based DR, the emergency program consists of a response of the customer to deficiencies in the balancing reserve. In this context, the TSO provides incentive payment against a load reduction.

Following these explanations, the market-based demand response is the main scope. In this context, the aggregated load resulting from the customer change in their consumption trend is directly traded in the electricity markets, including the balancing markets. Demand response is then compared to the other provision resources participating, and is subject to the same compensation payments, technical, and market requirements to access the market. Explicit demand response requires a market player acting between the customer and the requesting TSO. In fact, the customer can contract either an independent aggregator or their supplier. The implicit demand response offers to the customer a fixed payment rate in exchange of their load.

4.3. Benefits and challenges in demand response services

Demand response benefits the system at the operational, security, economic, and environmental levels. At the operational level, demand response benefits the TSO by increasing the reliability and ensuring the stability of the grid. Economically, demand response as a resource participating in the balancing, reduces the costs in the balancing markets. However, from the TSO point of view, enabling demand response requires the development of a regulated framework enabling its participation, and a review of the technical requirements. Taking Iberian market as an example, the implementation of the interruptible load program does not ensure a full DR participation as it has not been activated recently and small-scale participants are excluded. In parallel, Germany has put in place the curtailment program and extended its usage until 2022 (SEDC,2017). Although aggregated demand response is allowed, the 5 MW minimum bid is challenging for small-scale participation.

The integration of intermittent energy resources raises the challenge of balancing the supply and demand continuously. In this context, demand response is considered as a support resources to balance fluctuations. Technically, demand response is characterized by its fast ramping features compared to conventional power plants. The customers' load can be adjusted instantly. This fast reaction is a very important in the balancing markets, especially in FCR, due to its continuous activation. Demand response is proven to reduce the need for capacity mechanisms, as it reduces residual peak loads (Weck, et al., 2016). In fact, by integrating a wide range of flexible options, including demand response and storage, the obligatory capacities reduce, which results in greater overall cost-efficiency. Implicit demand response benefits are not often clear to the customers. In fact, the financial benefits from dynamic tariffs are not applicable to all types of customer profiles that have limited options to adapt their consumption patterns. With the integration of smart meters, customers would be offered additional flexibility beyond dynamic tariffs (Burger , et al., 2016).

Demand response is conditioned by the consumption patterns of customers. Compared to the generating units that produce and trade energy with the ability to meet higher minimum bid sizes, demand response is dependent on the volume of change in the customers' consumption. However, the residential sector can only participate with a low alteration of their consumption. The participation of DR in balancing market is challenged by extensive availability periods due to the small availability potential of customers (Katz, 2014). For instance, in Germany the availability requirement of the tertiary reserves were 16 hours, before being shortened to 4 hours in 2014 (SEDC,2017). Concerning the reserves market, another technical feature consists of the frequency of activation increasing the complexity for demand response to participate. Generating units by their operational nature are able to meet a high number of activations in contrast to demand response, which is reliant on the number of participants, and well as on the volume of consumption change.

5. Independent aggregators as new market players

In the European legislations intending the energy markets, many references were made for demand side response aggregators. The benefits of the aggregators have been recognized by the European Directive. The Energy Efficiency directive regarded aggregation has an adequate solution to face the current challenges in the electricity markets including the dependency on the imports considering also the climate change issues. Undeniably, demand response and energy efficiency are strongly related as demand response contribute to energy savings. Thus, the concept of aggregation was broadly exposed as providers of short-duration loads services referring to small scale DR aggregation to be sold or traded in the energy markets. However, the directive stressed on an important issue related to the balancing markets. In fact, it recommended to the TSOs with the collaboration of the DSOs to enable the DR aggregators in the ancillary and balancing markets accordingly to their technical requirements. In other words, the structure of the balancing markets should not only be serving large generating units, but also remove the discriminatory barriers toward small-scale DR aggregation. In 2016, the commission regulation for the establishment of a Network Code on Demand Connection de highlighted the role aggregators and defined these market players as demand facilities or distribution system offering demand response services. The regulation highlighted the importance of demand response to increase the flexibility in the energy markets enabling also the active participation of the customer. A first mention to independent aggregators was made as it stated that the customer upon agreement with a third-party can offer their flexibility. According to the regulation, the independent aggregators should be considered a single user. In 2019, the European directive stablishing harmonized requirements for the internal market focused on independent aggregators as direct participants in the balancing markets. The regulation set baseline for member countries to adapt their balancing markets emphasizing on the integration on the right of independent aggregators to access these markets. In this context, the consumer status shifted to prosumer. In fact, the customer has the right to contract with an aggregator without the consent of its supplier. In addition, other aspects concerning the customers were presented such as the proportioning the contact termination fee between the third-parties and the prosumers in fair manner. The compensation issue between the BRP/ supplier and independent aggregators was brought underlying that the third-party should if needed financially compensate the balance responsible party if imbalances results in financial losses. The compensation challenge should not be considered as market barrier.

Considering the emphasis of this thesis, the directive established in 2017 proposing a guideline on electricity balancing is the most relevant. In fact, technical and regulatory requirements were explicitly set as well as the open access for DR independent aggregator to actively participate in the balance between the supply and demand. These market players are considered as balancing service providers of energy or capacity services enabling them to comply to the same provision and settlement requirements.

Figure 18. Evolution of EU directive targeting DR independent aggregators.

5.1. Aggregators as demand response enablers in the balancing market

Following the European directives on Energy Efficiency published in 2012, and on the establishment of guidelines on electricity balancing (GLEB) customers became able to take part in the electricity market, contribute to maintaining its stability and deviate the flexibility from conventional power plants. In a high flexibility integrated system, the customer’s role is switching to prosumer by participating in the balancing market. The participation of the customer in demand response is dependent on the economic benefits, environmental uncertainties, and price incentives (Burger , et al., 2016). In a general context, the aggregator gathers the flexible loads, production, and storage of selected customers and inject it in the electricity markets. The aggregator is a market player in charge of the technical implementation and the trading operations in the electricity market. However, the role of the aggregator will differ depending on the business model chosen. In fact, the aggregator can act like an independent third-party, a retailer, or a service provider.

In the aggregation business, the customer is referred to as a prosumer, which participates by its willingness to change its consumption patterns. Prosumers are classified depending on their size, from industrial customers offering large-scale flexibility to residential customers contributing by a small-scale demand response block. USEF, a Dutch foundation developing smart energy technologies and implementing DR aggregation pilots,has designated DR as an Active Demand and Supply asset (de Heer & Van der Lan, 2017). The objective of the prosumer is to guarantee the final delivery of flexibility to the aggregator, as mentioned in the contractual terms, in exchange of financial compensation. Aggregators manage a portfolio of prosumers, trading with suppliers, Balancing Responsible Parties, DSOs, or TSOs, through the BRP meeting the technical and regulatory requirements (Faria & Vale, 2018). The BRP interferes in the balancing portfolio of the BSPs, which are the aggregators. As different aggregation models emerge, various players are currently taking part of it. The smart meter data company which is in some cases the DSO is exchanging data flow with the aggregator concerning the energy trends of the consumers. Because unplanned demand response can lead to grid congestion, aggregator operations need to be clarified to the DSO overseeing the distribution grid in its operational region (de Heer & Van der Lan, 2017).

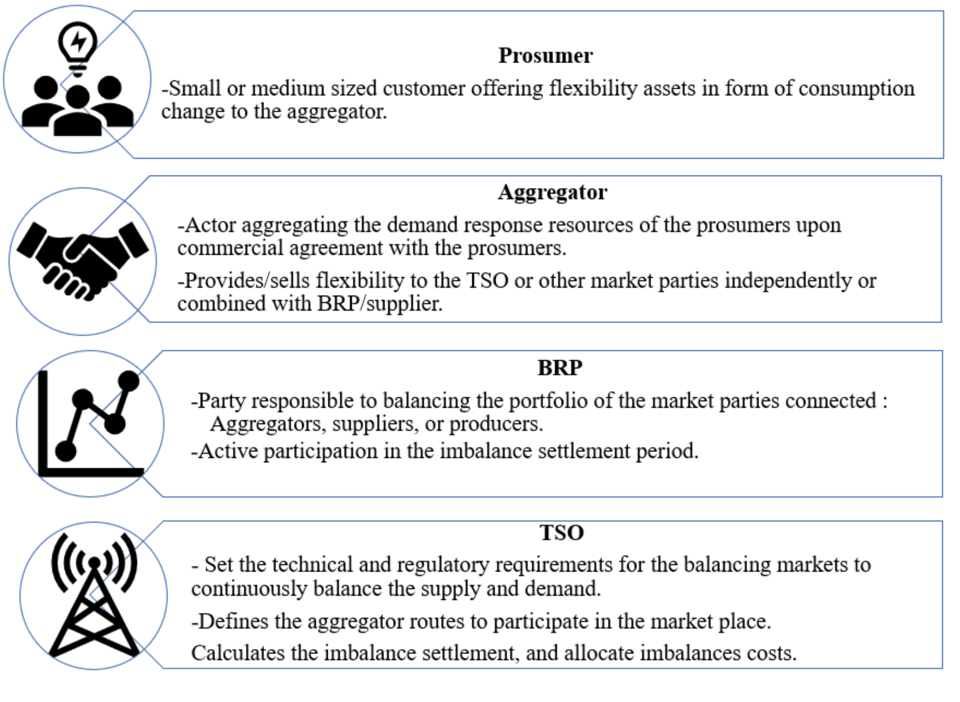

Figure 19. Role of selected market players in DR aggregation.

5.2. Fundamentals of aggregation

An aggregator is an entity that gathers DER capacity, for instance from units or small-scale customers and sells it in the electricity markets. The distributed resources include demand response distributed generation, including renewable sources, and energy storage. Their objective is to facilitate the transaction by acting as an intermediator between the customer and the electricity market participant that exploits the resources.

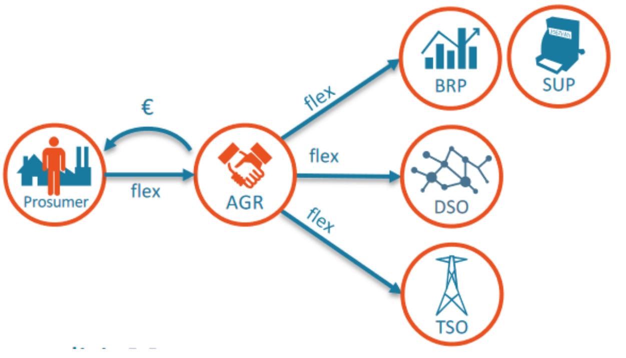

Figure 19. Operating process of DR aggregator and its relationship with market players (de Heer & Van der Lan, 2017)

Flexibility in aggregation is defined as the willingness of the customer to change their consumption pattern (Ikäheimo, et al., 2010) . In the context of this thesis, the aggregators are providing and selling the flexibility expressed as explicit demand response aggregated from the prosumers to the balancing markets. The aggregator composes its portfolio ensuring to meet the technical and regulatory requirements to the marketplace. Based on the volume activated, the prosumers receive a remuneration for their services, and the independent aggregator is liable for the services offered to the TSO for instance. To aggregate the flexibility, a real-time measurement of the customer´s consumption is required, and the use of smart meters plays a central role in enabling aggregation. The compensation challenge is rose in the balance settlement of the BRP. By changing the consumption trend of the customers, the aggregator changes the balance of the BRP. The compensation method varies depending on the model used. The aggregation affects the DSO as the flexibility of the prosumers is at the level of the distribution network. However, this thesis does not investigate further the issue.

For a full understanding of the aggregation fundamentals, USEF presented an example (de Heer & Van der Lan, 2017). The automatic Frequency Reserve accepts balancing capacity and energy services and its frequency is measured by the TSO every 4 seconds. In this case, the aggregators are either the Balancing Service Provider if acting as an independent entity or collaborate with a supplier or a BRP. However, in general cases the aggregator holds explicit demand response aggregated as active energy bids. In the first stage, the TSO, TenneT, will contract the energy and capacity services offered by the aggregator meeting the technical requirements. In the scheduling phases, the bids are delivered by the aggregator to the TSO and the DSO is informed by the aggregator DR portfolio to avoid any interference in the distribution network. In real-time operations, the TSO measures the services delivered in the aFRR according to the measurement and verification requirements, and the aggregator is notified to activate its services. The aggregator is held accountable for non-meeting the availability and delivery of the services. In the imbalance, settlement the activated energy is remunerated and the BRP portfolio is balanced.

5.3. Current types of aggregators

The aggregator has engaged curiosity through literature reviews analyzing its market role in the balancing market and beyond, but also its added value toward the concept of flexibility. In this thesis, the main focus has been aggregation of explicit demand response. In addition to the technical barriers that unable the participation, the business models of aggregators might also be a burden. In fact, one requirement could require the aggregator to be affiliated to the suppliers. Thus, various models of aggregators emerged over the years. The business models of aggregators define the role of the aggregation, its relationship with the prosumer, but mainly answers the question of who can become an aggregator. Currently, six models of aggregates are identified in the market distinguishing between the combined and independent aggregator (BestRES, 2016). In addition to the normal operation in the electricity market, BRP or suppliers can act like aggregators. Diversely, the independent aggregator is an emerging actor that solely aggregates flexibility from the contracted prosumers resulting in more competition in the electricity trade.

The DSO acting as an aggregator is a controversial type. In fact, The DSO as a market party responsible for the distribution of electricity isn´t allowed to directly aggregate demand response but would request its activation to reduce the system bottlenecks. Therefore, the combination DSO-aggregator is not explained further in this thesis.

The current types of aggregators exciting in Europe are classified as the following:

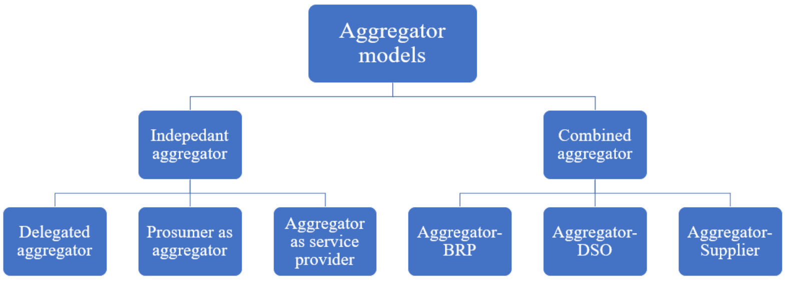

Figure 20. Categorization of existing DR aggregators models.

5.3.1. Combined aggregators

Considering the European directives, and market design, the combined aggregators faces lower regulatory and market barriers compared to the independent aggregator. In fact, the complexity of implementation and the compensation challenge between the supplier aggregator are reduced significantly as the combined aggregator already operates in normal circumstances in the electricity market (BestRES, 2016).

Combined aggregator-supplier:

In this model, the aggregator is upon agreement of the customer or so-called prosumer, combined with its supplier. Thus, the aggregator will propose a package to the customer with the ability of supplying electricity and using its flexibility in exchange of financial compensation. In this model, the aggregator is playing the role of the supplier and the BRP. The balance responsibility is directed to the BRP of the supplier.

In more details, the supplier and its balance responsible party are already bounded by an existing contract. The aggregator will then establish a new contract with the BRP of the supplier creating a package of a combined roles. The transition from retailer to retailer-aggregator is less complex as the retailers have an existing linkage with the electricity markets and the consumer profiles consumptions are recorded in their balance. In fact, as the fourth pillar of electricity system, the retailer has the role to sell electricity to the customer and organize purchase of flexibility. With the unbundling of the electricity markets, the customer is free to change and select their own retailers and thus enable smoothly demand response. This model offers a real advantage to the aggregator as the financial compensation due to the imbalances generated are absent between the two market parties

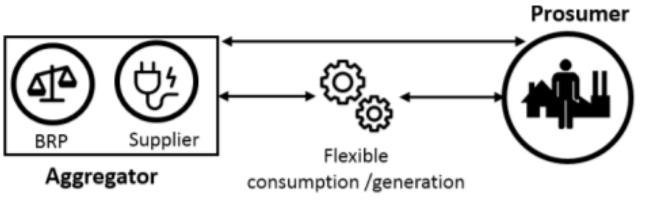

Figure 21. Combined aggregator/ Supplier operating process (J.K, 2018).

Two-BRP model:

In the opposite of the previous model, the prosumer has two contracts with two market parties. The customer will be supplied by electricity through a contract with its supplier, and its flexibility will be handled by an aggregator combined with a balance responsible party. In this model both supplier and aggregator are independent of each other. However, both are related to their balance responsible party. This model illustrates the compensation challenges with the intervention of two BRPs as the aggregator by using the flexibility of the customer might influence the supplier BRP imbalance (J.K, 2018).

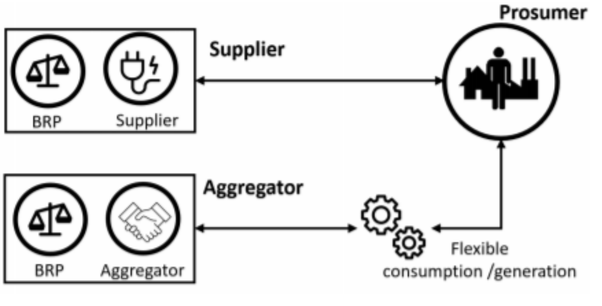

Figure 22. Combined DR aggregator/BRP operating process (J.K, 2018).

5.3.2. Independent aggregator models

The independent aggregator interacts directly with the customer and the aggregation services do not require the collaboration with the supplier. In addition, the third-party does not act like a Balance Responsible Party nor is it associated with the customer´s supplier. Therefore, the independent aggregator freely chooses the contract types with the customer, and the permission from the BRP to change the customer consumption trend is not needed (de Heer & Van der Lan, 2017). Aggregating demand-side response from the small customer and trading it in electricity markets is challenging as the energy is usually bought beforehand. The independent aggregators face an issue with the customer-supplier creating the need for the supplier compensation. This underlines the importance of defining the exact role of the independent aggregators and other parties.

Independent aggregator as a service provider:

This model positions the independent aggregator as a service provider only. The market party unlocks the flexibility of the prosumers but does not sell it at his own risk. In fact, the flexibility is offered to other market parties. In the electricity economic value chain, the service provider is not active, as the flexibility is not sold. In this model, the role is seen as organizational only (BestRES, 2016).

The delegated aggregator:

The delegated aggregator is the main focus of the thesis. As an independent aggregator, the delegated type sells the flexibility of the prosumers to markets parties or market places including balancing markets at its own risks which is the main difference between the service provider and the delegated. The imbalances are financially settled by the balance responsible party of the supplier connected to the prosumers following the type of compensation method selected. As an active market participant, the independent aggregator is hold accountable for failing to meet the availability and delivery requirements in the market place resulting in financial penalties (BestRES, 2016).

Prosumers as aggregators:

This model acquires the role of the aggregator by offering their flexibility. This model is profitable for large scale units or industrial, as they are able to aggregate large flexibility sizes and sell it to the market places or other market participants such as their supplier (J.K, 2018).

5.4. Compensation challenge

The compensation issue is closely related to the imbalance pricing and generate risk management for independent aggregator willing to grow in the sector. The compensation challenge depends on the business model used for aggregation. The independent aggregator is detached of the customer´s suppliers and operates the flexibility of its customer by changing their consumption trends affecting directing the balance responsible party portfolio. In more details, the energy consumption of the customers is changing as response the independent aggregator demand response activation. This results in supplier´s losses as the measured demand forecasts are being disrupted. This creates an imbalance between the volumes of energy purchased by the supplier and the consumption of the customers. Due to these losses of energy. The BRP of the supplier is responsible for settling its imbalances, in this situation, these imbalances are subject to fees from the TSO as they rise the need for further energy balancing services (NordREG, 2016). Thus, the introduction of the independent aggregator arises the issue of the BRP/supplier compensation. The figure 23 illustrate the compensation challenge. The activation of the demand side response resulted in an unmatched production and consumption in the supplier portfolio. In this case, demand response activation is assumed to be the only factor influence the consumption trend of the customer which remains relative as other elements might participate and should be taken into account.

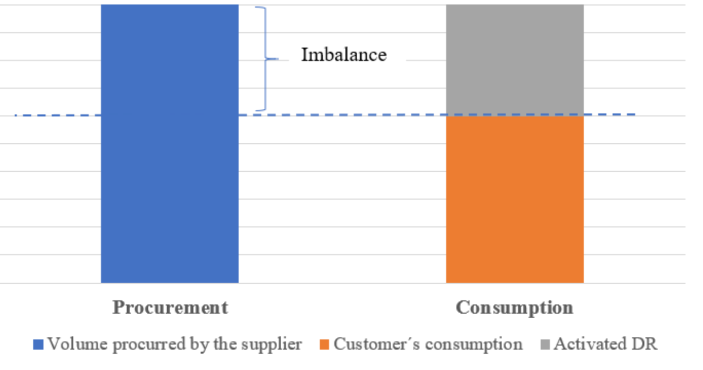

Figure 23. BRP/ supplier compensation challenge resulting from DR aggregation based on (Pearce & Forsman, 2018).

Aforementioned, the compensation challenge is strongly related to the business model adopted by the aggregators. There are three main compensation models illustrating the financial role of each party applicable for the independent aggregator (Pearce & Forsman, 2018). In the models presented, it is assumed that the BRP and the supplier are combined. The imbalance volume correction with no compensation requires the implementation of an additional settlement step. In this model, the TSO is acting as a neutral party correcting the BRP portfolio and attributing the prices depending on the demand response volumes activated. The independent aggregator does not compensate financially the supplier or the BRP. In the same logic, the imbalance volume correction and compensation models, the TSO interferes in correcting the imbalances of the BRP. In addition to that, the independent aggregator compensates the BRP for the DR volumes activated in accordance to a reference price. Lastly, the BRP can be compensated directly via the imbalance settlement process without further steps.

In normal circumstances in which demand response in not activated, the supplier/BRP sells the electricity to the customers and is consumed as planned. Thus, the revenues obtained are the difference between the procurement of electricity from day-ahead market the selling price. These revenues would be affected in case of DR independent aggregators intrusion (Pearce & Forsman, 2018). Because the customer is changing its consumption, the supplier is not able to sell the planned electricity. With the imbalance correction and no compensation model applied, the imbalances of the BRP/Supplier are cleared before the imbalance settlement resulting in a loss of revenues (day-ahead price) for the surplus of electricity. The independent aggregators would be the financial beneficiary with the market price. In case of the implementation of the no imbalance volume correction model, the TSO is charged to clear the imbalances by calling balancing services, and the BRP would receive imbalance price in addition to a loss of the day-ahead procurement price. The independent aggregator revenues would remain the same as the first model. In the third model, the cash flow of the imbalance volume correction and no compensation model resembles to the third model. In addition, the BRP receives compensation from the third-party aggregators either expressed as day-ahead price or set by the system.

The ability to provide demand response differs from customers according to the installations and behavior level. From the aggregator point of view, demand response is usually requested in form of load shifting which involves the customer to reduce its consumption during certain periods, but its energy use remain stable over the day. This can lead to increase of consumption after the activation of demand response also referred to it as rebound effect. At the BRP/supplier level. the rebound effect is a challenge as the electricity procured is not sufficient during these hours. The activation of up-regulation bids will lead the supplier to procure additional electricity, in addition to an imbalance fee paid to the TSO. To hedge the risk, the supplier can forecast the rebound hours and procure the electricity in the intra-day or day-ahead market, however this requires communication flow between the aggregator and the supplier. The challenges faced by the BRP/supplier impact on the retail prices, and thus on the customers. Taking the case of rebound hours, if the first compensation model is applied. the supplier has to procure additional electricity in addition to the losses of revues resulting in an increase of the procurement estimated to 20-40% higher than normal circumstances (Pearce & Forsman, 2018).

Table 2. Benefits and challenges comparison between the three compensation models.

Compensation model	Benefits	Challenges
First model	-Financial benefits for the independent aggregator	- Financial losses (DA price) of the BRP -Increase of retail prices
Second model	-High financial position of aggregator/customer	-Increase of balancing fees from TSO, other BSPs point of view
Third model	-Financial compensation of the BRP -Less financial benefits for customers	-Slight financial losses for the independent aggregator

5.5. Value proposition of the aggregator in the balancing markets

In the, the value of the aggregator is presented as economic and technological within private and system levels. Aggregation facilitate the integration of RES in selected electricity markets, as the customer or so-called prosumer holding RES loads or generation have a small size to directly participate due to the market entry barriers (Ikäheimo, et al., 2010).The question of economic value arises a question within the regulator that might affect the market entry. The profitability behind the aggregation business is different depending on aggregation in the large scale or so-called monopoly in which demand response has limited access or widening the market to smaller level and opening competition (Burger , et al., 2016). By offering aggregated DR in the balancing markets to the system operator, the aggregators generate revenues. In the case of the UK, it has been projected that offering 3MW of demand side response aggregated in the Short-Term Operating Reserve, aggregators receive an economical revenue of 66,000 pounds per year (Niesten & Alkemade, 2016). The aggregation business is growing leading to the creation of innovative business models. Currently, aggregation can be through Virtual Power Plants, Microgrids, or Storages via electrical vehicles for instance. In 2016, the VPP market value was estimated to USD 762 million and is expected to significantly grow by 26% in 2023 reaching 4597 million (IRENA, 2019).

DR aggregation demonstrates benefits at the market-economical level by decreasing the marginal costs. In the electricity production field, marginal costs denote the total operating costs of the production of each MWh of electricity. Conventionally, power plants are required to increase their output in to meet an increase of peak demand leading to high marginal costs if the production is relatively small. In this case, DR aggregation could be used to reduce the loads and hedge against the economic risks. At an intentional scale, the benefits of aggregators are already highlighted in various implemented projects. In fact, the aggregators Tesla with the collaboration of the South Australian government elaborated a virtual power plants connected 50,000 households equipped with solar PVs (IRENA,2019). The aggregation of their flexibility is estimated in long term to meet approximately 20% of the South Austrian daily power demand equivalent to 250MW. These benefits will also impact on the wholesale prices by decreasing it to $3/MWh for each 50MW brought to the system via aggregation. According to the VPP, the energy bill of the contracted customers can decrease up to 30%.

The economic value of DR aggregation certainly depends on the model adopted. In such, if the retailer acts also as an aggregator, the benefits of activating demand response resides in the reduction in purchase price as the electricity prices will be lower (Calvillo, et al., 2016). In case of independent aggregators, the estimation of the economic value is more complex as the compensation of the BRP/supplier is a must to be taken into account. At the customer level, the activation of DR reduces the consumption and thus generally results in lower bill prices. However, as discussed in the section 5.4, customer´s flexibility increases the supplier provision of electricity in the rebound hours, which leads to high retail prices.

As a fundamental baseline, the integration of the aggregation in the electricity system reduces the uncertainty in securing the supply. As a matter of fact, aggregators enable the enhancement of the energy efficiency in the electricity market by reducing peak demands by activating demand response to reduce the consumption of the prosumers or increase it during low electricity prices for instance (Babar, et al., 2013). In addition to that, they are enabling the competition and increase of provision in the balancing markets considering the progressive widening of the balancing market to demand response. With an active participation in the balancing markets, independent aggregators can provide supportive balancing services. For instance, Enbla Virtual Power Plant located in the New Mexico state can provides a flexibility capacity estimated between 20 MW and 25 MW which is equivalent to a conventional power plant (IRENA,2019). However, determining realistically the benefits of aggregator, it is worth to mention at which market level the aggregation results in added value. The main question remains if the aggregation benefits the whole system or the market place only. The system operators benefit also from the demand response aggregation as it reduces the service systems costs, and increases the reliability. In fact, aggregated demand side response can be used by the TSO aligned with the DSO to increase the reliability of the grid operation in order to decrease the congestion, and to regulate the voltage in addition to its balancing purposes.

Demand response is characterized by its decentralized nature. In fact, DR implies small-medium scale customers such disconnected and independent residentials, commercial or industrials. This highlight the variability of the properties and volumes of load offered. To trade this flexibility in the electricity markets, each customer needs to fulfill the technical requirements (minimum bid), and pre-qualification tests that requires the installation of metering system. In case of participation in the Interruptible load program, customers are required to have the adequate communication infrastructure to receive the activation signal from the TSO for load curtailment purposes. This creates complexities for small-scale customers highlighting the value of an aggregator to enable Demand Response at small and medium level. The aggregator has the ability to manage these complexities such as conducted the pre-qualifications at the pool level. In addition, with meeting the minimum bid that are often high enough to not enable residentials to directly participate.

Table 3. DR aggregation benefits.

Levels	**DR aggregation benefits**
Customers	- Enabling participating in the balancing market by meeting the minimum bids. -Financial compensation. -Removal of pre-qualification and testing complexities. -Provision of the technical and communication infrastructure.
TSO	-Provision with balancing services in the reserves. -Securing the supply and demand in real-time. -Supporting the intermittent energy resources. -Increasing system flexibility
BRP	-Diversified balancing sources in their portfolio -Increase the availability of BRP in balancing services provision -Self balancing (Netherlands case)

6. Methodology and framework development

6.1. Methodology and selection of comparison features

To help maintaining a stable system frequency and manage the imbalances of the balance responsible parties, demand response is provided in the balancing energy and reserves markets by BSPs. This thesis focuses on the participation of aggregated DR by third-parties in selected balancing markets including Finland, United Kingdom, the Netherlands, and Iberian market. A comparative framework is proposed with selected technical and markets requirements to normalize the analysis and identify entry enabler and barriers. The balancing markets structure and terminology used in the countries is at the moment not homogenous. It was deemed important to uniform the balancing products referring the ENTSO-E terminology as a reference. The structure of the comparative framework is strongly based on the terms and conditions of the balancing products published by the respective TSOs. In addition, the technical and market barriers affecting DR entry were taken into account. As the balancing market in Finland is fully open for demand response aggregation, it has been taken as a baseline. The requirements to participate in the balancing markets are categorized as technical and market requirements including the regulatory and economical aspects usually designed by the TSO in collaboration of the DSO in some instances. The components of the framework are selected based on their importance and influence on the integration of demand response and independent aggregators. For instance, the technical requirements are regarded as functional and each participant has to pe-qualify prior to the participation in the balancing markets. With this said, the technical requirements include the timing design variables of the balancing markets including for instance the frequency of activation, the activation time and the product resolution. Some requirements might intersect between technical and market such as the procurement time. In fact, part of the timing variables, the procurement can be regained as technical due to its reference to the timing of bidding, or an economical requirement as it referred to the period or frequency when the BSP can provide the balancing service to the TSO. The regulatory status of DR independent aggregators is a sine qua non for the development of the framework. It is then important to identify regulated and non-regulated frameworks. The selected requirements are defined based on their impact on demand response. The design of the balancing markets defining the requirements was originally implemented for large generators. The introduction of demand response through aggregation highlighted the importance to re-design the requirements specifically adapted to enable independent aggregators and increase the competition. The evaluation of third-party DR aggregators follows the linkage logic presented in Appendix I.

6.2. Definition of components of the framework

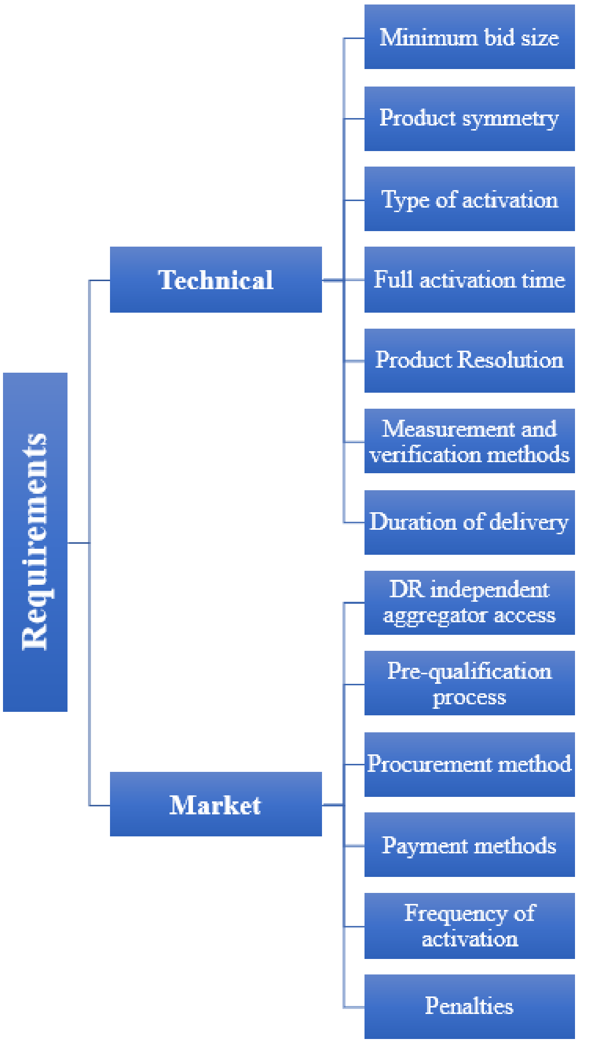

Figure 24. Categorization of the technical and market requirement used in the comparative framework

6.2.1. Technical product requirements

The technical requirements are also referred to them as physical properties that defines the pre-conditions for Balance Service Providers to access the reserves and ancillary services. It is naturally that the requirements differ due to the nature of electricity requires multiple balancing products for restoration of frequency purposes but also for restoration the reserves activation. For instance, the Frequency Restoration Reserve will be used to take over and restore back the FCR.

Minimum bid size: The minimum bid size is the main technical requirement that defines the ability of BSP to participate in a market place. This technical requirement is regarded as enabling the independent DR aggregator to participate is considering small load participation instead of oversized bids.

Frequency of activation: The frequency activation simply indicates the number of times the reserve is activated in a specific time period. As applied to the procurement methods, the recurrence of activation depends on the purpose of the reserve (Abbasy, et al., 2010). For instance, the Replacement Reserve is rarely activated. The frequency of activation is strongly correlated with the type of operation of the reserve balancing market. For instance, the FCR by nature needs to be continuously activated. When determining the frequency of activation of each balancing market, the TSO needs to align the gate closure opening of the markets accordingly. This determines when the balancing service providers is needed to be available.

Full time activation: The activation of the resources is done after receiving the notice from the TSO. It is defined as the maximum time allowed for the participant to response to the notice and deliver the balancing market. The contribution in balancing markets is limited by short notices raising the issue of communication and physical installation of automated technology as the aggregator sends a control signal to the customer in order to active demand response (Admie, 2017). Additional factors influence the FAT such as the number of customers, and the types of devices and their consumption.

Delivery duration: The duration delivery is defined as the availability of the balance service provider. Demand response providers are unable to sustain a long duration delivery compared to generating units. This is strongly related to the availability requirements of BSPs.

Symmetry of the bids: Regulatory bids are categorized as up-and down. The up-regulating bids are activated when the generation is lower than the demand. Thus, the up-regulating bids are presented as either an increase of the production or a decrease in the consumption. The opposite applies to the down-ward regulating bids. In fact, the system imbalance can also be due to a surplus of generation greater to the demand. The down-ward bids are a solution enabling a decrease in the production or an increase in the consumption. With respect to demand response, separate symmetrical services allow a smooth participation of aggregators as customers can offer single direction flexibility (Cappers, et al., 2013).

Product resolution: The product resolution defines the minimum time the participants should offer their services. Long product resolution periods are a burden for demand response aggregators as customers are able to change their consumption trends only for a limited number of hours.

Measurement and verification:

The measurement and verification are processes carried out by the TSO in order to quantify the volume delivered by the service provider and verify its compliance with the technical requirements. This quantification will be used for the financial settlement addition, it verifies the performance during and after the product activation. This criterion defines if the measurement of demand response is undertaken differently than the conventional resources provided. This criterion requires the participants to install equipment's such as smart meters, ICTs resulting in additional cost to automate the measurements of demand response. In fact, the TSO requires the aggregators to send measurements data at a specific time resolution for reliability purposes. As the aggregators might contract multiples customers, equipment installment costs tend to be a burden in regard of this requirement (CEER,2014). To enable DR aggregation, it is important that the measurement and verification are conducted at the aggregated level and not at the asset level.

6.2.2. Market and regulatory requirements

The market requirements illustrate the regulations set by the system operators defining the route for market participants, their roles in the balancing as well as different compensation methods for their balancing services provision. Part of the market design, the roles between the BRP, customer/s supplier and independent aggregators are defined. Thus, the market requirements join between regulatory and economical

Aggregation requirements: Aggregation requirements are considered as a regulatory criterion defined by the TSO that specifically targets aggregators. The aggregation requirements can encompass the ability of the BSP to aggregate from different BRP balances or not. These requirements might also include the ability for BSP to participate in additional balancing product at the same time.

Payment methods:

In the balancing markets, the market participants are compensated by energy or capacity payment referred to them respectively as utilization or availability payment. The utilization payment rewards the providers for their service delivery and is expressed as €/MWh. The availability payment compensates the availability or the ability to response to the instruction and is expressed in €/MW. The utilization payment is considered as the energy payment and encompasses two methods including pay as bid or marginal pricing. The Pay as Cleared also called the marginal pricing method is favorable for DR aggregators and encourage new market players to participate in the balance market by increasing the competition. Using marginal pricing, the participants will be automatically composed as the opposite of the pay-as bid considered as an incentive price.

Pre-qualification process: Prior to participate in the balancing market, the BSP shall pass the pre-qualification tests set by the TSO. The pre-qualification influences the positioning of independent aggregators in the market. The pre-qualification can be done at an asset or pool level. To enable demand response aggregation, it is recommended that the pre-qualification process takes place at the aggregated or pool level rather than asset or customer level. The aggregated loads should be treated as a single unit.

The pre-qualification is documented by the TSO, and usually include:

- The maximum power MW.
- Type of load.
- Technical description of the control system.
- Real time data measurement

It is the responsibility for the BSP to carry out the prequalification test in accordance to the technical requirements defined for each reserve unit. The results are evaluated by the TSO measuring the ability of the providers to participate and result in acceptance or rejection of the bids. Another constraint can consist of long time processing the pre-qualifications of the BSP.

Penalties:

Penalties are attributed to participant that do not fulfill the delivery and availability requirements. High penalization does not encourage demand response aggregators to participate. The penalties defined by the TSO differ and are usually calculated based on percentage that is reduced from the availability or utilization payments. Penalties can also include a temporary or definitive exclusion from the balancing market place.

Procurement methods:

The procurement method refers to the timewise market when the balance service provider can provide the TSO with the balancing bids. For instance, in Finland the terms daily, hourly, and yearly markets are used. The hourly market refers to the procurement of the reserves on a hourly basics. In more details, the volumes in the hourly markets are defined for the next day after the closure of the Day-ahead market. The yearly market is the procurement of volumes to be activated in the reserves for the next calendar year as well as the procurement prices. The daily, hourly, and yearly markets require an agreement set between the BSP and the TSO prior the procurement of the volumes. The procurement method reflects the time of bidding of the reserve's capacity and the balancing energy markets that is cautiously arranged by the TSO, and should be coordinated. The need of procurement depends on the requirements of the TSO and the design of the reserves. As an example, the FCR for normal operations activated by Fingrid is procured continuously. For this reason, some countries such as the Netherlands and Spain implemented an obligatory procurement contract with the generating units as they constitute a major share of the FCR supply.

7. Comparative analysis of selected case countries

7.1. Finland

7.1.1. Overview of the balancing market in Finland

In Finland, the balancing market is operated by the TSO Fingrid. The Transmission System Operator in Finland balances the deviations and the imbalances between the generation and the consumption for each hour through the activation of the reserves. The reserves can be activated manually or automatically. Reserves are procured from the parties (balancing parties). Fingrid main responsibility is to maintain the frequency of 50 Hz. In Finland, eSETT is responsible for the imbalance settlement upon agreement with the Balance Responsible Parties (Fingrid.b, 2020). The power balancing market is referred to it as the manual FRR in Finland. As discussed in the previous chapter 3, Finland follows the N-1 balancing. According to Fingrid´s balancing market requirement report (Fingrid Oyj, 2020) the balancing market also referred to it as reserve power market follows the article 157 of the guidance system and the EU regulation 2017/1485.

Fingrid considers any reserve provider unit fulfilling the technical requirements as a Balance Service Provider. As a general requirement, the BSP shall contract with the TSO prior to participate in the balancing markets. If participating in hourly and yearly markets, the BSP shall set agreements separately for both markets (ACER,2012). By definition, a BSP a market player that provides the TSO with balancing services. However, the specifies of the roles differs from country to country. The party could own or contract with an external party owning the balancing units, or act as a BRP.

The structure of the Finnish balancing market encompasses energy and reserve markets. The balancing energy bids are accepted from all resources including demand response through aggregation, and the minimum size accepted is 5-10 MW depending on the type of activation. Fingrid allows the participation of both upward and downward energy bids activated within 15 minutes. In 2017, the balancing energy market bids reached a volume of 350 GWh (Fingrid.a, 2020). The bids are proposed every 45 minutes prior to each operation hours referring to the gate closure. The procurement of the balancing capacity and energy by Fingrid differs timewise (Fingrid,2019). In fact, the balancing energy bids are ordered in the delivery day and procured every operating hour after the closure gate of the intra-day market. On the opposite, the balancing capacity bids are ordered prior the delivery day by one week, and the capacity providers are requested to place a bid in the balancing energy market as well.

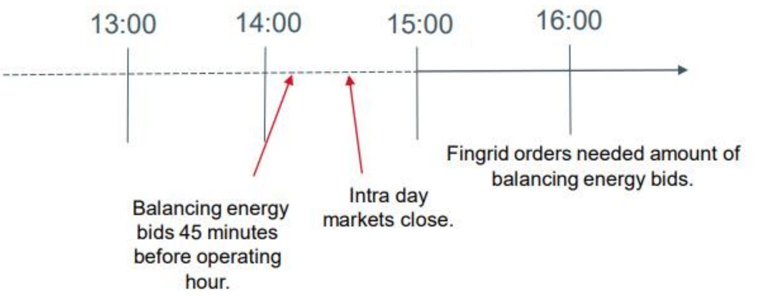

Figure 25. Timeline of the procurement of the balancing energy bids by Fingrid (Fingrid,2019).

The aim of the balancing reserves operated by Fingrid is to procure enough up-ward capacity when lacking of reserve generation from power plants. The capacity bids are traded in a weekly auction, and the price to compensate the balancing capacity is the same applicable to the up-regulating bid in the energy balancing market.The reserve capacity is activated after using the energy balancing bids.

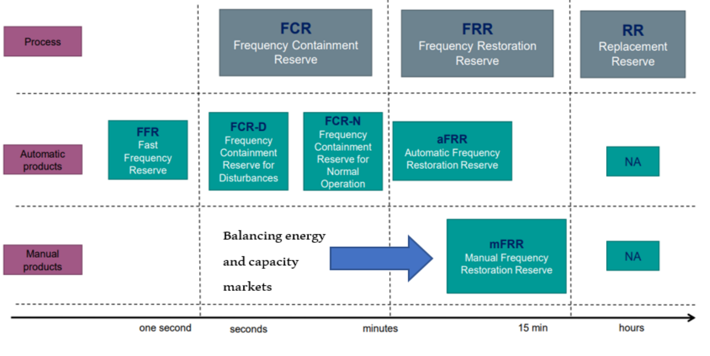

Figure 26. Balancing market structure in Finland (Fingrid,2019).

In Finland, the FCR is divided into markets, depending on the need and the speed of activation. The Frequency Containment Reserve for normal operations is activated as an active balancing method to continuously stabilize the system frequency. Technically, Fingrid uses the FCR-N to maintain the frequency within the range of 100mHz. The Frequency Containment Reserve for Disturbance is linearly activated within second and used mainly to adjust considerable frequency deviations (. Thus, FCR-D is considered more as mitigation balancing reserve and solve the consequences of the imbalances. The Frequency Containment Reserves are joined between the Nordic Countries including Finland, Sweden, Norway and East Denmark with an obligation to maintain a 600MW capacity in the FCR-N for normal operations, and a total of 1,450 MW in the FCR-D (Kuivaniemi, et al., 2017). The volumes of the reserves are thus defined to satisfy the synchronous system needs.

According to the Fingrid´s FCR instruction manual, the procurement of the FCR-N and FCR-D is conducted through yearly and hourly markets. However, the procurement of the capacity is conducted separately for each reserve. The participation in the hourly market shall not interfere with the ability of the BSP to participate in the yearly market. This means that the BSP is allowed to participate in the hourly market only if the full contracted balancing volume is delivered in the yearly market.

In the FCR-N, Participants are required to bid a minimum volume of 0,1 MW and a maximum capacity of 5MW. In accordance to the technical requirements, the provision shall be measured and delivered with an accuracy of 0, 1MW.Upward and Downward balancing capacity is fully activated depending on the frequency deviation range. If the system frequency is equal or lower than 49,9Hz upward balancing capacity is activated. If the frequency is measured to be higher than 50,1Hz, the down-ward capacity is then activated. The activation requirements changed in January 2020, as the frequency deviation dead-band changed from 50 ±0.05 Hz to 50 ±0.01 Hz.

To participate in the FCR-D, BSP should provide a minimum bid capacity of 1MW and a maximum volume of 10MW.The participation in both FCR-N and FCR-D requires a prequalification test to ensure that the Balancing Service providers fulfil the technical requirements at pool level. In addition, Fingrid defines verifications and measurements requirements for aggregators participating in the FCR. The aggregating units are required to provide to the TSO both real-time data and historical data in such that they aggregated units meet the technical requirements. Aggregators are given the choice to test the resources as a whole unit or individually. The FCR-D as it is used to increase the power, thus only up-regulatory balancing capacities is accepted. As the Frequency containment reserve is directly activated by the TSO, it does not require close interaction with the Balancing Responsible Parties for the imbalance settlement. Yearly and hourly market places are available for participants to place bids in the FCR. The yearly market is organized by Fingrid each autumn and the volumes are priced following the yearly fixed price conforms to the accepted bid with the highest price. The hourly market is organized on hourly basis. However, the price differs accordingly since Fingrid does not necessarily purchases on an hourly basis balancing capacity. The market structure in the FCR allows providers flexible participation as the yearly participants can also provide bids to complete their required contracted volumes in the hourly markets. Payment methods differ between FCR-N and FCR-D. Providers are compensated for their capacity availability. The price differs depending on market time participation. Concerning the FCR-D, in the yearly, the average price is approximately 2€/MW/h compared to a dozen of euros per MW/h in the hourly market. The compensation in the FCR-N is higher in the yearly market as the participants are remunerated following their availability and the activated net energy. Fingrid estimated an average of 13€/MW/h in the yearly market (Fingrid , 2020.a).

In Finland, the Frequency Restoration Reserve is deployed to re-establish the system frequency and to solve the power imbalances in real-time. Fingrid distinguishes between two types of FRR. In 2013, aFRR was introduced in the Nordic balancing market as a reserve to improve the frequency quality of the system. The aFRR is used to restore the frequency back to its nominal value as well as to take over the FCR and to release it to its normal operations (Fingrid Oyj, 2019). This reserve is automatically activated as is used to complement the mFRR in its function to restore the frequency of the grid. The frequency is measured continuously. Thus, Fingrid sends to the Balance Service providers signals defining the power change and its direction. This means, that a negative sign requires the BSP to provide down-regulating bids. A positive sign will therefore refer to a up-ward regulating bids. These bids should be activated 30 seconds after receiving the notification. The participants are required to conduct pre-qualification and verification tests prior to the bid submission. In addition to that, the market participants should offer capacity bids that are located in Finland in case they are not connected to the TSO grid. The Balance Service Providers are compensated by capacity payments. In fact, aFRR is a balancing capacity markets that does not offer energy compensation (Fingrid, 2020).

Upon a common decision with the Nordic TSOs, the volume and procurement hours of aFRR are planned to increase. as part of the establishment of ACE known as Area Control Error as a performance measure to control the balancing of the Nordic area. By 2021, the volumes of the capacity market aFRR will increase from 300 MW to 600 MW (ENSTO-E,2017).
In the Finnish balancing market, mFRR plays to major roles. In the context of this thesis, mFRR can be used as an active reserve to hedge and protect the frequency deviations in real

time. In this case, mFRR is referred to it as balancing energy markets. The bids activated the balancing energy markets are conducted in price order. In addition, mFRR can be activated by Fingrid to restore the FCR, and aFRR when they reach their activation limit. Fingrid uses both energy and capacity balancing markets in the procurement of mFRR. The balancing energy prices are determined using marginal prices meaning that the most expensive bids will define the up-ward regulation bids and the opposite applies to the down-regulating bids (Fingrid Oyj, 2020).

The capacity balancing markets ensures that there is enough volume in the mFRR to maintain the balance between the production and consumption. Therefore, the capacity bids are activated after the use of the bids in the energy balancing markets. The contracted BSP participating in the mFRR capacity markets are required to also participate in the energy balancing markets to complement the voluntary bids submitted. In these circumstances, Fingrid ensures a continuous provision of the energy balancing markets in case of unexpected imbalances. The procurement of balancing capacity is conducted on a weekly basis tendering process. BSP can participate with a minimum bid size of 5 MW and a maximum size of 50 MW (Fingrid Oyj, 2020). The mFRR is considered as an important balancing product in the Nordic as the volumes procured in the aFRR remain limited.

7.1.2. Status of demand response in Finland

In Finland, the final electricity demand rose from 82,5 TWh in 2015 to 90 TWh in 2019, in addition the total net imports consisted 24% of the total electricity consumption in 2018 (Statistics Finland, 2018). The supply of electricity has also undertaken positive changes with an increase in wind and solar PV generation (IEA,2018). However, to secure the supply, the national TSO Fingrid is still relying on the imports of electricity from neighboring countries such as Sweden and Russia.

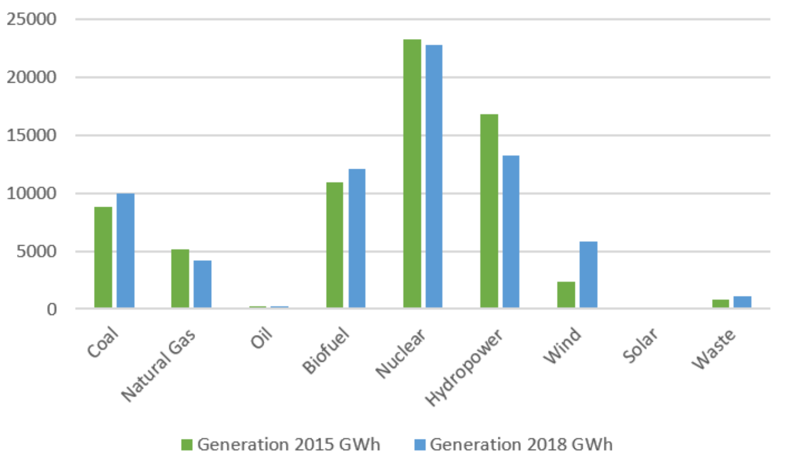

Figure 27. Finnish Electricity generation 2015 versus 2018 in GWh (IEA,2018)

According to Fingrid, demand response can participate the balancing markets places including the Frequency controlled normal operation reserves, Frequency controlled disturbance reserve FCR-D, aFRR, mFRR(balancing power market), mFRR (Balancing capacity Market) as well as the day-ahead market, intraday market both Nordpool markets and strategic reserves.

Table 4. Demand Response participation (MW) in the Finnish balancing market (Fingrid, 2018.b).

Market	Demand Response share in 2014 MW	Demand Response share in 2018 MW
Day ahead Market	200-600	200-600
Intraday Market	-	0-200
Balancing Power Market mFRR	100-300	100-300
FCR-D	70	430
FCR-N		4
Fast Disturbance Reserve	385	-
Power Reserve	40	-
Peak load reserve	-	22
aFRR	-	-

The integration of demand response has been tested in various pilots. In 2014, Fingrid launched a project with the collaboration of Seam Group, a company offering different types of demand response services to customers (Häkli, 2014). The pilot tested the ability of a frozen warehouse to act like a reserve provider in the FCR-N through demand response. It consisted of adjusting the consumption and the power of the devices such as refrigerators, vaporizations, and condensers during approximately 6 months. The main outcome of the project is to evaluate if the requirements enable the participation. In fact, one of the challenges mentioned is that Fingrid technical requirement to enter the ancillary service market (FCR-N) is based on power plants. In 2015, the first results have been communicated and the progression of the project highlighted the potential of aggregation in the electricity market reserves. In fact, the frozen warehouse achieved a balancing power of 300 kilowatts that can be three times higher equivalent to 900kW. This is the potential of one site if aggregated can be much more (Fingrid, 2015).

The smart metering roll-out was completed in Finland in 2013 under the Finnish regulation (Decree 66/2009). In 2017, the Energy Agency in its Agency for the Cooperation of Energy Regulators and to the European Commission report has estimated the installation of smart meters at 99%. The hourly measurement data of the customer are used in the balance settlement. The deployment of smart meters allowed the supplier to increase the flexibility and offer to the customer dynamic contracts other than the Time of Use tariff contract established since the 1970s (Anon., 2017). Under this advancement, it was estimated at the end of 2016, 7% of retail customers benefited from these contracts in which the price depends on the hourly consumption and prices of electricity based the spot market price (Authority, 2017). Finland is considered as a pro-active country leading the smart metering installation. It is estimated that smart meters are installed in almost every 3,4 million electricity metering points (Energiateollisuus, 2017).

7.1.3. Independent aggregators as market players in Finland

In a general aspect, DR aggregators are allowed in all balancing markets in Finland. However, the conditions are not homogenous to all the reserves. The participation of DR aggregators is allowed in both FCR-N and FCR-D (Barbero, et al., 2020). In fact, the balancing service providers are allowed to aggregate production and consumption balances from different balance responsible parties in both yearly and hourly markets in the FCR. In the balancing energy and capacity markets mFRR, market parties are only allowed to aggregate the production and consumption balance. In other words, aggregation of reserve resources is accepted if under the same balance responsible party. Aggregator are demanded as all market parties to fulfill the pre-qualifications tests, and verifications to participate in the balancing markets.

In addition, Fingrid established a grid development for the period of 2019-2030 where demand side management is seen a key asset in the balancing markets. In these circumstances, aggregators and virtual power plants are fully recognized as market participants in the balancing markets (Fingrid, 2018.e). Various pilots have proven their potential in widening the flexibility of the grid. However, the development of the adequate business model is still undergoing. The pilots tested various compensation models identifying the suitable one for independent aggregators. At the moment, this market players are required to set an agreement with the customer´s supplier or/ and balance responsible party prior to participating in the balancing market at the exception of the FCR-D. The imbalance settlement process in Finland is quite attractive to demand response aggregation, as the balancing responsible party is not financially affected by the imbalances caused by the DR activated. The TSO, Fingrid, is charged of correcting the BRP area. One main enabler resides in the pre-qualification process. Aggregators as balance service providers are to fulfill the pre-qualification tests. In this context, Fingrid assesses the portfolios at the aggregated level and not at the customer level enabling small scale DR participation. Demand response offers to Finland an opportunity to lose from its import's dependency. The benefits were embraced by the Finnish TSO that open its balancing market to demand response participation through aggregation including FCR, aFRR, mFRR, and RR products. However, technical entry requirements preclude to some extent the participation of DR independent aggregators. Regulations and market design are part of these challenges. Demand Response aggregation from different areas is allowed only in the FCR-D. In the replacement reserve, aggregators are allowed to participate with a minimum bid of 10 MW. Because, it is rarely activated and estimated to one to two times per year, it is not considered as a market place for independent aggregators (Barbero, et al., 2020).

Table 5. Technical and market requirements for DR aggregation in the Finnish balancing market.

Requirement	**FCR-N**	**FCR-D**	**aFRR**	**mFRR**	**RR**
DR Independent aggregator access	Yes	Yes	Yes	Yes	Yes
Minimum bid MW	0,1	1	5	5-10	10
Procurement	Yearly and hourly		Daily	Weekly	2-3 years
Activation time	3 min	50% in 5 seconds. 100% in 30 seconds responding to a change of -0,5Hz	30 sec- 5min	15 min	15 min
Frequency of activation	Continuous activation	Several times per day (Barbero, et al., 2020)		According to accepted bids	Rare activation
Delivery duration	Continuous	Until frequency = 49,9 Hz for 3 min	Continuous	15 min	NA
Product symmetry	Yes	Up	Separate Up and Down	Up	Up
Capacity payment	Availability payment	Availability payment	Availability payment	Availability payment	Pay-as bid
Energy payment	Activation payment based on net energy Marginal price	Energy fee	Activation payment Marginal price based on the mFRR price Pay-as bid	Marginal price	NO

7.1.4. Relevant Finnish pilots

Within the motivation to increase the electricity market flexibility, Fingrid launched a prototype in 2017 project involving independent aggregators acting in the balancing and reserves markets. The project was in collaboration between Helen and Voltalis (Fingrid, 2019.b). The pilot involved Helen, a Finnish producer and retailer, using real estate reserve power including diesel engines. Votlalis is an aggregator in France since 2008 and now, it aggregates small loads from 100,000 French households (Fingrid, 2018.c). In this pilot, Voltalis is aggregating flexibility demand within the Finnish households. The pilot intends to give access to the independent aggregator models to the manual Frequency Restoration

Reserve Market. The aggregation from different BRP´s balances is only allowed in the FCR markets; However, this pilot tests the possibility of such practice in the mFRR, and focuses on analyzing the exchange of information between the different parties, and the development of a suitable business model for independent aggregators. In order to develop an adequate business model for the independent aggregator, Fingrid implemented within its pilot a reimbursement compensation model also referred as imbalances volume correction with compensation. In this context, the TSO clears the imbalances of the BRP based on the activation of demand response, and compensates or charges the BRP based on the day-ahead price. The independent aggregator is remunerated for the balancing services with the difference price between the day-ahead and the mFRR market price (Pearce & Forsman, 2018). Without the compensation model, the BRP is subject to financial losses in case of activation of up-regulation bids. As the third-party instructs the customers to decrease their consumption, the supplier therefore, automatically loses the electricity purchased in the retail market beforehand. In the contract, the BRP would gain additional financial value in case of down-ward regulation as the customers requires additional consumption of electricity.

The pilot undertaken by Fingrid highlights the advantages of the remuneration model allowing fair trading rules for both the third-party and the BRP. However, its application requires high measurement and verification requirements to accurately determine the actual delivery of the BSP. According to Fingrid, the project is expected to expand in the early 2020 as no relevant results has been showed yet (Fingrid, 2019.d). The aim is to give access to the actors to the manual Frequency reserves and expand the access in the balancing energy market. Fingrid allows all the balancing services providers interested in proving more flexibility to participate in the pilot by signing the agreement contract.

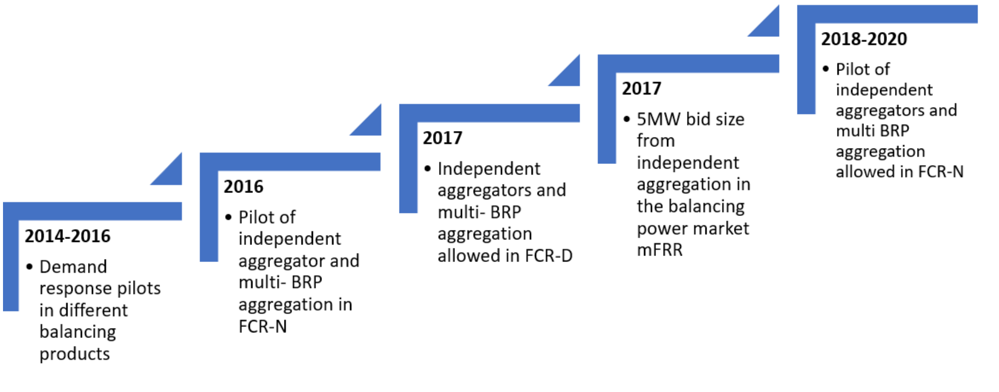

Figure 28. Timeline evolution of Finnish DR aggregation pilots.

7.2. Netherlands

7.2.1. Overview of the balancing market in the Netherlands

Part of its balancing market, the Dutch TSO offers in parallel ancillary services in accordance to the Directive 2009/72/EC including the balancing reserves that are part of the thesis context. In the Netherlands, the balancing market is composed of the primary, secondary, tertiary and an emergency power reserve. According to TenneT, the balancing market is mainly composed of the aFRR, mFRRsa, and mFRRda. Both regulating and reserve power that stand for aFRR and mFRRsa are used to correct the imbalances in real time. In fact, the generating unit connected with the TSO as obliged to participate, and thus, TenneT procures its balancing services from the mentioned reserves. The BSP have the ability to voluntary participates or sign a contract in the aFRR mandating them to submit a certain volume. The mFRRda provision structure is quite different as no bids are submitted, and only the availability of power is contracted. Part of its balancing market, the ancillary reserves or also called the balancing capacity reserves in the Netherlands include the black start capability, redispatch, and the compensation of losses in the network (TenneT, 2020). However, the participation of aggregation or demand response is very low and irrelevant in this thesis. Currently, the provision of these reserves is solemnly reserved to large power plants which consist a real barrier to small scale aggregators. Thus, they are excluded in the analysis of the balancing market.

As part of the transparency responsibility of the Dutch TSO, TenneT publishes the real time energy volumes activated in the balancing energy market as well as the price of the last activated bid. TenneT applies the marginal pricing as mechanism also referred to it as regulation prices or uniform pricing system. In more details, the pricing mechanism in the Netherlands is determined by the direction of the bids. For instance, the price of the up-ward is determined by the highest price of the activation ones. The downward bids price is on the opposite equal to the lowest price bid of the activated ones. This principle if applied for the aFRR, mFRR. This price uniformity is an incentive generated by TenneT to reduce the power imbalances. The pricing mechanism also included the mid-price concept that is applicable in two cases including when the TSO does not activate in energy balancing bids, and when reserve pricing occurs. The mid-price in an average price of the lowest price of the up-ward bids and the highest of the down-ward bids. TenneT is considered as passive or reactive TSO as it activates the operating reserve to restore the actual system imbalances and not specifically to anticipate the future deviations.

Table 6. Dutch Reserve terminology and its ENSTO equivalent.

ENSTO-E terminology	**TenneT terminology**
FCR Frequency Containment Reserve	Primary control
Automatic Frequency Restoration Reserve aFRR	Regulating Capacity
Manual Frequency Restoration Reserve mFRR	Reserve Capacity mFRRsa
	Incident Reserve mFFRda
Replacement Reserve	Replacement Reserve

TenneT describes the balancing process in a timewise manner. The D-1 represent the day-ahead prior to the delivery day. The BRPs are required to submit they schedules of consumption, production, and trades. The TSO then assess the transaction and evaluates the balances for each Imbalance Settlement Period. During the delivery day, the TSO activates the balancing energy submitted and restore within 15 minutes any imbalances. Prior to the delivery, the BSP are allowed to change or adjust their submission schedules up to two imbalance settlement periods. The settlement occurs in the day after the delivery day D+1 at 10:00 am.

The Dutch TSO Tennent is responsible for the high voltage grid managing the interconnection of transmission between Netherlands and join European countries in addition to the balancing markets. TSO offers two programs for information provision purposes to the participants to share the information prior to the delivery of physical energy targeting mainly the Balance Responsible Party (J.K, 2018):

- T- prognosis: Information of the quantity or flow of electricity to be transmitted through the electricity system.
- E-program: Information of the balancing portfolio of the BRPs including the supply and demand. The E-program is relevant to the balancing markets as the information is used for the imbalance settlement in later stages.

The allocation of balancing responsibility is allocated by the Dutch TSO TenneT via two routes. As the market parties are required to inform the system operator about their scheduled production and consumption, in addition to the transmission needs. TenneT offers the possibility to conduct their programs themselves or via a balancing responsible party (SEDC,2017). The Balance Responsible Party should according to TenneT manage the portfolio of at least one unit connected to the grid. In the Netherlands, the assigned BRPs enter the planned operations in a energy program called e-programmed in which the sum of all the scheduled production and consumption of the BRPs is available to the TSOs. The Balancing Responsible Parties are also referred to as Program Responsible Parties in the Netherlands, and they are categorized depending on their value.

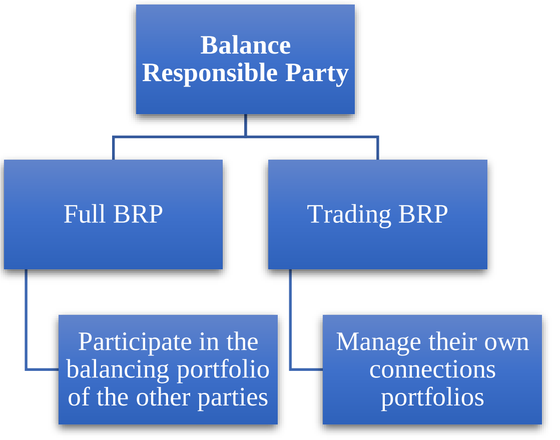

Figure 29. Categorization of the BRP types in the Dutch balancing market.

The primary reserve in the Netherlands, also called *Primaire reservevermogen TenneT B.V* (TenneT, 2020). The primary reserve in the Netherlands is used to restore the system frequency at an international scale regardless of the location of the shortage. Thus, the volume required is determined by the ENSTSO-e on a yearly basis. The FCR works in a synchronous system as such that the TSOs are allocated yearly a frequency bias percentage that defines their participation share depending on variables such as their net production and consumption relative the sums of the areas sharing the FCR (synchronous areas). In 2019, the Netherlands frequency bias was 3,7% which converts to a participation of the Dutch FCR to 111MW up and down directions (TenneT, 2018.c). The harmonization of the balancing markets across Europe is in favor of the Netherlands as TenneT recorded that 17% of the FCR volumes are acquired through common auctions on the FCR platform. Evidently, changes in the Dutch FCR are being discussed for further uniformization. In a report published by TenneT in 2018 approaching the development of FCR framework, real time measurements data provided by BSP to the TSO might change to 4 seconds resolution to possibility of 1 second's resolution mandatory of all participating units which challenges the market entry of DR aggregators. The procurement of FCR bids is conducted under the concept of common auctions. Under this method, TenneT procures 30% of its FCR from generators connected to its control block part of the mandatory participation. The non-mandatory bids are then activated by merit order beginning the lowest price bid.

The Frequency Restoration reserve is divided between the balancing energy market and the capacity balancing reserves to exclusively maintain the balance in real-time.The Dutch balancing market refers to the aFRR as regulating power and the mFRR as the reserve power. Incontestably, the TSO role in balancing market is prominent and direct. As part of its functions, TenneT is charged in monitoring the quality of the BSP bids delivered in the aFRR on a daily basis to ensure that the power response of the BSP is in accordance with the requested value. Providers are able to provide up and down regulatory bids. The TenneT offers the possibility for market players to place free bids. However, the units registered as Balancing Service Providers are bound by contract to participate at least by one bid volume and should be available for the entire imbalance settlement period applicable during their contract with TSO.The activation of the bids is conducted automatically by the TSO. In fact, after the gate closure, the imbalance settlement determines the volume of bid to be activated. The BSP are necessitated to meet a 7% ramp up or down requirement of the bid volume per minute to ensure that the system frequency is restored within 15 minutes. The participants should provide at a bid of a minimum size of 1MW and 999 MW at maximum. In addition, the Balancing Service provider is allowed to provide three bids if the size is smaller than 4MW.The bids offered in the aFRR are sorted by TenneT in a bid ladder classifying the bids in a cost-based order. To ensure a continuous balance, TenneT offers monthly and weekly basis tender period to participate in the aFRR, and the price of the bids injected in the aFRR are determined by the prices of the highest and the lowest bids activated. After the imbalance settlement, the providers are compensated by their energy delivered and imbalance prices. Following this reasoning, TenneT rejects directly the bids of the BSP with prices higher that the defined prices (TenneT, 2018.d).

The Dutch TSO distinguishes between two types of manual frequency restoration reserve: mFRRsa which is schedule activated and the mFRRda directly activated. The technical requirements for mFRRda and mFRRsa are detailed in the product specification manual presented by TenneT respectively (TenneT, 2018.a) and (TenneT, 2019.a). The mFRRda is activated if incidents are maintained or unexpected long duration deviations occurs. In the Dutch balancing market, the mFRRda is considered as an emergency power reserve or an incident reserve for its activation purpose. The bids are contracted on a monthly and quarterly basis. Two types of mFRRda can be distinguished. The downward mFRRda necessitate a decrease in the production or a decrease in the load/demand at the opposite of the mFRRda upward. In overall, the technical requirements are quite similar. However, the participation in the mFRRsa is not mandatory, and the participation of BSP remains voluntary. At the contrast with the mFRRda, the mFRRsa does not apply bidding or availability requirements and can participate if they have sufficient capacity available. Both types are operating reserve more specifically defined as spinning reserves, and the availability of the providers should be kept continuous for the defined time or a percentage availability determined by the TSO. In 2019, TenneT contracted a total of 1405 MW up regulatory bids and 1281 MW down regulatory bids in the mFRRda. As applied to the aFRR, the Balance Service Providers are required for the entire duration of the contract to provide the mFRR directly activated with the power volume agreed on. The Dutch TSO determines the quantity of energy to be delivered in the mFRRda based on the energy settlement period, and the metered volumes that the Balance Service Provider made available for activation. To participate in the mFRRda, the BSP and market parties should contract at least 20MW.The up-ward mFRRda should be activated within 10-15 minutes. The down-ward reserve is activated within a short time at maximum 10 minutes. The market parties and the BSP should be able to activate the power fully and sustain it for at least 60 minutes. TenneT encourage the Balancing Service Providers to measure and verify the power required following the given verification options. The verification method used in the mFRR consists of metering the activated value in a trend of 5-minutes KWh.The BSP should make the metering data available every 5 minutes to the TSO.

7.2.2. Status of demand response in the Netherlands

In the Netherlands, considerable changes in the generation of electricity are expected to be made in order to meet the EU Energy Roadmap and Paris agreements target set to 2050. In a study published by TenneT, renewable energy would consist a solid share of electricity generation with a dominance of wind power and solar PV to hedge the wind variations during certain months (TenneT, 2019). Thus, flexibility is seen as an active solution to be integrated in the Dutch electricity market encouraging demand response to be part of the trade portfolio of the balancing responsible parties. As shown in the figure, demand response is expected to play a major role in supplying the electricity market with flexibility. At the moment, demand response is actively used part of the BRP portfolios especially in the wholesale market (SEDC,2017).

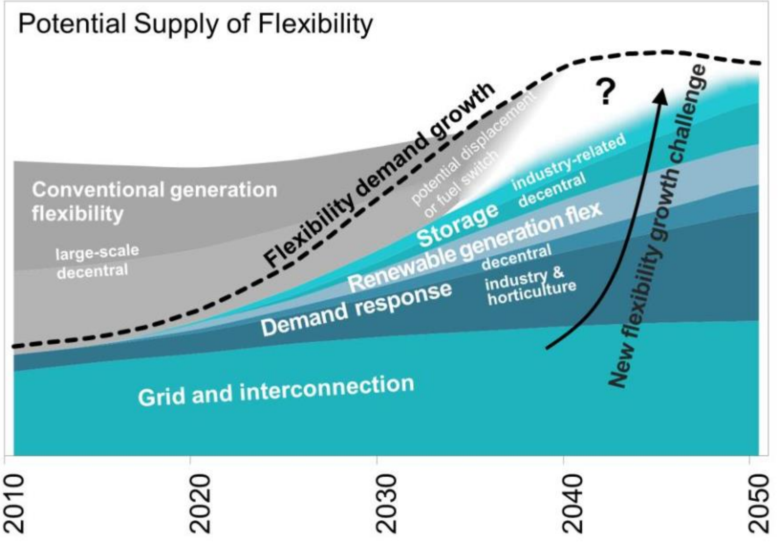

Figure 30. Role of demand response in the flexibility growth framework in the Netherlands (TenneTa,2019)

In 2019, TenneT measured the participation of demand response in its markets. The results highlighted that DR biggest share of participation was in the day-ahead market and a lower share in the FRR.

Table 7. Demand Response participation (MW) in 2019 in the Netherlands (TenneTa,2019).

Market	Demand response participation MW
Day-ahead	700-2,000
Ancillary services	90

The main enabler of demand response in the Netherlands resides in passive balancing of the balance responsible parties. In fact, these markets players are allowed to manage their own imbalances in their portfolio. Because TenneT makes the data of real-time imbalances including the activated volumes and imbalances prices public, it allows the use of demand response for balancing purposes. In this way, the BRP voluntary participate in the balance of the system without being part of the bidding ladder and are compensated if they adjust their own imbalances instead of being financially penalized (de España Zaforteza, 2019). In fact, it has been estimated that demand side response is mainly used by the BRP part of their passive balancing. In the Netherlands, demand response in allowed in the balancing market as a single or aggregated resource, as well as in the intra-day and the day-ahead markets. In 2015, TenneT implemented a version of the Emergency Power Program called “Omgekeerd Noodvermogen” allowing DR symmetrical bids to participate (SEDC, 2017). The deployment of the smart meters in the Netherlands enables currently customers to participate in the balancing markets by aggregating their flexibility. Practically, the direct participation of customers is quite complex as they are requiring as service provided to fulfill the pre-qualification tests at the aggregated level. However, customers can contract with an aggregator with an agreement of the balancing responsible party. This requirement burdens the integration of independent aggregators in the balancing markets.

In overview, demand response has access to the balancing markets in the Netherlands. Previously, its participation in the primary reserve is quite complex as it requires symmetrical bid and is mainly reserved the generating units. However, a pilot runned by TenneT in the FCR allowed demand response aggregation starting 2018 (TenneT, 2018.c) .Demand response is mainly visible in the aFRR and the mFRR schedule activated as the minimum bids are 1 MW. In addition, the mFRRsa allows voluntary participants for balancing services in addition to dispatch services. The mFRR directly activated requires a minimum bid of 20MW which technically prevents demand response participation.
In 2007, the Dutch government agreed in introducing smart meters in the electricity system by 2014. However, the bill has been voted earlier by the Upper House on 22 February 2010 (Government.nl, 2011). In the Netherlands, approximately 7.8 million residentials are accounted. Along with the Ministry of Economic Affairs and Enexis Nerbeheer, 900,000 electricity smart meters have been installed by the company now. The investment of smart metering deployment in the Netherlands is estimated between €1,1-1,5 billion (Future Power Technology. 2018).

7.2.3. Independent aggregators as market players

Demand Response aggregation is allowed in the aFRR and mFRR including the directly activated and scheduled activated reserves. On the other side, independent aggregators are not yet given a full access in the balancing markets. In fact, aggregators are required to participate only upon agreement with the BRP in the FRR and RR. This requirement results from the passive balancing methodology applied in the imbalance management. In the context of the Netherlands, passive balancing means the ability for BRP to participate in the balance of the supply and demand without going through the bidding process. Thus, the demand response contribution is limited to aggregators. In this context, the BRP is responsible for trading the flexibility portfolio provided by the aggregator in the balancing markets. This aggregation can be also done via a third-party however, an agreement with the supplier is mandatory as the customer are allowed to reject or accept the offer. The mandatory agreement between the aggregator and the BRP raises the challenges of the compensation. According to (Lampropoulo, 2016), the imbalance settlement of the BRPs becomes complex if considering aggregated portfolios. In the mFRRda, TenneT clears the imbalances using a pricing based on the difference between the reference values and the power output. Therefore, as discussed in the section 5.4, the rebound effect due to the activation of demand response is not taken account leading to financial losses at the level of BRP/supplier.

The Electricity Market available in the Netherlands is supporting the demand response offered through aggregation in the following format (SECD,2017):

- **Aggregator-supplier:** This combination offers the possibility to supply and aggregate the demand response from the customer by one market party. In this case the role of the BRP and the supplier are both fulfilled by the aggregator.
- **Aggregator-BRP**: The consumer has a contract with the supplier to purchase the electricity. In this case, the consumer has also a separate contract with the aggregator to sell the flexible loads.
- **Service provider aggregator**: In here the role of the aggregator in aggregate the loads and give access to the other facilities. It does not play the role of the supplier nor does it play the role

At the moment, the small-scale aggregation is not widely participating in the balancing markets. Demand response is mainly provided by generators, balance responsible parties or retailers (SEDC,2017). One enabler highlighting a potential participation of independent aggregators is the low minimum bid size in the FCR, aFRR, and mFRRsa equal to at least 1MW(TenneT,2020). In addition, the pre-qualification process is conducted at pool level allowing aggregators to act on behalf of their customers with an agreement of the BRP.

The FCR requires symmetrical products that limits the participation of small-scale DR aggregation. In addition, the measurement process is economically challenging as the aggregators are required to share the measurement data within 4 seconds resolution increasing the operational costs as each unit must be installed with a metering system (TenneT,2018). Considering these limitations is still regarded as a great potential for independent aggregators to participate as there is no requirement for the compensation of the activated energy. However, in March 2017, independent aggregators are given access to the FCR after TenneT completed a pilot without prior agreement with the

BRP/Supplier (TenneT, 2018.b). This led to massive changes implemented in 2018 targeting the regulatory but mostly importantly in the technical requirements. In fact, marginal price to settlement the TSO-BSP imbalances was applied. The frequency of procurement increased from weekly to daily all-day procurement widening the participation of small-scale demand response.

Although the minimum bid seems attractive for DR participation, aggregators face a challenge as symmetrical products are required to participate in the aFRR (TenneT, 2018.c). Separation between the down-ward and up-ward regulation should be closely considered by TenneT. Similar to the FCR, the aFRR is subject to strict real-time data measurement. In this product, the lead time defined as the period between the bidding and the activation process is a real technical barrier. In fact, participants are given one hour corresponding to 4-7 imbalance settlement periods (Lampropoulos, et al., 2018). This is considered as a long period to effectively enable the participation of demand response aggregators. The same requirements apply to the mFRRsa (Faria & Vale, 2018). The length of the contracts is relatively seen as technical barrier in this thesis. In fact, long contract might be considered in case of integrating intermittent resources due to the weather independency. However, it is worth mentioning that the aFRR contracts duration are quarterly/ annual highlighting the potential of third-parties aggregators participation.

TenneT proposes the mFRR schedule activated the mFRR directly activated that both enable the participation of DR aggregators. With the undergoing changes, TenneT up-dated certain technical requirements in its balancing markets allowing for instance short bidding periods as in the mFRR. In fact, the bid period time moved from 5 minutes to 1 minutes. However non-transparency issues raised many questions regarding the DR aggregation. In fact, TenneT might activate the bids from the merit order in the mFRRsa, and directly activate the mFRRda to solve the imbalances. Since the market participants are compensated with utilization only, it is not economically profitable for them as the capacity payment are not applicable. The mFRRda offers DR aggregators to provide separate up or down regulatory bids and as the mFFRsa offers energy payment. However, at the moment, small scale aggregators are not able to enter the mFRRda as the minimum bid to participate is over-sized and requires at least 20MW.In addition, the providers are to fulfill 97-100% availability. According to TenneT, aggregation offered in mFRRda in large scale as it offers competition. However, for small units, measurement is technically a burden. Pooled resources must consult with the BRP provide TenneT with real time measurement on a five minutes metered kWh resolution, and applicable for each resource. Thus, aggregated measurements are not allowed. Although demand response aggregators are allowed in the two mFRR products, market barriers are to be considered. As a matter of fact, TenneT activates the mFRRda as a further supporting balancing tool to the FCR and aFRR. However, the reserve is not available in merit order in each imbalance settlement period for the balancing service providers as applied in the aFRR reducing the transparency of TenneT toward participants. In addition, the TSO, could in some circumstances active directly the mFRRda by-passing the mFRRsa. This possibility reduces the economic value of the aggregators as they receive only energy payment for their participation (Lampropoulo, 2016).

In terms of frequency of activations, the FCR is continuously activated, and the aFRR is triggered several times per day slowing the participation of small-scale DR aggregators. Both mFRRsa and mFRRda are activated depending on the need. In 2017, the mFRRsa was activated 27 times. At the opposite, the frequency of activation of the incident reserve increased starting 2016 reaching to 40-50 times per year. However, the participants are limited by the progressive reduction from 50 k€/MW/year to 10k€/MW/year of the capacity payment over the years (Lampropoulo, 2016).

The penalties are often a burden for independent aggregators as they are by contract obliged to meet the availability and delivery requirements. In the Netherlands, aggregators failing to meet the availability in the FCR are subject to a penalty based on pro-rata system. The BSP is mandated to reimburse the payment in case of non-response or insufficient delivery. To encourage BSP to fulfill their availability obligation, TenneT is discussing a possibility to further strengthen its penalties. However, on a general basis, the penalties are regarded as fair. In fact, in the mFRRda, the service providers are not subject to financial penalties on every delivery period.

Table 8. Technical and market requirements for DR aggregation in the Dutch balancing market.

Requirement	FCR	aFRR	mFRRda	mFRRsa
DR indepedant aggregator access	Yes	No	No	No
Minimum bid MW	1	1	20	1
Procurement	Daily	Monthly and weekly	quarter and monthly basis	1 or 2 ISPs before the submissions of the bids
Activation time	30 sec	7% per minute ramp-up speed, 15 minutes	10-15 min	Activation at least one supply period of ISP. 15 minutes
Frequency of activation	Continous	Several times per day	NA	27 in 2017
Delivery duration	4 hours	1 hour	NA	1 hour
Product symmetry	Yes	Yes	Separate Up-and Down	Separate Up-and Down
Capacity payment	Availability payment	Availability payment	No	No
Energy payment	NO	Marginal price	Marginal price	Marginal Price

7.2.3. Relevant Dutch pilots

Prior to the pilot, the Dutch FCR was provided 30% by the connected generators to the TSO (TenneT, 2020). In other words, its provision was mandatory for large generators and thus small-scale aggregator of renewable energy resources or demand response were unable to enter the market. To test a potential flexibility in the FCR, TenneT implemented a pilot enabling DES balancing service provider to participate in 2017 (TenneT, 2018.b). The pilot involved the participation of five players including ENGIE acting as an independent aggregator.

According to the FCR pilot report published by TenneT, the main purpose of this pilot is to elevate the technical and regulatory barriers as well increasing the number of participants. Due to the current technical complexity in the FCR, the TSO modified the requirements. In fact, the market players were allowed to participate with a minimum bid size of 100kW rather than 1 MW, and were qualified to participate directly in the delivery period. The bids were rewarded differently than the normal operation process. The participants were allocated average process and the non-conformities were not subject to penalties. After assessment of the pilot results, TenneT concluded that the participants were able to provide enough capacity in the FCR. However, the main barriers included the product specification and the measurement requirements.

The testing resulted in major changes in the current FCR requirements. In fact, TenneT modified the pre-qualification measures and requested measurements such as the sampling rate of power as well as the frequency measurements. TenneT noted that the reduction of the minimum bid was a real enabler in the pilot. However, the TSO decided not to change this technical requirement, because it could experience cost losses if FCR accepts lower bids. It highlighted that DR aggregators could struggle economically wise if participating in the FCR. However, TenneT underlined the importance to priorities lowering the bid period from one week to 4 hours to enable demand response aggregators. In fact, long lead times in the balancing markets are one of the technical requirements that burdens DR integration.

7.3. United Kingdom

7.3.1. Overview of the British balancing market

To understand well the balancing services in the UK, it is important to differentiate between the services and mechanisms proposed by the national TSO. The balancing mechanisms in the UK were introduced in 2001 by the regulator and the government and are used to trade balancing market in real-time every half operating hour (Elexon, n.d.). The Balancing Mechanism code describes and guides the balancing services. The generating units providing in the balancing services are connected to the national grid and provides bids or offers are referred to as balancing mechanism units and non-balancing mechanism units. The Balancing mechanism Units are all the participants including generators, or DER participants and are connected to the National Grid and metered following the Balancing code in the UK (Elexon.a, n.d.). The Non-Balancing Mechanism Units are utilities or units that provide balancing services but are not registered as balancing mechanisms. The difference resides in the process of the Balancing Mechanisms. If a unit is registered the TSO has the right to change in the timescales, and the TSO can use the bids immediately at the opposite of non-registered units. In this context, balancing mechanisms are an organizational tool used to manage the balancing services in the UK. The balancing markets in the UK are structured broadly as presented in the figure. This thesis focuses mainly on the Reserve and Frequency Response Service.

Table 9. National Grid reserve market terminology and its ENTSO-E equivalent.

ENTSO-E terminology	National Grid terminology
FCR	Firm Frequency Response FRR
	Enhanced Frequency Response
Frequency Restoration Reserve	Fast Reserve FR equivalent to aFRR
Replacement Reserve	Short Term Operating Reserve STOR
	Supplemental Balancing Reserve SBR
	Demand-Side Balancing Reserve DSBR
	Demand Turn-up Reserve
	TERRE

In the UK, the payment used in the balancing markets slightly differ from the other cited countries. In addition to the capacity and energy payment, the TSO attributes other payments explained in the table below according to the National Grid:

Table 10. Payment methods available in the UK balancing market.

Payment	Definition	Market place use
Utilization fee	The BSP is compensated for its energy delivered up- and down (£/MWhr)	STOR. Fast Reserve, EFR, DTU. Replacement Reserve
Availability fee	The BSP is compensated for its availability for the reserve provided within the availability window. It is expressed in £/MW/hr basis.	STOR, Fast Reserve, DTU. Primary, secondary, high frequency responses.
Nomination fee	Fee attributed to BSP for responding to the call to provide the service within the nomination window (£/hour)	FFR, Fast Reserve
Window fee	Fee attributed for each BSP nominated for the window ((£/window)	FFR

The British TSO, National Grid ESO, is responsible for ensuring the balance between the supply and demand continuously. The National Grid expressed its motivation to transition its electricity market toward sustainability. In fact, the share of renewable energy resources constituted 29,2% of the national electricity generation in 2017 (Gov.uk, 2019). With a high penetration of wind power, this share increased significantly by 11% between 2017 and 2018. To support its transition, the TSO published a framework to integrate demand response in its electricity system encouraging I&C stakeholders and small-scale customers to participate in the balancing markets. In addition, the Office of Gas and Electricity Markets, Ofgem, highlighted that up to £4,7 billion of financial benefits could be realized in 2030 through the increase of flexibility pointing out demand side response including DR aggregation (Ofgem, 2019). In its report, Ofgem emphasized on the role of independent aggregators securing the system balance. In 2016, these market players offered 76% of the total volume of demand response in the Capacity Market auction accounted for 1,4GW. According to Ofgem, the access of DR independent aggregators depends on three level. The access, measurement, pricing, and balancing responsibility levels. In parallel to the motivations of Ofgem, National Grid modified its balancing and settlement code in 2018, recognized virtual power plants as DR independent aggregators (van Rensburg, 2019). ELEXON plays a major role in the balancing services as it regulates the Balancing and Settlement Code in the UK, including the assessment and determination of participation routes of the balancing providers. One of the key responsibilities consist of taking part of the imbalance settlement. ELEXON monitors the production and the consumption of the generators and the suppliers, and their technical and market compliance it oversees the smart meter rollout expected by 2020.

In the UK, the balancing services are composed of Frequency Services, and Reserve Services. The system operator continuously monitors the frequency nominal value, and uses the frequency reserves to maintain its stability. With the forecasted data on the volumes, and generation taking into account the grid faults, the TSO procures from different providers including DSR frequency services. These services are categorized as dynamic frequency responses that are continuously provided and used for normal operations, and non-dynamic frequency responses activated for large disturbances. These services are equivalent respectively to the FCR-N, and FCR-D in the Finnish reserves market. On the other hand, the reserve service is used in case of sudden changes in the demand or lack of generation for instance. The National Grid procures further generation or requires a demand reduction to respond to the changes.

Reserves Services:

The main purpose of this thesis is the balancing products offering access to DR participation. In addition to the reserves illustrated in the figure, Super SEL is part of the reserve’s services. However, DR aggregation is not allowed, thus this product will be excluded from the analysis.

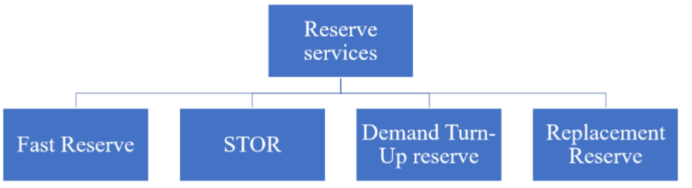

Figure 31. Types of reserve services.

Fast Reserve:

According to the National Grid´s Fast Reserve manual of instruction (National Grid, n.d.), the reserve is automatically activated and fulfills the role according to the ENTSO-E codes of the aFRR. In the UK, the Fast Reserve is used as a fast response reserve providing an increase of generation or decrease in the consumption. The participants in the Fast Reserve can provide either Firm Service or Optional reservices. Both participants require meeting the same technical requirements. To access the Fast Reserve, balancing service providers should supply at least 25 MW at a speed of delivery greater or equal to 25 MW per minutes and sustain it for at least 15 minutes. They are remunerated in three different payment methods including the availability, nomination, and utilization fees.

Replacement Reserve:

The Replacement Reserve was introduced in 2019 as joint platform between participating EU countries and UK to share balancing services. The TERRE complies with the technical and regulatory requirements set by EBGL and activated by the central European Platform Libra (Elexon.b, n.d.). As part of the European directives concerning the Electricity Balancing Guidelines, the UK has set up the Replacement Reserve and can be used for exchanging balancing products within the participating TSOs.

The Replacement Reserve has seen consequent changes as its access has been widen to nontraditional participants including aggregators following TERRE platform. The Connection Use and System Code defines the contractual connecting the participants to the TSO including the procurement of the balancing services. In this code, the participants considered in the Replacement Reserve are Generator, Supplier or aggregators acting as virtual lead parties. In the UK, the participation in the Replacement Reserve is mainly through the TERRE Platform. The procurement of the RR is conducted through auctions on an hourly basis, and the participation remains optional. The participants are offered two routes to participate in the RR. They can either register as Primary Balancing Mechanism Unit or Secondary Balancing Mechanism Unit according to the System Operator guidelines.

The participants in the Restoration Reserve are directly paid by Alexon for the volume of energy delivered in addition to the imbalance volume. Upon the submission of the bids by the participation, the national TSO National Grid assess the requirements after the gate closure and ensures that no congestion of the transmission lines. The specific requirements of the RR are presented in the table 12.

Demand Turn-Up:

The demand turn-up reserve concerns mainly large generator such as CHP generators willing to increase or decrease their demand alongside with the renewable energy generation in the UK to maintain a balance in the system. The National Grid Operator registered the need mainly in the night or during the summer afternoons. The TSO encourages the following participants or technologies to take part of the reserves. To participate in the DTU, the participants are required to provide a minimum bid of at least 1 MW, with a possibility for aggregators to participate if the minimum site aggregation is at least 0, 1MW.The participants are required to have a metering system and provide the TSO with half hourly or each minute metering. As the reserve balances the renewable energy generation in the UK, the availability is dependents of various factor including the weather. For that reason, demand turn up reserve grants a certain flexibility to the providers. In fact, they are requested to communicate their delivery capabilities e.g. for how long in a single instruction (National Grid.a, n.d.).

From 2017 to 2018, the duration of the demand turn-up deliveries fluctuated from 3 hours 34 minutes to 4 hours 36 minutes respectively. As applicable for the duration of the delivery, the speed of the delivery of the provider is assessed case by case as the delivery of CHP generators would be faster than an aggregator for instance. In the demand turn-up reserve, the participants are requested to submit their MW availability for the reserve. Therefore, no obligation to participate in every availability window. The participants are compensated by availability and utilization payments. The procurement of the Demand Turn-up is in addition under the influence of the economic efficiency. For instance, if alternative solutions are financially more suitable for the TSO such as the activation of super SEL reserves. As a matter of fact, in 2017, 87 MW were available for demand turn-up. However, 4 % of the overall DTU services were utilized due to competitive prices of other services, but also due to the non-expected variance in the demand profiles during summer 2017 (ESO, 2019).

Short Operation Term Reserve STOR:

The short-term operating reserve is activated when balancing between the supply and the demand during the day is needed due to inaccuracy of the forecasts for instance. The National Grid Operator might procure additional generation or request reduction in the demand from balancing mechanism including aggregation or other providers. The TSO highlighted its preference for South East England and Wales providers as they are located closely to high demand areas. As such, STOR participants are able to provide up and down regulating bids during the availability windows including the morning and the evening peak. To participate in the STOR, the BSP including DR independent aggregators are required to provide at least 3MW, and response 20-240 minutes after motivation and sustain an availability for 2 hours (National Grid.b, n.d.). STOR offers a certain participation flexibility to BSP as they can provide other balancing markets at the same time if they fulfill their agreement with the TSO.The TSO procures the STOR in a competitive tender ahead of time and on an average of three times per year. The balance service providers are compensated with availability payment for their capacity provided during the availability windows. The availability payment is stated in the contract agreed with the TSO. After activation of the STOR, the balance service providers are in addition paid by a pre-defined utilization price. Each year, the TSO aims to procure on average 1800-2300 MW of STOR (National Grid.c, n.d.). The balance service providers are instructed following the balancing mechanism code, and the remaining provided are guided and metered following the STOR Dispatch code.

Frequency response services:

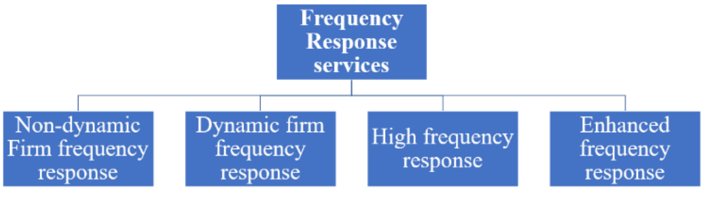

Figure 32. Types of frequency response services.

The Firm Frequency Response is dedicated to hedge consequent frequency deviations related for example to sudden power plant shut downs. According the National Grid product description (National Grid.d, n.d.) , the TSO tenders' bids on a monthly basis. Two physical products are given access to participate in the FRR, the static and dynamic frequency response, and their activation depends on the frequency deviations defined in the Framework Agreement. The static physical products referred to them as non-dynamic products are used for normal operations and to manage the changes of the frequency measured seconds by seconds. On the opposite, the dynamic frequency response as its name suggests is activated continuously to restore the frequency deviation included in the range 50Hz ±0.015Hz. Balancing mechanisms participants are able to participate in the FRR services, and aggregated loads from demand side response if meeting the 1 MW technical requirements have the possibility to participate. According to the National Grid, the providers of FRR are able to contribute in other balancing markets when not participating in the FRR. The participation in the Firm frequency reserve is remunerated by four types of payments methods including the availability payment for the capacity procured, response energy fee for the real-time energy provided by the nominated BSP, nomination, and window initiation fees. The procurement of the FRR depends largely on the wing generations, and demand forecasts. The largest requirements remain the secondary response (National Grid, 2017).

The Enhanced Frequency Reserve in the UK is the equivalent of the Frequency Containment Reserve. In fact, it is the first procurement made in case of frequency deviation. The National Grid stated that the European regulation for the harmonization of the balancing markets would not affect the technical and regulatory requirements of the Enhanced Frequency Reserve. To participate in the EFR, balancing service providers are required to submit at least 1MW symmetrical bids consisting of low and high frequency services, and each bid to fulfill the same duration of delivery set to a minimum of 15 minutes. The BSP are compensated for their availability only expressed in £/MW (National Grid, 2016).

7.3.2. Status of demand response in the UK

The role of demand response in UK is significant in the future. The EU Large Combustion Plants Directive (2001/80/EC) related to closing the coal power plants and the reduction of greenhouse gas emissions. Currently, the UK is driven by the urge to decrease its dependency on coal by reducing its contribution in electricity generation from 40% in 2012 to 3% currently (Gov.uk, 2020). In this context, the integration of demand response in the balancing market has been highly promoted (ESO, 2018). In 2016, the National Grid claimed that 6% of its ancillary reserves was procured via demand side resources including demand response. In the same year, 6,7% if the contracted STOR and 5% of the FRR were through DSR. By the end of May 2018, National Grid stated that 30% of their ancillary services were attained through demand side response. This share is expected to increase in 2020 reaching 50% (ESO, 2018).

Table 11. DSM volumes participation in the UK balancing services 2016-2017 (National Grid.e, n.d.)

Balancing Service product	Volume in 2016 MW	Volume in 2017 MW
Frequency response	374	617
Short Term Reserve	1745	1369
DSBR	515	0
Fast Reserve	0	300
Total	2634	2286

In the UK, the participation of the demand response also though aggregation is possible in the balancing markets mainly in order to balance the supply and the demand. The authorized participants in the UK can be communities, aggregators, or Energy Service Companies. In the United Kingdom, the balancing markets were dominated by the back-up power plants.
In the UK participants such as aggregators, large industrials including commercial profiles, as well as small to medium enterprises are given access to provide a demand-side response in the ancillary market (ESO, 2018). Various examples support this advancement (National Grid.f, n.d.). For instance, the Colchester Hospital University with the collaboration of the aggregator KiWi Power. By integrated demand response with the help of the metering system. The facility has an excess of 2MW by the capacity of their own generator that could be injected in the National Grid to balance the system. This is possible mainly because of the high availability of their generators and fast response time. The advantage is the availability of payment as compensation (National Grid.g, n.d.).
The Short-term operating reserve has been considered as the potential market for demand response in the UK in 2015 (Curtis, 2015). In fact, it is used in the UK to provide the National Grid with secure power when the demand and the generation are not matching the forecasts. As demonstrated in the table, the STOR consists of the biggest market for providing demand response. It is considered as a sort of reserve that offers balance when the demand is higher than the schedule and hedge the lack of generation. The technical requirements to participate to STOR simplify the access to demand response including the low minimum bid to participate (3MW), and the response time (20 min). The demand response procured in the STOR is partially composed of load reduction estimated 150-250 MW and partially as load replacement.

The flexibility of the UK balancing services drove the creation of the Firm Frequency Response bridging to encourage small providers to participate in the FRR by constituting a portfolio of 10MW starting with 1MW. This option allows contracting terms of maximum of 2 years (National Grid.e, n.d.). The situation has evolved since then, and the demand response has now full access to the capacity markets. Implicit demand response in the UK includes Triad payments (Ofgem, 2016). These types of payments consist of charging customers that consumed electricity within the three half hours during the settlement period characterized with peak demand (National Grid, 2015). This period is identified between November and February. The triads payment is considered as the major implicit demand response enabler in the country. Along with balancing services, ToU tariffs have a high potential in the UK. In research conducted to measure the benefits of the time of use tariffs, 30% of the survey participants showed a willingness to switch to static ToU tariffs (Nicolson, et al., 2018). However, dynamic tariffs remain more suitable when variable DER generation is integrated.

Explicit demand response in UK has seen changes in 2017. In fact, the Ofgem decided to close the use of the Supplemental Balancing Reserve and the Demand Side Balancing Reserve introduced in 2013 a balancing services option (Copley, 2017). As the capacity contracted for 2017-2018 was 54.43 GW, the reserves in question were no longer needed for cost efficiency matters. The Demand Side Balancing Reserve was open mainly for large providers equipped with a metering system and willing to decrease their demand to support the National Grid balancing services during the winter period (Bingham & Preston, 2015). Based on this, the demand response market decreases as the Demand Side Balancing reserves constituted 20% of the DSR volumes procured in 2015. In addition, it offered aggregator a great opportunity to participate as the reserve allowed industrials to have their demand capacity aggregated by a third-party. The technical requirements were partially in favor of aggregator parties as the minimum bid required was set to 1MW, and small sites aggregation was encouraged. However, the half hourly metering system required the unites to install smart meters accordingly which consists a relatively technical and economic burden.

The tradition reading in the UK consisted of one energy reading by 3 months conducted by inspectors (ESMA,2008). According to the UK government report for the Q3 2019, 8 million smart meters were accounted compared to 17.7 non-smart meters in September 2019 which increased by 4,1 compared to 2018. In addition, 28% of the residential buildings are equipped with a smart meter. On the contrast, on the large supplier side, there is a decrease by 6,4% compared to the previous quarter and 748,700 million smart and advanced meters were installed by energy suppliers (Beis.gov,uk, 2019).

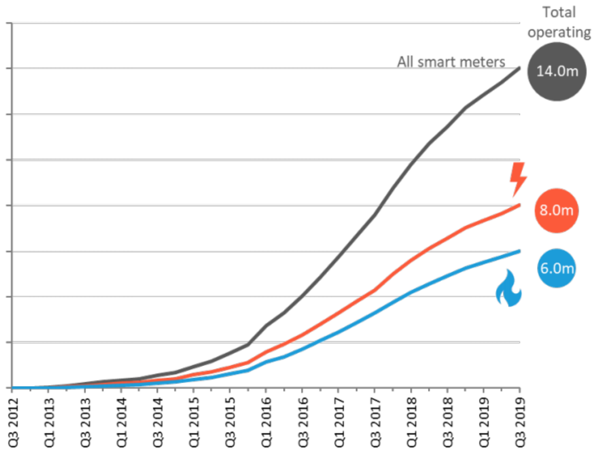

Figure 33. Evolution of the smart meter's installation at the residential level (Beis.gov,uk, 2019).

7.3.3. Independent aggregators as market players

In the UK, the status of independent aggregators is regulated and referred as Virtual Lead Parties or Balancing Service Providers prosing assets to the balancing market. The creation of the VLP results from the grid changes National Grid applied to support the project TERRE exchanging balancing services in the Replacement Reserve in order to comply with the European balancing legislations (Elexon.b, n.d.). Thus, the Replacement Reserve remains currently the adequate market place for independent aggregators in the UK. The market participants can provide energy balancing services close to real time, less than one hour prior to the delivery. To participate, the BSP are required to provide at least 1MW, and meet the delivery period of 15 minutes. The activation time is set to 30 minutes. For their energy delivered, the participants are remunerated through a pay as cleared method or so-called marginal price.

Table 12. TERRE Replacement Reserve platform exchange technical and market requirements (ENTSO-E, 2018.a).

Product characteristics	**TERRE/ RR product specifications**
Minimum bid size MW	1
Full activation time	30 minutes
Delivery period	15-60 minutes
Product resolution	15 minutes
Product symmetry	Yes
Energy payment	Utilization payment/ marginal price
Capacity payment	NO

The aggregators in the UK are able to access two types of balancing services including the frequency response services and the reserve services (ESO, 2018).

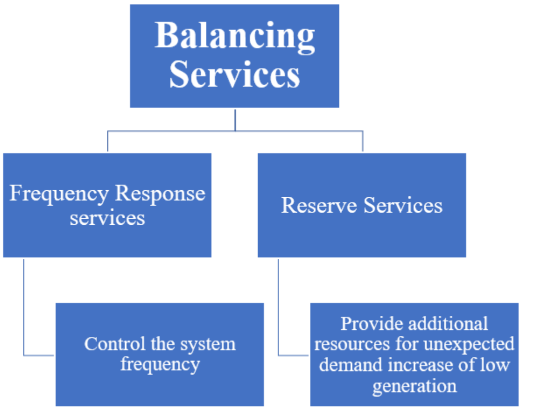

Figure 34. Balancing markets categorization in the UK.

To access to the balancing markets, the aggregators are required to have a bilateral contract with the supplier. The participation of independent aggregators is greatly debatable as it results in imbalances in the supplier/BRP portfolio caused by the activation of demand response. For the purpose of selling the load management in the balancing services, the market participants are able to aggregate from the customer in all the country. At the moment, the TERRE platform is the only enabler of independent aggregator in the UK.The Firm Frequency Response is an open balancing market to the demand response aggregators. It has seen changes since the minimum requirements decreased from 10 MW to 1MW to comply to the ENTSO harmonization of the balancing markets. As defined by the National Grid, the FRR offers the possibility for BSP to provide services that are not accessible in other markets mainly due to the high minimum bid sizes. The FRR offers a certain flexibility to the BSP as they are able to provide other balancing products in addition to the FRR. However, the lead times are a burden. In the technical requirements set by the TSO, the participants are required to provide tenders for at least 2 recommended hours. Independent aggregators are less likely to be able to provide tenders for long and consecutive hours compared to generating units.

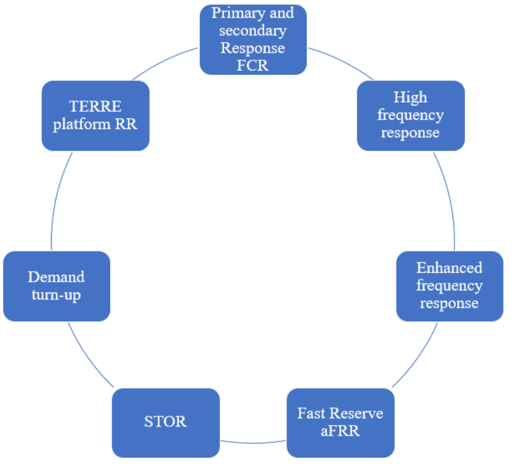

Figure 35. Balancing market products allowing DR aggregation in the UK.

STOR has been considered as the ideal market place for demand response aggregator to participate. National Grid expended the STOR by creating two sub products including the STOR Premium Flexible and the STOR runway to provide DR aggregator a better market position. At the present, STOR is attracting less the aggregators mainly due to the lead times. In fact, the availability window was 11-13 hours per day. It is clear that demand response resources could not be sustained for long lead times. To participate in the STOR, the market participants are to provide a minimum bid of 3 MW limiting automatically the participation of small-scale DR aggregation. Offering many advantages such as a short delivery duration of 2 hours, and non-symmetrical products as only up-ward regulatory bids are accepted, the STOR could ideally be adequate for VLP (equivalent to the VPP) participation. As a matter of fact, the pre-qualification process is done at the aggregated level, and the providers are remunerated of their utilization and availability. Although STOR presents advantages toward DR aggregation, its average availability and utilization payment prices dropped in 2018 compared to 2017. In fact, the average availability payment in 2017 was estimated to £2.14/MW/h compared to £1.04/MW/h. In parallel, the average utilization payment decreased from £87.91/MW/h to £76/MW/h in 2018 (ESO, 2018). Following the explanations of the TSO, this sudden price drop resulted from an increase in market participants leading to highly competitive prices.

In 2013, the Fast Reserve was opened to demand side resources including demand response aggregators. In the UK electricity market code, the participants are referred to as non-Balancing mechanism providers. This initiative enables the Fast Reserve to be open to competition and increase the number of participants as its need is continuous and is activated on average to 10 times per day. In 2018, the National Grid observed a lower participation of demand side flexibility sources estimated at 3 providers only highlighting the high bid size threshold set initially at 50MW (ESO, 2018). According to the same report, the TSO enabled a wider access for demand response sources by decreasing the minimum bid to 25 MW in 2019.

The Enhanced frequency Reserve limits the participation of demand response specifically through independent aggregators as the technical requirements remain strict. In fact, the providers are required to remain 95% available during the 4 years contract term as the reserve is continuously needed and activated (National Grid, 2016). In addition, the TSO highlighted a preference for large scale sizes such as 50 MW that could be aggregated blocks although the minimum bid size remains 1 MW. In addition to that, the measurements methods are technically a burden. The metering data should be recorded and sent to the TSO every second. Thus, the qualification of independent aggregators in such service remain uncertain.

The demand turn-up encourages demand side resources including demand response through aggregation to participate by offering down regulation bids. The demand Turn-Up offers an optional participation window in case the aggregators fail to meet the availability or delivery requirements in the fixed window which can be seen as a real advantage. In addition, the pre-qualifications and measurements methods are fair and accessible. The DTU offers small scale DR aggregators to participate in the reserve balancing markets by low and achievable requirements. In 2018, 39 MW of load management were accepted by the TSO from 3 participating units (ESO, 2018). In addition, the average utilization and availability remained relatively stable between 2017 and 2018. The National grid noted a slight increase in the average unit sizes participating reaching 7.7 MW in 2018. Considering the benefits of the DTU, the participation of independent aggregators it is not economically efficient as the compensation is based on availability and utilization payments. In fact, the number of utilizations of the Demand Turn-Up decreased significantly from 2016 to 2018 as it has been activated respectively 323 times to 41. This is mainly due to the lack of number of providers as 11 BSP participated in the demand turn up against 5 in 2018. In 2019, the demand turns up was not procured by the National grid due to the availability of lower price balancing alternatives (National Grid.a, n.d.).

One main enabler for independent aggregators in the UK consists of the diverse payment methods in addition to the utilization and availability payments. As an example, the participants in the Firm Frequency Reserve equivaling to the FCR are given window initiation fee, and nomination prices encouraging the participation.

With the development of the balancing markets in the UK, Ofgem has discussed in several reports the benefits of independent aggregators supporting the call for a smart and flexible energy system. In 2016, demand response has been considered as not fully exploited in the balancing markets. In a survey conducted by Ofgem in 2016, market players including DR aggregators noted that the roles of the parties as well as the incentives provided lack of structure. The survey indicated that 74% of the respondents prefer to be compensated via utilization payment instead of availability payment as the demand side resources are not frequently called highlighting the lack of economic benefits for independent aggregators (Ofgem, 2017). This is strongly related to the fact that aggregators, are enabled to participate in some instances to various balancing markets.

- Complex routes to participate in the balancing markets
- Wide range of balancing products
- Lack of energy payment and strict measurement and verification tests.

In addition to the technical requirements, Ofgem emphasized on the importance of measuring the aggregated demand response. In fact, under the instruction of an aggregator, the prosumer can change its consumption to a lower or higher level. Thus, it is challenging to differentiate between the change in the demand of a customer under normal operations and change in demand under the aggregator agreement. In addition, a cost reflective pricing is necessary to the establishment of DR aggregation in the UK. In other words, the compensation challenge of the supplier must be solved.

Table 13. Technical and market requirements of DR aggregation in the UK balancing market.

Requirement	Primary response	Secondary response	STOR	Fast Reserve	Demand Turn Up	Enhanced Frequency Response
Independant DR aggregator access	Yes					
Minimum bid MW	1		3	25	1	1
Procurement	Monthly		3 three tenders in the year	Tendering on a monthly basis	Tender process 3 times per year.	Sporadic
Activation time	5% in 2s,100% in 10 s	30s	4-20min	2 min	6 hours 6 min on 2018	1s
Delivery duration	20s	30 min	least 2 h	least 15 minutes	2018 was 4 h 26 minutes	At least 15min
Product symmetry	NO		Up	Up	Down	Yes
Capacity payment	Availability fee		Availability payment £/MW/h	Availability payment £/MW/h	Availability payment £/MW/h	Availability payment £/MW/h
Energy payment	Response energy fee for non-BM providers only £/MWh		Utilization payment £/MWh basis	Utilization payment £/MWh basis	Utilization payment £/MWh basis	No
Other payment	-Window initiation fee £/window - Nomination fee (£/hr) -Availability fee Paid per hour (£/hr)		Optional payment	Nomination, positional fee £/hour	No	No

7.3.4. Relevant pilots in the UK

Demand response aggregation have captivated the interest of various companies in the UK. Prior to the change in change in the balancing market regulation in 2019, demand response aggregators participated in the British ancillary markets upon an agreement with the customer´s suppliers. Flexitricity is one of the leaders in the UK managing flexibility portfolios of its customers and trading it balancing reserves including the Frequency Response, and STOR. In 2012, the company involved with the Royal United Hospital managing the consumption of two standby diesel generators to provide mainly the ancillary service STOR, and the program of reduction of triad charges referred to as triad management. The load management project resulted in a capacity of 1.2 MW, and revenues estimated at £40,000MW (Flexitricity, 2012).Within its case studies, Flexitricity participated in 2015 in managing the load of Norish, a cold storage warehouse and logistics business providing the

STOR with a capacity of 0,9 MW. The project consisted of reducing the electricity consumption initially set at 21 GWh per year by shutting down the cooling plant for short durations (Flexitricity, 2015).

Limejump, is a leading Virtual Power Platform company in the UK offering aggregated flexibility resources in the ancillary services. It is considered as the first DSM VPP in the UK offering its services in the balancing market. In fact, the National Grid permitted Limejump to be the first aggregated balancing unit to access both reserves market and balancing mechanisms proving services in parallel with conventional generating units (Davies, 2018). The company targeted the Frequency Response including both static and dynamic responses as an ideal reserve market place trading flexibility from energy storage and aggregated demand side response. In 2020, Limejump included in its flexibility portfolio the 20 MW gas-fired power plant implemented by Ylem Energy while providing remote dispatch services (Limejump, 2020).

7.4 Iberian countries

7.4.1 Structure of Iberian balancing market

The Spanish balancing market is part of the Iberian Electricity Market MIBEL joining Portugal and Spain. REE accounts four types of reserves: The primary, secondary, and tertiary regulation as well as a slow reserve. However, the participation in the primary reserve is obligatory and is not subject to any remuneration. Thus, the primary reserve is not part of the ancillary markets. REE defines the reserves part of the balancing markets as system services used to adjust. In May 2012, the balancing markets include an additional up-ward reserve in which participants are remunerated through balancing mechanisms for their up-ward regulating bids (SEDC,2017). In all reserves, the aggregation is not allowed. This means that the participants are obliged to submit separate bids in the Spanish balancing markets. The participation in the Spanish balancing markets requires a pre-qualification and verifications tests that excludes aggregated DR. In March 2019, the Up-ward balancing energy procured by the TSO was estimated to 299 GWh, and the down-ward energy balancing was -311 GWh (REE,2020).

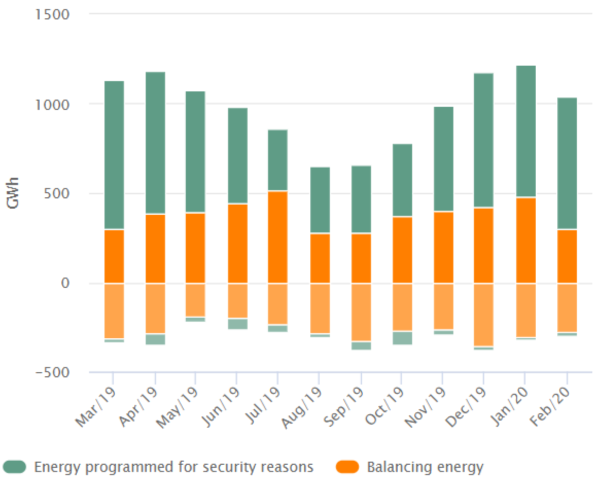

Figure 36. Balancing energy procured by REE in 2019-2020 (REE,2020)

In Spain, the Balance Responsible Party plays a major role in the imbalance settlement. In the context of this thesis, aggregation is allowed in the day-ahead and intra-days markets. However, by obligation from the TSO, the BRP should send disaggregated energy portfolios of the units under their control. For instance, a generation units of wind power can have various installation but should be under the responsibility of one BRP. In Spain a BRP can be generation units, retailers, or third-party BRP representing the generating or consuming units. By definition, the imbalance settlement allocates the costs of the BRPs imbalances schedules. In Spain, the imbalance settlement is conducted for each BRP portfolio and for each hourly settlement period

Table 14. REE reserve terminology

Reserve terminology REE	**ENTSO-E equivalent**
Balancing energy from Replacement Reserve, Slow Reserve	Energies of the current deviation management services
Frequency Containment Reserve FCR	Primary Reserve
automatic Frequency Recovery Reserve aFRR	Secondary Reserve
Manual Frequency Recovery Reserve mFRR	Tertiary Reserve

Part of its primary function, REE closely supervises the real-time generation including from wind power, and the consumption after the closure of the intra-day market. During the imbalance monitoring phase, the TSO accounts the traded volumes in both intra-day and day-ahead markets with the unmet volumes of the generators. Balancing markets including the reserves act in case the imbalances are higher than 300MWh.

Table 15. Reserves procurement data in Spain 2019 (REE,2020):

Market Place	**Reserve**	**Product symmetry**	**Regulating energy GWh 2019**	**Regulating capacity 2019**
Balancing capacity and energy markets	Secondary reserve	Up-ward	971	594 MW
		Down-ward	-1,679	-497 MW
Balancing energy market	Tertiary Reserve	Up-ward	696.9	-
		Down-ward	-1,356.5	-
Balancing capacity market	Additional Up-ward reserve	Up-ward	-	1,433 GW
Balancing energy market	Deviation management Reserve	Up-ward	2,225	-
		Down-ward	-866	-

The participation in the primary reserve is not compensated by the TSO, driving a mandatory participation for the generator. In fact, generator connected directly to the transmission network of the REE. The primary reserve is activated depending on the change in the frequency. The primary reserve is automatically activated within 30 seconds for a maximum duration of 30 seconds. In this thesis, the primary reserve is not considered among the balancing markets in Spain due to its design structure. In Spain, the procurement procedure is based on the production availability of the plants. Therefore, it is not subject to a competitive nor balancing mechanism procurement. In addition, the primary reserve is not considered during the imbalance settlement (Fernandes, et al., 2016). To ensure a continuous provision of the primary reserve, REE applies inspections randomly to the generators verifying their compliance with the technical requirements. In fact, generators are required to provided 1.5% of the nominal capacity.

The participation in the secondary reserve remains optional for generators and other market players. As a TSO, REE uses the secondary reserve as active balancing service to correct automatically the frequency deviations specifically to the power exchange schedule of the Control Block. The secondary reserve or the aFRR is supplied mainly by large generators. The provision of the secondary reserve is conducted through auction one day prior to the delivery D-1 in normal situations. However, REE might consider procuring capacity in real time if expectancies are perceived. Both up and down regulatory bids called in Spain regulation bands are accepted but procured separately. The secondary reserves are activated 20 seconds to 15 minutes which is its maximum duration. Participants are compensated for their capacity and energy via availability and energy price. The price is formulated in €/MW, and the energy price is not taken into account.

The secondary reserve in Spain encompasses various technical barriers for the integration of decentralized energy resources. The project TEWNTIES tested the integration of a large scale VPP that supply the ancillary markets with load control of wind farm generations and industrial consumption (Red Eléctrica de España, et al., 2013).The participation in the secondary reserve requires a bid of at least 10 MW. Furthermore, the total up and down regulations capacities must be proportionate to the total of both symmetrical capacities required by the TSO on hourly basis, making the access for DR very complex. This limitation is related to the natural intermittence characteristics of the renewable generation. For a small generating RES unit, the provision of upward capacity in the secondary reserve would require a generation below the potential availability of the renewable resource. The provision structure of the secondary reserve is designed as such each generating unit complying with the technical requirements is assigned one Balance Responsible Party. In consideration of the foregoing, aggregators from different BRP balances would be forbidden.

Penalties in the secondary reserves are applicable to all market participants. In fact, if not meeting the contracted regulatory capacity. Providers are subject to a penalty of 50% the cost of the secondary reserve market price for each MW non submitted. Since each regulatory zone capacity should equal currently to at least 300 MW, REE attributes penalties to the areas not fulfilling the threshold up to 150% of the capacity marginal price (REE, 2019). Providers that repetitively fail to provide the contracted capacity in the secondary reserve face harsher penalties as they could be revoked to participate in the future.

The tertiary reserve is activated to restore the aFRR and resolve the imbalances between the production and consumption. The direct participation of DR in the tertiary reserve through aggregation is strictly forbidden in the tertiary reserve as applicable to other reserves. However, under particular situation, the TSO could activate the interruptible load capacities in the mFRR as a demand response program. Market participants are remunerated only for the energy activated in case the reserve is activated for real-time balancing purpose. In Spain, the tertiary reserve is mainly supplied by generators and pumped storage units. To participate, the providers are required to submit a minimum bid of 10 MW. However, REE allows that the value can be reached through the aggregation of various installations or generating units (REE, 2019).

The tertiary reserve is activated for a maximum of 2 hours. In the day before the delivery tertiary reserves, the providers are required to send the bids at 23:00 maximum. The tertiary reserve represents an eventual opportunity for DR aggregators due to its flexible design. For instance, market participants are allowed to up-date the bids 25 minutes prior to the gate closure (REE, 2019). The providers of up and down regulating bids in the mFRR are accountable in case on non-conformity of the requirements and in circumstances of deviation from the contracted balancing energy with the TSO resulting in imbalances. The providers of up-regulating bids are subject to penalties consisting of the energy supposed to be delivered summed to 20%.

In Spain, the deviation management reserve is equivalent to the Restoration Reserve (RR). Its main purpose is to solve the frequency deviations that occurs between two intra-day periods. The participation in the RR remains optional for market parties. The additional up-ward reserve was introduced in 2012. To participate in the reserve, the participants have to provide a minimum bid size of 10 MW (SEDC,2017).

7.4.2. Overview of demand response status in Iberian market

In Spain, implicit demand response has been incorporated in the electricity market in 2014 as a response to high electricity prices. In fact, Spain was recognized among the highest in Europe. In fact, the electricity price for households increased from 21.77 c€/kWh to 23.83 c€/kWh between 2017 and 2018 (Statista, 2018). Part of the economic stability of the electricity system initiated in 2013, and allow customers a certain flexibility, Spain introduced a real time pricing program PVPC. The program consists of voluntary price for small customers to decrease their electricity bills and have a contracted power of maximum 10kW (REE, 2014). In addition to this technical condition, customers are required to have a smart meter with hourly measurement installed as the prices will reflect their hourly consumption through the day. The installation of smart meters was supposed to be fully achieved in 2018. Therefore, REE estimated that more than 16 million customers will benefit from the real time pricing.

Explicit demand response is mainly reserved to large customer including industrials. At the moment, explicit demand response is achieved through the interruptible load program and regulated by the Spanish TSO REE designed to counterbalance in case of lack of balancing resources. Thus, its need is limited and has not been used for several years. As a matter of fact, DM was not given access in balancing markets and ancillary services in 2015, and the aggregator was considered only in the wholesale market participating on the consumption side (SEDC,2017). However, on the same year, flexible loads and the renewable resources have access to the balancing markets through the interruptible load program as it has known a change in its requirements. In fact, block bids of curtailed loads are allowed to participate in the DM program, and the minimum requirement in Spain was set to 4MW and in the Insular Spain, Canaries Islands, and Baleares 0,8 MW.

In Portugal, explicit demand response has not fully taken part in the balancing market nor does it participate in the reserve markets. Spain and Portugal share the same balancing market architecture, thus as applicable to Spain, the interruptible load program is the only explicit demand response driver at the moment. However, it prohibits aggregation reserved to large industrial participants due to the high minimum bid of 4MW. In addition, this program has not been called recently by the TSO and is activated exclusively in emergency situation. Therefore, the pre-qualifications, measurement and payments methods for demand response resources are not modulated. Considering the lack of regulations, demand response independent aggregator is not defined yet, and its balancing role is not yet taken into consideration.

The change in the electricity generation structure in Portugal might lead to an eventual opening of the balancing markets to demand response. In fact, wind energy as well as hydropower consisted of 45% of the total electricity generation highlighting the high integration of renewable energy resources. In light if these changes, Portugal has integrated flexibility in its balancing markets through pumped-hydro storages. Along with this, several pilots have been implemented to test the benefits of demand response (Annala, et al., 2018). One relevant example involves the development of an automated demand response technology with the collaboration of EDP Inovação, a research department related to the DSO, Everis, an IT consulting company, and Efacec Energia, a company specialized in providing demand management solutions. With the agreement of the New Energy and Industrial Technology Development Organization (NEDO) along with the National Laboratory for Energy and Geology in Portugal. The main goal is to adjust the demand and supply vital for maintaining a high share of intermittent energy resources by controlling automatically the air-conditioning systems at the Lisbon City Hall. Based on the variation of renewable energy generation and the forecasted demand, the automated system controls the consumption of the HVAC devices in accordance also with the weather forecasts' project started in 2016 and ended in December 2019. Furthermore, the pilot intents to assess the business models as it involved in addition local electricity retailers and virtual power plants (Dainkin, 2018).

At the moment, the metering activity in Spain is regulated, and the rollout is mandatory (Tounquet & Alaton, 2018). The responsible party implementation and the accessibility for third-parties processing and accessing the data are given by the DSO. According to the Spanish TSO, Red Eléctrica de España, the installation of smart meters in Spain would provide two major benefits:

- Time-based pricing
- Ability to remotely read and manage the consumption data.

Additionally, the TSO has stated that smart meters have not yet been installed in the residential sector. Failing to have real time consumption data, settlement profiles methods are used to estimate the hourly demand profiles (REE, n.d.).

However, Spanish ambition to increase the flexibility within the smart grids is shown in initiatives through various projects. Part of the Star (Grid Remote Management and Automation System) project, the company Iberdrola installed more than 10 million smart meters in Spain (Iberdola, 2017). The installation of smart meters in Spain will allow nearly 28 million customers to benefit from the real time pricing. The smart-meter roll out was expected to be achieved at the end of 2018, however, the installation has been conducted gradually. In 2014, REE estimated that 11.91 million customers were equipped with the technology, and this number increased to 17.53 million in 2016 (Lopes & Coelho, 2018).

Currently, Portugal has no framework of smart-meter roll out. In Portugal, the long terms benefit of smart meters installation rose in 2012. According to the Portuguese TSO, approximately 33% of the residential buildings are equipped with smart meters. Motivation has been shown by pilots such as InovGrid which installed 31,000 residential customers (low voltage) with smart meters (EDP,2018).

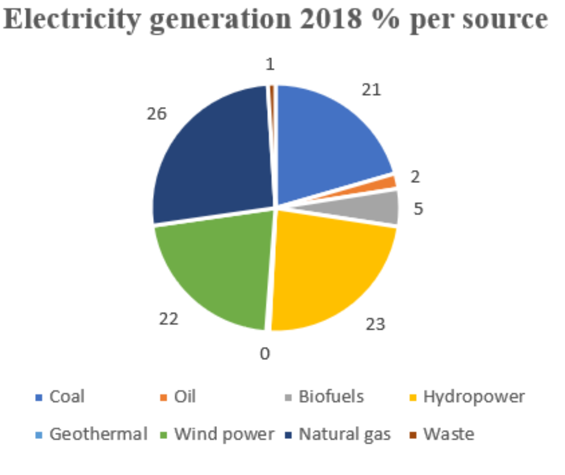

Figure 37. Portuguese electricity generation (%) per source in 2018 (IEA,2018).

7.4.3. Status of demand response aggregation in balancing market.

Currently, the aggregation of DR in Iberian market is forbidden in the balancing markets. The interruptible load program which is considered as the only demand response route available for aggregator does not give access to these market players (Ministerio de Energía, 2018). REE uses DR to secure the system balance along with the reduction of system costs including the ancillary services costs. These technical and economic criteria define the need for the program activation respectively as a rapid response tool to in case of emergency situation and in circumstances that system adjustment services (reserves) costs are higher than the DR program. The interruptible load program is directly managed by Red Eléctrica and supervised by the National Commission of Markets and Competition. This program is considered a balancing mechanism, or simply a flexibility tool. In this program, participation for small scale providers is complex as the minimum requirements to participate is 5MW (REE, 2017). Thus, the demand response in Spain allows only generators and large industrials that are directly connected to the TSO grid through ICT system. Providers of the program include in Participants that are connected to the DSO face a challenge to participate in the program, as DSOs are not allowed to predict in advance the loads. However, in special circumstances, the DSO is allowed to call out the use of interruptible load program in case of re-dispatching or curtailment of generators. In 2013, REE decided to increase the competitiveness through this program by using an auction system based to allocate the service based on a descending price. The TSO contracts block of load reduction of 5MW and 90MW and decides on their activation in case of emergency (Ministerio de Energía, 2013). Participants are compensated for their reduction availability and the energy price. Therefore, the remuneration is formulated in terms of the availability of power €/MW and the execution of power reduction.

The participation to the interruptible load program is certainly very competitive due to its technical requirements. Generators and large industrial are required to be available immediately, 15 minutes, or 2 hours at maximum after notice. In 2018, changes in the programs have been entered in force. The program providers are offered two execution options that require a reduction of power responding to the order from the system operators: An instant execution without notice or a fast execution after a notice of 15 minutes. Each of the execution methods can be active maximum two times consecutively for a maximum duration of one hour (REE, 2017). The delivery period has been shifted from beginning of January to the first of June till the end of December. The 90 MW blocks of demand reduction were replaced by 40 MW.

Verification of the interruptible load:

The service operator is responsible to verify the operations of the interruptible load program. With a condition to be linked directly to the TSO via an ICT system, the service provider is required to provide REE with the hourly consumption schedule in a monthly basis. The verification process of the interruptible load services is conducted based on the availability, and the fulfillment of technical requirements. The verification also includes a precision of the consumption program delivered by the service providers that communities the forecasts with an accuracy of at least 75% (REE, 2017).

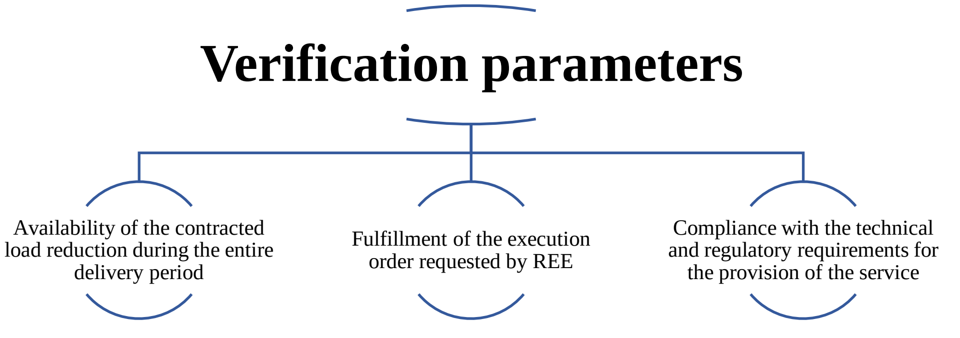

Figure 38. Verification parameters of the Interruptible Load Program in the Iberian Market.

The availability of the contracted loads reduction is verified on a monthly basis by the system operator and is based on the hourly measurement through ICT. The purpose is to verify that the provider maintains the interruptible power contracted during the auctions. As two products are available in the interruptible load program, different condition apply to the suppliers. For instance, providing the 40 MW must achieve an availability of at least 91%. This program is activated maximum once per day, and five times per week (REE, 2017).

Table 16. Evolution of the capacity contracted and total costs of the Interruptible Load Program in the Iberian Market (Arenillas Gay & Laverón Simavilla, 2015).

Auction year	Capacity assigned MW	Total cost million €
2015	3,020	508
2016	2,890	503
2017	2,975	525
2018	2,600	NA

In 2018, 2,600 MW of interruptible load capacity were assigned and applied to a period to 38 hours from January to May (SEDC,2017).

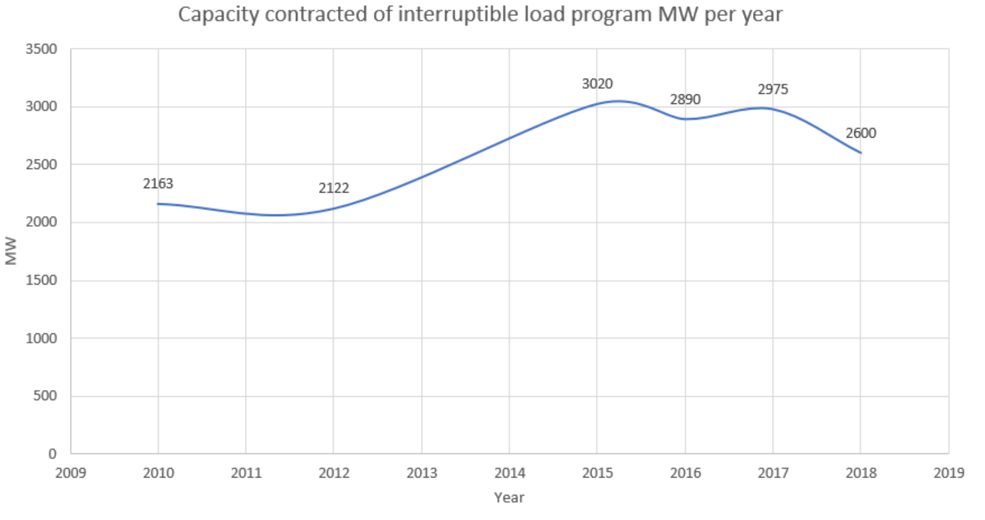

Figure 39. Evolution of the capacity contracted in the interruptible load program MW/year.

The balancing market design in Spain is complex in such that the minimum regulatory bids are one of the major challenges and burden for DR independent aggregators to participate. However, the country motivation to increase its flexibility and introduce decentralized resources such as renewable energy is driving the change. Demand Response trough interruptible load program is allowed in the tertiary reserve under special technical requirements. However, this program has not been recently called. In fact, Spain didn´t experience any relatively large imbalances requiring the activation of the program which led in 2016 an eventual closure of the incentive-based program due to the structure of the technical requirements as well as the lack of regulatory definition of the role of the participants (Conchado, et al., 2016).

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Table 17. Technical and market requirement of the Interruptible Load Program in the Iberian market (SEDC,2017) (REE, 2017).

Requirement	**Mainland**	**Islands**
Minimum bid size MW	5-40 block product	0,8
Activation method	Automatic	
Activation time	**5 MW product:** Maximum 240 hours/ year 40 hours/ months **40 MW product:** Maximum 360 hours/year and 60 hours/ months	Maximum 120 hours / year
Availability upon notification	**5 MW product:** Three options: Immediate availability 15 minutes after notification 2 hours after notification **40 MW product:** Two options: Immediate or a minimum notice of 15 minutes	Five option: From immediate availability to 2 hours after notification
Payment method	The cost if expressed in €/ MW -Availability of power -Effective execution of power reduction	

Penalties in the interruptible load program:

Prior to the participation in the interruptible load program, the system operator requires a financial guarantee to cover an eventual non-compliance of the service provision. In this context, REE applies penalties are applicable in case of non-fulfillment of the technical requirements as the in case of a failure to execute the power reduction. Penalties are formulated in form of payment obligation that can reach a maximum of 120% of the remuneration associated with the availability of the power awarded in the auction (REE, 2017). In case of eventual repetitive failure of execution of the power reduction, the service provider can face an exclusion from the service and a complete loss of remuneration. Service providers located in the Canaries and Baleares participating in the program are subject to the same penalties with a percentage up to 100% of the remuneration in case of two repetitive failures in the same year.

7.4.4. Development toward demand response aggregation

Even though demand response aggregation is not yet a provision resource in the balancing market, it has been a subject under the study scope of REE. In 2012, the Spanish TSO implemented a demand response aggregation pilot named AGREGA involving four medium industry scale, and an aggregator ASE Servicios Energéticos (REE, 2013). The project aimed to control the consumption of the industry facilities and provide at least 4MW aggregated demand response. The aggregator provided the customer with an hourly consumption forecast with defines the increase or the decrease of the consumption. The activation duration ranged between 1 to 3 hours maximum. The pilot was implemented for one year and aimed to closely analyses the business model and routes of integrating aggregators in the electricity market. Thus, three focal points were selected including the information exchange between the TSO, aggregator, and customer, the operating process between TSO-aggregator, and finally, verifications and measurements methods. Despite the testing, the results remained broad and unimpressive. In fact, REE concluded that the project improved the knowledge in the field that could lead to eventual developments.

The wind power generation is expected to increase in the future. Under the framework of adapting its electricity system to the changes, REE expressed in 2013 its motivation to focus on DSM and more specifically demand response as a solution to provide flexibility. REE underlined that the DR is already developed at the industrial level, and the objective of the pilot is to crate measures for the commercial and the residential sectors.

The Spanish balancing system is undoubted in need of changes as the induction of flexibility in its electricity system would become vital in the incoming years. Intermittent generation is increasing significantly reaching 47,1% of the total generation in 2020 (IEA,2018). At the moment, wind power constitutes the high RES with an up to date generation of 209 GWh (REE, 2020.b). With a high penetration of wind and a progressive growth of solar power, the electricity system could benefit from demand response to balance the intermittency. However, at the moment, REE uses pumped storages and CCGT as a flexibility measure at the mainland and island levels (Sigrist, et al., 2016). The high share of wind power impacted the balancing services in Spain especially in the tertiary and slow reserves due to the its weather dependency nature. The deviation management reserve (slow reserve) is used to balance consequent deviations higher than 300 MWh between the scheduled generation and the demand covering the period between two intra-days sessions. Thus, the reserve should constantly take into account the wind power forecasts from D-1 to real time. It is important to mention that the large and unexpected wind power ramp are intricate (Sorknæs, et al., 2013). In point of fact, wind power generation partially caused a significant imbalance between the generation and the load in the Texas in 2008, which caused the call for the Reserve Capacity and a reduction of demand as a backup resource (O. George, et al., 2010).

In 2016, the tertiary reserve was open for decentralized resources to participate. The European regulation published in June 2019 defining the internal electricity markets encouraged demand response, the active participation of customers, and aggregation. The Spanish responded to these regulations by publishing review the balancing conditions leading to changes in increasing the national competition in the balancing markets as well as the re-definition of the market players including small scale participants, BSP, and BRP (REE,2019). In fact, balancing service providers are given the access of aggregation of demand side resources as well as energy storages, and generation and the participation in all balancing services (FlexCoop, 2019). In its Article 8, aggregators have been fully recognized and a roadmap to register as a Balancing Service Provider have been drafter. As a matter of fact, the technical requirements have also been changed in accordance. According to the resolution of the National Commission of Markets and Competition published by the Spanish TSO in 2019, BSPs are now required to participate with a minimum supply capacity of 1MW instead of 10 MW to participate in the European exchange reserve platforms including aFRR, mFRR and RR (REE, 2019) . The integration of the Spanish balancing markets in the European balancing energy platforms allowed a uniformization applicable starting 2020 of the technical requirements. The implementation of the roadmap is expected to take place 12 months from the approval of the guidelines published by REE. The report rose the regulation zones requirement challenging the participation of BSP. The secondary reserve is subject to tough requirements due to its initial design. The procurement of the secondary reserve is conducted through regulations zones or areas that regroup the portfolios of the balancing providers and assigned a Balance Responsible Party. To establish one regulating area, the capacity of all units or BSP should be at least 300 MW. According to the new requirements, each secondary regulation zone should have a minimum of 200 MW to enable its participation in the aFRR. This requirement is recognized a major burden for aggregators reducing their competitiveness in the market.

8. Discussion

Following the analysis of the technical and market entry requirements in the selected countries, it seems that Finland and UK are currently leading the transition to a flexible balancing market. In Finland the independent aggregators status is regulated and fully recognized as a balancing service provider. The pilots undertaken in the FCR and mFRR proved that the compensation challenge could be seen as a market barrier. In the UK, the independent aggregators have the status of a Virtual Lead Party. Following the European guidelines in establishing an exchange platform of balancing energy in the Replacement Reserve referred to it as TERRE project, National Grid removed the barriers in its settlement and balancing code. However, at the moment the access of DR independent aggregator is still dependent on the agreement of the customer´s supplier as the compensation of BRP issue is not yet solved. In the Netherlands, the participation of third-party aggregators has been unlocked in the FCR following a pilot conducted in 2017. Despite this advancement, third-parties are mandated to have an agreement with the BRP in order to participate in the aFRR, mFRRda, and mFRRsa. While the Iberian balancing market is at the moment closed to demand response aggregation, Spain and Portugal could eventually give access to third-parties as they are part of the TERRE project. However, currently the interruptible load program seems to be the only market available for demand response noting that it has not been activated recently. To be included in the program, participants need to contract at least 4 MW of curtailed load. Nonetheless, this program can be considered as an optimistic opportunity to direct the market toward further flexibility. In the Netherlands, the independent aggregator is required to have an agreement with the BRP, in addition, the access to the market requires a participation of 20 MW which clearly constrict small DR provision. The figure 40 positions the selected balancing markets in terms of minimum bid size, and regulatory status of independent aggregators. France and Germany have been included to further illustrate the European market. The French electricity market is a supportive example to be taken into account in parallel with Finland as currently it is fully open for demand response and DR independent aggregators. A framework defining the roles of aggregators and BRPs has been implemented in 2013 enabling France to be along with Finland a leading country in the context (Leal-Arcas, 2019). Demand response participation dates back to 2003 starting with industrials to residential aggregation by the end of 2007.The fast deployment of smart meters smoothly enabled the consideration of small-scale aggregation in the balancing markets. Currently, independent aggregators are able to participate in the balancing markets including the mFRR, FCR, aFRR and the RR. In 2014, the French TSO, Réseau de transport d'électricité, alleviated the agreement with the balance responsible party. However, considered as slight barriers, independent aggregator with a bilateral agreement with their customers are required to sign a contract with the producers which is mainly EDF (Électricité de France), an electrical utility charged to trade electricity, in order to participate in the FCR and aFRR (SEDC,2017). However, one should note that regulation framework is complementary with the technical structure of the balancing market. In fact, even though DR independent aggregators are fully allowed to participate, the minimum bids make it relatively complex as similar in the UK. Both aFRR and RR require at least 10 MW (RTE, n.d.). In addition, symmetrical bids are obligatory. One enablers of independent aggregators reside in the availability as BSPs can participate only in selected days excluding the 24/7 availability. Furthermore, the TSO set a baseline solving the compensation challenge between the aggregator and the BRP. Following 2013, independent aggregators are required to financially compensate the BRP/ retailers taking into account the aggregator imbalance caused to the BRP portfolio and the retail price of electricity (SEDC,2017) (CER, 2016). This unique compensation scheme participates in the development of demand response by solving the compensation challenge.

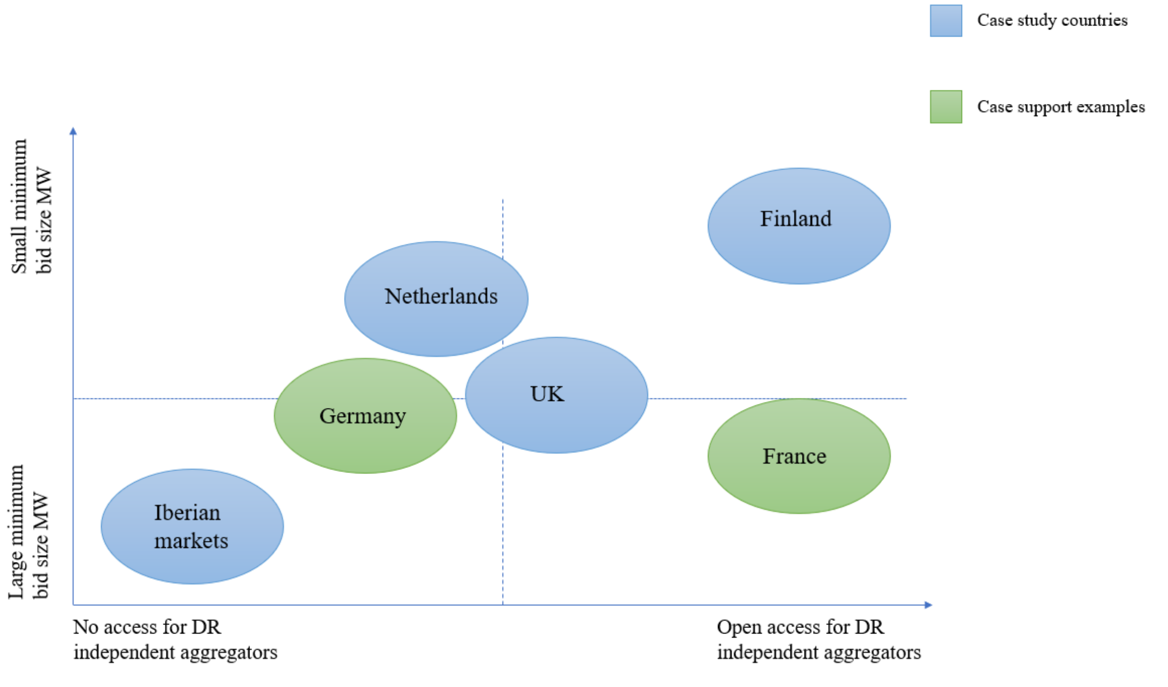

Figure 40. DR independent aggregator status position conditional to selected requirements.

It is complex for an emerging market player to integrate the balancing market designed for large generation units at the first place. Technical, economical, and regulatory barriers are certainly a burden even if the status third-party DR aggregation is regulated. The main issue remain the minimum bids required to enter the market. The harmonization of the balancing minimum bid requirements to 1 MW is seen as a head start for DR independent aggregators. For financial purposes, these market players need to aggregate a large amount of flexibility (demand response) to be economically viable. Thus, reducing the size bid to 0,1 MW would widen the access. With the implementation of the Replacement Reserve balancing energy exchange platform, countries such as Spain and Portugal could in the future remove this technical barrier as at the moment the participation is mainly targeting large generating units. With no regulatory framework for independent aggregator set at the moment, the secondary and tertiary reserves require an oversized minimum bid of 10 MW. The harmonization of the minimum bid size is taking place rapidly in some EU countries, the minimum bids are still consequent. In the UK, the TSO reduced the bid of the Fast Reserve (aFRR) from 50 MW to 25MW. In the Netherlands, the mFRRda although open to demand response aggregation requires a minimum bid of 20 MW.

The minimum bid size and product symmetry constraints are highly correlated (Burger , et al., 2016). In fact, if a reserve requires symmetrical product with a high minimum bid of for instance 3 MW, the third-party is obligated to participate with 3MW upward and 3MW down regulatory bids. In this context, demand response would be valuable in case of contracting a large number of customers. In this situation, the aggregator would be able to meet the symmetrical requirements by assigning each unit a direction in the consumption trend. As a matter of fact, this is not achievable by single units’ providers. Thus, unsymmetrical products increase the provision certainty.

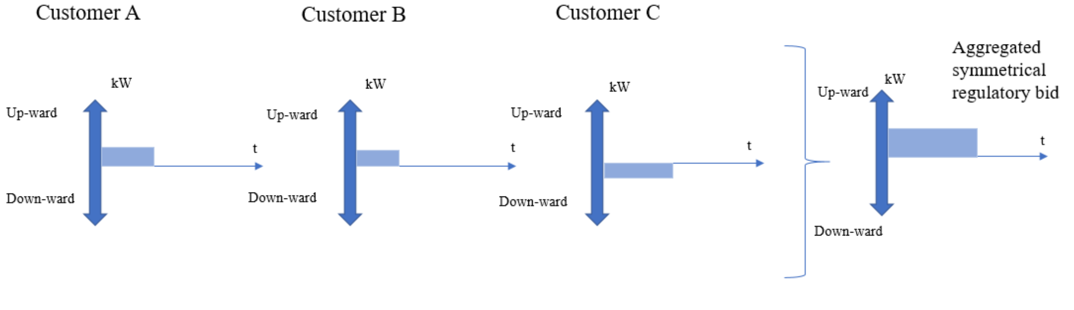

Figure 41. Benefit of DR aggregator in meeting bid symmetry requirements (Burger , et al., 2016).

As a fundamental of the balancing market bidding procedure, the time horizons such as the activation time, the product resolution, and the length of delivery must be carefully adapted to demand response. At the opposite of generating units that determine the output production of electricity, demand response main providers are customers that are supplied by a retailer. Thus, DR independent aggregators are constrained with the consumption patterns. This specific features limits DR as a resource to be available for long period of times. In parallel, customers are on average able to provide demand response services for 1-2 hours, thus the delivery duration for third-party aggregators is limited compared to conventional generating units (Barbero, et al., 2020). To enable the access of these market players, the product resolution should be reduced. However, a short-term balancing market (referring to short delivery periods) increases the risk not supporting the system balance. As established in Europe, both short- and long-term balancing market products are available. The Finnish mFRR (15 minutes delivery period), and British STOR (2 hours delivery period) reserves are a great example enabling the participation for independent aggregators. Although, the FCR in Finland is fully open for DR third-party aggregation, by nature it requires a continuous availability. In addition, participants in the Enhanced Frequency Reserve in the UK are required to fully to meet 95% of the availability requirements. Thus, it limits the balancing services providers to participate in other balancing product. The BSP are obligated to provide symmetrical bids. Knowing that the minimum bid is set to 1 MW, the participants are required to at least provided 1 MW of high frequency response, and 1 MW of low frequency response and deliver the assists the same amount of period. Even though DR aggregation is allowed, the availability constraints limits their participation. Aforementioned, the availability is set at 95%, however, in a manual instruction report, the TSO expressed its preference for 24/7 availability. In the UK, the analysis demonstrated a difference between the reserve services and the frequency response services as the first product are characterized with longer response times and duration of the delivery compared to the second.

Penalties are often a burden for DR independent aggregators to participate in the balancing markets. The activation of the reserves requires the market participant to make its capacity available to either increase or decrease the generation depending on the symmetrical requirements. This availability is compensated by the TSO. On the other hand, the energy is also needed to be balanced in real-time. Thus, if the balance service providers fail to meet the delivery after the call and the availably requirements, penalties often consisiting of additional fees over the marginal cost are applied. In the case of demand response, an aggregator would face these penalties if one of the units (customers) fails to deliver. In the Netherlands, DR aggregators failing to meet the availability requirements in the FCR, face strict penalties corresponding to approximately 10 times the availability payments. On the other hands, Fingrid, the Finnish TSO, set fair penalties for DR participants consists of a reimbursement of the availability payment of not meeting the delivery requirements. In British balancing reserve market, the penalties are relatively objective at the exception of the STOR. As a matter of fact, BSP failing more than once per month are reduced 1-30% of their availability price.

In Europe, the imbalance pricing schemes used are single and dual pricing systems. The Nordic countries such as Finland apply the dual pricing. However, the Nordic TSO agreed starting the second quarter of 2021 to shift to single pricing (eSETT, 2019). The dual pricing approach depends on the direction of system imbalance. For instance, if the balance responsible party imbalances are in the same direction of the system, it receives marginal pricing on the energy activated in the reserve. On the other hands, if the imbalance is at the opposite, the party is usually attributed day-ahead prices. Other countries such as the Netherlands, UK, and Iberian market apply the single unit pricing in which the imbalances are priced according to the marginal price. The pricing schemes affect DR independent aggregators by either creating an opportunistic value or constrain them. The single pricing schemes are less valuable for an aggregator as it will be penalized or paid a marginal pricing.

In the context of payment methods, the revenues of the independent aggregators depend also on the frequency of the reserve activation. A high number of activations will positively affect the utilization payments as the availability is fixed. The procurement of the balancing services is designed by the TSO. A monthly or yearly tender based procurement is often a burden for demand response in general. In fact, it is complex to predict the consumption change of the customers weeks or months ahead. As such, daily tenders benefit independent aggregators to participate as applied in the Finland in aFRR.

Considering the regulatory requirements, the balance service providers including single units or acting as independent DR aggregators are to fulfill the pre-qualification tests. To enable third-parties in the reserve markets, the assessment should be conducted at the pool level as applied in Finland and UK for instance. Pooling refers to the aggregation of demand side response at a small scale in order to meet the technical requirements. Considering this fact, the aggregated at the unit level will lead to an exclusive access of the reserve to large generation units. The DR independent aggregators would not meet the requirements if each customer must fulfill the pre-qualification processes.

Commonly, the FCR due to the nature of its operations is continuously activated, the notification times are very short and the minimum bid sizes are in general 1 MW expect for the Finnish case in which the independent aggregators are enabled to participate with at least 0,1 MW. In addition, the provision is done through daily auction, and the product resolution is harmonized in all the reserves to 1 hour. By definition, product resolution refers to the bidding time horizon, and determine the time resolution of frame in which the BSP has place bids in the balancing markets, or offer its flexibility.

The measurement and verification methods are defined by the TSO and require a communication of real-time data. The roll-out of smart meters plays a major role in this requirement. In a country such as Finland where smart meters are widely used, measurement and verification conducted at the pool level have a low impact as the aggregators would not have to cover the costs of the physical installation and would be subject to only communication of real-time data fees expressed as €/month. However, in the Dutch case, the smart-meter roll out is expected to be by the end of 2020. In the FCR and aFRR the providers need to be equipped with a metering system and communicates the real-time data on a resolution of 4 seconds. TenneT, the Dutch TSO, discussed a possibility to modify the time resolution to 1 seconds. A measurement system at the resource level is thus very challenging for independent aggregators. Considering the volume of flexibility, a customer has to offer and the high installation costs of smart meters in each unit, the revenues of the independent aggregator might be affected.

To be fully considered as an independent aggregator, the agreement between the BRP should be removed. The dependency on the BRP is an issue that needs to be resolved within countries such as Finland and the Netherlands. In fact, the challenge of the compensation is automatically brought out. At the moment, the Nordic country is still undergoing a pilot testing the reimbursement model in the mFRR. The model explained in the section 7.1 ensures the integration of independent aggregators in the balancing market and ensure a fair allocation of costs both BSP and BRP. It is important to note that without the reimbursement model the BRP would be negatively impacted in case the aggregator offers up-regulation to the TSO. As a matter of fact, the energy bought in advance would not be activated. The opposite would result in additional income for the BRP as the customer consumption would increase leading to additional sales.

Table 18. Summary of the DR independent aggregators barriers in selected balancing markets.

Country	Identified barriers
Finland	- Minimum bid sizes in FRR and RR 5 MW and 10 MW. - Aggregation from different BRPs is not allowed except in FCR. - Agreement between BRP/aggregator is needed.
Iberian market	- No access for independent aggregator
Netherlands	- mFRRda min bid size 20 MW - Measurement and verification: High resolution real-time data measurement. - Agreement with BRP/independent aggregator except in the FCR. - Verification based on visual inspection in the aFRR. -Long lead times in the aFRR (between 4-7 ISPs). - Activation of mFRRsa can by by-passed by the TSO leading to the activation of mFRRda directly. - Compensation of BSP only by utilization payment in the mFRRsa
UK	- 10 MW minimum bid size in aFRR - High product resolution in FCR. - Demand Turn Up has not been activated in 2019 - Procurement method is limiting DR participation - High availability requirements in the EFR

9. Conclusion

As a reliability and security pre-requisite, the balance between the production and consumption is a fundamental pillar for a well operated electricity system. The need of balancing markets is currently the centerpiece of research. In overview, balancing services providers contribute to stability of the system through energy and reserve balancing services. While the balancing energy is procured close to real-time, the reserves markets are characterized with defined technical requirements and provided generally ahead of time. The structure of the reserve market is usually composed of primary response (FCR), secondary response (aFRR), and tertiary response (mFRR). Nonetheless, the design of the balancing market differs in terms of products across the countries.

With the motivation to fulfill the climate change and integration of high RES shares in the electricity generation targets, directing balancing markets toward flexibility becomes primordial. In fact, the traditional structure of the balancing market requesting balancing services from conventional large generating units. In addition to secure the system balance with complementary balancing services, demand response can bring an economical value by reducing the marginal costs.

Demand response has emerged as adequate solution responding to the changes the electricity market is undergoing. Technically, a direct participation of customer in the balancing market is extremely complex and requires the fulfillment of minimum bids and a installation of communication infrastructure. To enable the shift of the status of customers to prosumers participating actively in the balancing markets, DR aggregators take the responsibility to meet the pre-qualification process, and create a portfolio of pooled flexibility resources traded in the balancing market. Therefore, the DR aggregator is an intermediary market player between the balancing markets and the customers. By the activation of demand response, customers are compensated directly by the aggregators. It is important to highlight that DR aggregation is valid in both wholesale market and balancing market as applicable in the Netherlands, and Finland.

This thesis evaluated the technical and market requirements along with assessing the current status of DR independent aggregators in the selected balancing markets. Finland, The Netherlands, UK, Spain and Portugal were taken as case countries for the analysis. Third-party aggregators are defined as entities detached from the BRP/Supplier providing the same operation as a DR aggregator.

Whilst, the European commission is unlocking the access of independent aggregators, results obtained from the evaluation analysis of case countries demonstrated that barriers to independent aggregators are still exiting at the technical and market levels. As a market access pre-requisite, the regulation established by the system operators, REE and REN, blocks the access in the Iberian Market in which demand response is solely expressed in the Interruptible Load Program legible exclusively for industrial units. In addition, little attention is given to DR aggregators in the balancing markets and third-party aggregation is not allowed at the moment.

At the moment the participation of DR aggregation is allowed in relatively all balancing products across Finland, UK, and the Netherlands. Yet, it is challenges by high minimum bids excluding the participation of small-scale aggregators. In Finland. the participation of small-scale aggregated demand response in the aFRR, mFRR, and RR is complex due to the thresholds set. In the same context, demand response BSPs are challenged in the British aFRR and Dutch mFRRda. Prior to the delivery of the balancing services, BSPs are required to pass pre-qualification tests. As a pre-requisite, these requirements become a burden if it is conducted at the asset level. The same is applicable to the measurement and verification. The analysis highlighted that the selected countries measure the services at pooled level. However, high measurement resolutions oblige the aggregators to install online metering is which is relatively a challenge due to the high physical installation costs. In addition, balancing time horizons consists a major challenge in DR aggregator as a concept. Fast activation times, continuous activation, and long product resolution and service delivery are complex considering the specific features of demand response.

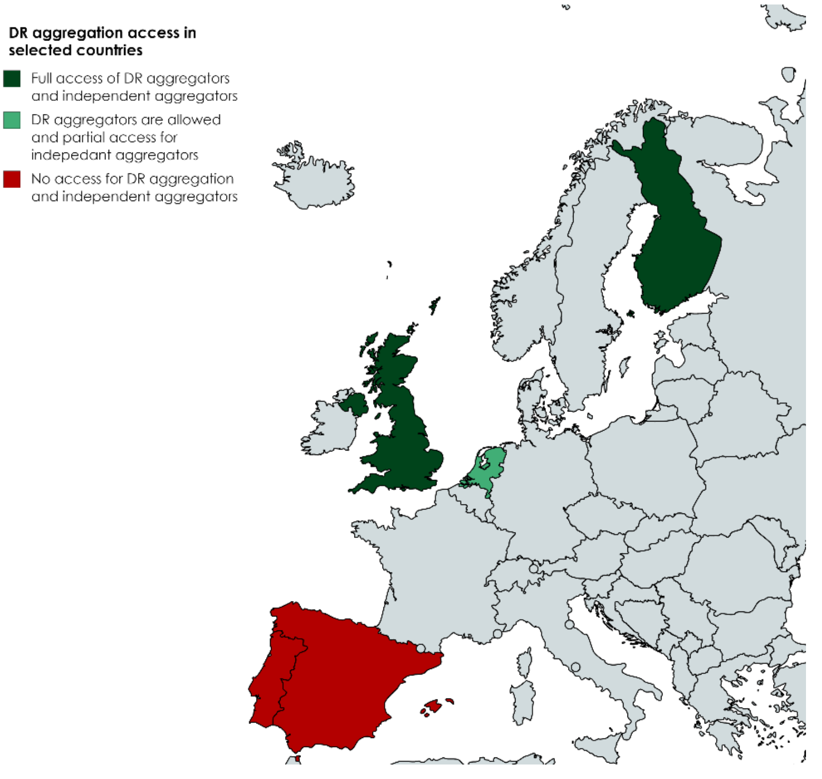

Figure 42. Map chart of DR independent aggregator access in selected European countries.

In the UK, the independent aggregators were firstly recognized in the Smart Systems and Flexibility Plan published in 2017 acknowledging demand response benefits. Following the implementation of the project TERRE, the British system operator regulated the status of independent aggregator in 2019 as Virtual Lead Parties. In Finland, independent aggregators were given access in balancing market ahead of other countries. However, at the regulatory level, an agreement with the BRP is still mandated by Fingrid in the aFRR, mFRR, and RR. As a matter of fact, the balancing service provider needs to either own the balancing services or agree prior with the supplier or the BRP. The FCR remains at the moment the adequate balancing product for independent aggregators in Finland. In the Netherlands, the issue between the BRP and independent aggregator has not been solved yet except in the FCR.Yet, major advancements have been made. Since 2017, independent aggregators are given access in the FCR, aFRR, and mFRR.

To support the transition and develop a suitable business model for these market players, several pilots are running including in the Finnish mFRR. Although the results are not yet clear, the compensation challenge has been pointed out as a major issue to be solved. This thesis presented three different compensation methods applied for the independent aggregators affecting differently the BRP/supplier and the customer. It has been highlighted that the imbalance volume correction with compensation would benefit the market players the most. At the market level, independent aggregators as BSPs face penalties for non-fulfillment of delivery and availability requirements. Because of aggregator´s dependency on customer´s behavior and ability to provide flexibility, and low availability periods of DR, third-party aggregators might be discouraged with high penalties applied such as in the Netherlands.

In light of increasing security of supply at the EU level, the European commission has implemented balancing services exchange platforms in the aFRR, mFRR, and RR products endorsed by various European TSOs including Finland, UK, The Netherlands, and Iberian countries. This initiative supports the Guideline on Electricity Balancing encouraging a harmonization of the technical requirements targeting lower minimum bid size set to 1 MW as well as the applicable of marginal pricing as the imbalance settlement price. In addition, the regulation emphasized on the procurement of separate up-and down regulatory bids as an enabling feature for DR aggregation participation. The exchange platforms could lead to an eventual change in the Iberian balancing market taking into consideration the compliance and alignment with the requirements set.

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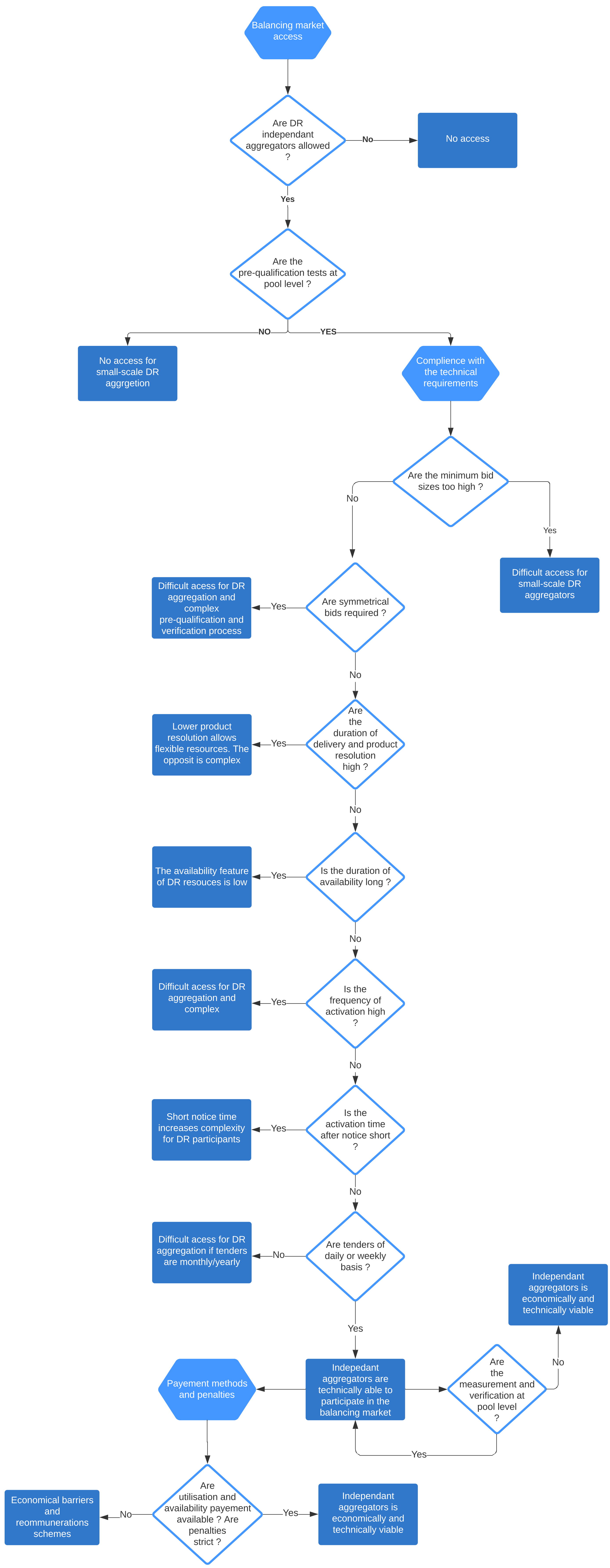
APPENDIX I. Flow chart of the technical and market barriers and enablers of DR aggregation participation in the balancing market.



APPENDIX II. Technical and market requirement of the balancing reserves in Finland.

Requirement	FCR-N	FCR-D	aFRR	mFRR	FRR Fast Frequency Reserve (Valid from 01/02/2020)
Participation of indepedant DR aggregators	yes BSP are allowed to aggregate from different BRP only in FCR		Yes Aggregation is allowed if resources are included in the same balance. Aggregation from different BRP balances is not allowed.	Yes Aggregation is allowed in the same balance area and resources should be in the same regulation area Aggregation of consumption and production is allowed **Exceptions:** If the minimum balancing energy bid size is not met in the same balancing area, BSP can aggregate in different balancing areas.	Yes Aggregation from different BRP balances is allowed. If the aggregator/ BSP has an hourly market agreement in the FCR, combined bids in the FRR and FCR-D are allowed. Participants of the yearly market in FCR-D can participate in FRR.
	Aggregation from different BRP balances is allowed.	Relay-connected reserves which single step activation cannot be aggregated.			
Minimum bid size MW	0,1	1	5	5 if ordered electronically, otherwise 10MW.	1
Procurement	Yearly and hourly market		Daily auctions during partial hours of day reported by Fingrid in advance.	Weekly procurement for balancing capacity. Daily for energy balancing bids.	FRR is procured on hourly market.
Frequency of activation	Continious	Frequently per day	Frequently per day	Depending on the bid	Rarely
Full activation time	Stepwise frequency deviation of 0,1 Hz. Full activation in 3 minutes.	Piece-wise activation. 50% capacity is activated in 5 seconds 100% is activated in 30 seconds responding to a change of -0,5Hz.	30 seconds- 5 minutes The volume activated should be 90-110% of the power requested by Fingrid.	15 minutes	Action time depends on the frequency deviation: 49,7 Hz : activation in 1,2 seconds 49,6 Hz: Activation in 1 seconds 49,5 Hz: Activation in 0,7 Hz The BSP can selected one option.
Delivery duration	Continuous delivery.	Until restoration of frequency The frequency should stabilize for 3 minutes at 49,9 Hz.	Continuous delivery	15 minutes	Two options: 30 seconds for a non-limited speed of deactivation 5 seconds (short support) for 20% of the reserve capacity / seconds.
Product resolution	1 hour				15 minutes
Product symmetry	Up and Down regulation	Up-regulation	Separate Up-and Down	Up- regulation	Up Regulation
Capacity settlement	Marginal Price	Marginal Price	Pay-as bid payment	Marginal Price	Marginal Price
Balancing energy compensation	Energy fee	-	Activation payment Marginal price based on the mFRR price	Marginal price	No
Pre-qualification	-Pre-qualification at pool level -BSP shall pass the pre-qualification test including the verification of the technical requirements and monitoring.				
Verification and measurement methods	Real-time data monitoring of the activation of the reserves procured by BSP the interval of real time data exchange should not exceed 60 seconds.		Real time data exchange of a maximum interval update of 10 seconds.	Real-time data monitoring of the activation of the reserves procured by BSP The interval of real time data exchange should not exceed 60 seconds.	Real-time measurement to monitor the activation of FRR. The BSP is required to deliver real time data to Fingrid of the volume MW. The resolution of the measured volume should be accurate of at least 0, 01MW.The internal of the real time data update should not exceed 60 seconds. **Aggregated Units:** Aggregated units are tested as a whole as and resources are test individually.
Penalties	Financial penalties for BSP.		BSP reimburses 100% of the fees paid by Fingrid.	Penalty for reducing or deleting a balance capacity bid. Temporary exclusion from the capacity and energy balancing market or cancellation of the agreement.	Penalties are attributed to BSP failing to submit the volumes contacted or do not fulfill the measurements requirements. Penalties are equal to 100% of the hourly price.

APPENDIX III. Technical and market requirements of the balancing reserves in the Netherlands.

Requirements	FCR	aFRR	mFRRda	mFRRsa
Independent DR aggregation access and DR	Yes BSP can provide the FCR with aggregated loads without an agreement with BRP.	No	No	No
DR aggregation requirements	The maximum bid size an aggregator can provide is 150 MW. Each DER capacity asset should not exceed 1,5 MW.	DR aggregation is allowed under an agreement with the BRP.	DR aggregation is allowed under an agreement with the BRP.	DR aggregation is allowed under an agreement with the BRP. BSPs can offer a maximum of 3 bids combining aFRR and mFRRsa for less than 4 MW per ISP.
Mininum bid MW	1	1, BSP can offer maximum three bids less than 4MW.	20, BSP can offer maximum three bids less than 4MW.	1
Participation	Mandatory	Mandatory for contracted BSPs.	Mandatory for contracted suppliers.	The bids are not contracted. No obligation for bidding and availability.
Procurement	Daily common auctions, 30% of the FCR is procured from connected providers.	Monthly and weekly tenders.	The emergency power is procured in quarter and monthly basis.	The call for activation can be 1 or 2 ISPs before the submissions of the bids.
Activation method	Automatic	Automatic	Manual	Manual
Full activation time	30 seconds	15 minutes Accepted bids must be able to ramp up or down by a minimum of 7% of the bid volume per minutes.	10-15 minutes	Activation at least one supply period of ISP (15 minutes) Activation of the mFRRsa is dependant on the prices of the bids offered. TenneT might by-pass the mFRRsa and activates directly the mFRRda
Duration of activation	Continious	≥ 4 seconds	≥ 15 seconds	N/A
Product symmetry	Yes	Yes	Separate up and down	Separate up and down
Frequency of activation	Continious	Several times per day	N/A	27 times in 2017
Capacity payement	Availability payment Pay-as bid	Availability payment Pay-as bid	No	No
Balancing energy compensation	-	Marginal pricing	According to the contract Marginal pricing.	Marginal pricing
Pre-qualification	Pre-qualification at pool level.	**Contracted provider**: The pre-qualification tests are applied for up-ward or down-ward regulating bids separately The BSP is required to submit bids for at least one consecutive week for each ISP. The BSP is called 10 times in this period. **Voluntary provider**: Conduct a pre-qualification to verify the regulating speed.	Pre-qualification must be conducted for both up and down regulations.	Yes, not including a test protocol for mFRRsa The BSP must pass the pre-qualification test with at least demonstrating which installation mFRRsa will be supplied with.
Measurement and Verification methods	Ex-post using the BSP data Measurement data on RPU/RPG level at 4 seconds resolution. Measurement at pool level.	The BSP must be equipped with metering system of a resolution of 4 seconds for 5 years. Verification conducted on a weekly basis and based on visual signal inspection.	The BSP should be equipped with metering system of a resolution of at least 5 minutes for 5 years. Ex-post verifications based on the reference value.	The BSP should be equipped with metering system of a resolution of at least 5 minutes for 5 years.
Penalties	Pro-rata penalty system is applied for non-delivery and non-availability estimated 100 times the price of the availability payment. Ongoing discussion on stricter penalties.	Monthly fee based on the non-availability of the BSP.	Penalties are defined in the offer contract.	N/A

Appendix IV. Technical and market requirements on the FCR reserves in UK.

Requirement	**FCR**			
	Primary Response	**Secondary response**	**High frequency response**	**Enhanced frequency response**
Independent DR aggregator access	Yes	Yes	Yes	Yes
Aggregator requirements	Assets are tested individually and aggregated. Participants can provide both FRR and other balancing services		Participation of the BSP in other balancing market is limited until fulfillment of enhanced frequency response delivery.	
Minimum bid to participate	1 MW			
Full activation	Activating 5% in 2 seconds and 100% in 10 seconds	30 seconds	10 seconds	1 second
Delivery duration	20 seconds	30 minutes	Indefinitely	At least 15 minutes, and maximum 30 minutes
Frequency of activation	Continuous	Continuous/discrete	Continuous	Continuous
Procurement	Monthly basis			Sopradic
Symmetry	No			Up and Down
Product resolution	4 hours			4 years
Capacity payment	Availability fee			
Energy Payment	Response energy fee for non-BM providers only £/MWh			No
Other payment	-Window initiation fee £/window - Nomination fee (£/hr) -Availability fee Paid per hour (£/hr)			No
Pre-qualification	BSP should be equipped with a metering system, the relay tolerance is within 0,01 Hz -Sustain the response for 30 minutes **For demand side providers**: The tests should be conducted by the service providers.			Assessment on 95% of the provider availability in addition to the quality performance factor
Measurement and verifications	Asset testing. the data should be sent seconds by seconds or minutes by minutes The performance of the BSP is monitored from time to time by the TSO during any sampling period.			BSP /DR aggregator should be equipped with a second by second metering system, and the data need to be recoded every second. TSO performs monthly monitoring and verification to ensure that the technical requirements are met.
Penalties	Non delivery: The availability and nomination fee at not attributed to the service provider. The contract might be cancelled if the BSP fails to deliver three successive times in the calendar month. Non-availability: The penalty is applied if the BSP does not fulfill the availability requirements more than 3 times in the calendar month, the contract is terminated. The availability and nomination fee are not paid to the BSP and if the window initiation fee is reduced if applicable.			Failing to meet the delivery requirements, the availability payment is reduced.

APPENDIX V. Technical and market requirements of the balancing reserves (aFRR and RR) in the UK.

Requirement	STOR	Fast Reserve	Demand Turn Up	Replacement Reserve TERRE
Independent DR Aggregation Access BSP / requirements	Yes BSP can offer generation or demand reduction Participation in the STOR does not allow access in other balancing services BSP can participate in up to 2 financial years,	Yes BSP/DR aggregators are allowed to participate in other balancing services only if they respond to the Fast Reserve during the start of each window	Yes It is not allowed to participate in other balancing products while supplying the demand turn-up. Aggregation from sites of 0,1 MW and above is allowed.	Yes DR aggregators can participate as Vitual Lead Parties. Independent aggregators can participate staring 30 June 2020
Minimum bid to participate MW	3	25	1	1
Full activation	4 minutes-20 minutes	2 minutes	6 hours 6 minutes on 2018	30 minutes
Availability	240 minutes after notification	Continuous availability	6 hours 6 minutes in 2018	At least 15 minutes
Delivery duration	Continuous delivery for at least 2 hours	BSP should sustain the delivery for at least 15 minutes	The length of delivery in 2018 was 4 hours 26 minutes	15-60 minutes
Frequency of activation	On average 3 times per week	On average 10 times per day	41 in 2018 with the participation of 5 BSP	Time to time activation
Procurement method	3 three tenders in the year.	Tendering on a monthly basis	Tender process 3 times per year. The availability windows differ from base months to peak months.	Auction periods
Product Symmetry	Up regulation only	Up-regulating bids	Down regulatory bid	Up and Down
Capacity payment	Availability payment £/MW/h	Availability payment £/MW/h	Availability payment £/MW/h	No
Energy payment	Utilization payment £/MWh basis	Utilization payment £/MWh basis	Utilization payment £/MWh basis	Utilization payment £/MWh basis
Other payments	Optional payment	**N**omination/positional fee £/hour	No	No
Pre-qualification	Prequalification at pool level	Pre-qualification at pool level The pre-qualification includes a combination of Volume weighted availability price and adjusted availability price, performance, speed response, and ramp rates.	Pre-qualification at pool level The pre-qualification includes tests in: Availability payment Utilization payment Response and recovery time and the duration of the response	Pre-qualification at pool level The parties should register as Primary or Secondary BMU
Measurement and verification	BSP/DR aggregators should be equipped with a metering system compatible with the STOR Dispatch Equipment, and the data should be sent minute by minute	BSP/ DR Aggregators should provide metering data minute by minute	BSP/DR aggregator should be equipped with a minute by minute or half hourly metering system.	N/A
Penalties	Penalties are attributed depending on provision failures. BSP failing more than once per month are reduced 1-30% of their availability price	N/A	N/A	N/A