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A literature review of Explicit Demand Flexibility providing energy services

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Abstract

Current power systems are characterized by the increase of renewable generation and distributed energy resources introducing more variability on the generation and enhancing the importance of the management in the consumption side. In this paper, a thorough review about the explicit demand flexibility (EDF) concept is addressed. This review, firstly, brings clarification over the different terms that have been used in the literature and the agents that are involved in the demand flexibility framework. Secondly, analyzes the different balancing services where EDF could participate, identifying the main barriers found for each market. In addition, it contributes to classify how mathematical models include EDF participation in ancillary services and congestion management, finding the main weaknesses and working lines for EDF integration in such models. Finally, a European overview is assessed to see where flexible resources have actual participation and how it is performed.

Keywords: Flexibility; Demand; DER; Balancing services; Congestion management; Aggregator; Europe.

Abbreviations:

Acronym	Meaning
aFRR	Automatic Frequency Restoration Reserve
AGR	Aggregator
AIM	Aggregator Implementation Models
AS	Ancillary Services
ATC	Available Transfer Capacity
BM	Balancing Markets
BRP	Balance Responsible Parties
BSP	Balance Service Providers
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbines
CEP	Clean Energy Package
DA	Day-ahead
DC	Direct current
DER	Distributed Energy Resources
DG	Distributed generation
DR	Demand Response

DSM	Demand-side Management
DSO	Distribution System Operator
EB GL	Electricity Balancing Guideline
EDF	Explicit Demand Flexibility
EG3	Expert Group 3
ESS	Energy Storage System
EV	Electric Vehicle
FCR	Frequency containment reserve
GHG	Green House Gas
IA	Independent Aggregator
IDF	Implicit Demand Flexibility
IGCC	International Grid Control Cooperation
mFRR	Manual Frequency Restoration Reserve
MV	Medium Voltage
NECP	National Energy and Climate Plan
OCGT	Open Cycle Gas Turbines
OPEX	Operational Expenditure
PV	Photovoltaic
REE	Red Eléctrica de España
RES	Renewable Energy Sources
RR	Replacement Reserve
RT	Real-time
RTE	Réseau de Transport d'Électricité
SUP	Supplier
TCL	Thermostatically controlled load
TOTEX	Total Expenditure
ToU	Time of Use
TSO	Transmission System Operator
V2G	Vehicle to grid
VPP	Virtual Power Plant
WIP	Work in Progress

Content

I.INTRODUCTION

Climate change has been an international concern since 1997 when some countries started to be aware of the high Green-house gas (GHG) emissions. Some of the most developed countries were interested in acting in consequence and carried out the Kyoto protocol, with the main aim of reducing GHG emissions [1].

In November 2016, several countries worldwide started moving in the same direction with the Paris Agreement. The main objective of this agreement was to limit global warming to 1.5 to 2 degrees Celsius above pre-industrial levels over the next century [2]. At the end of 2018, around 78% of total emissions in most European countries came from the energy sector, including energy used to power transportation sectors [3]. Therefore, an 'Energy transition' towards a more electrified and renewable system is being developed more seriously in recent years. European countries involved in the Paris agreement signed an update in 2018 with the 'Clean Energy package' (CEP) [4] that covers the following aspects:

- Develop a new electricity market design. This design includes the regulation framework about how demand and energy storage can participate in the markets and be connected to the main grid.
- Encourage and integrate Renewable Energy Sources (RES). The committed share of renewable energy in the EU's gross final energy consumption is set at a minimum of 32% by 2030. This percentage is translated to 74% share in the electricity sector.
- Increase energy efficiency. Member States must reduce their annual final energy consumption by 0.8% every year.
- Create a national roadmap for the following 10-year period (from 2020 to 2030). Each country had to develop a National Energy and Climate Plan (NECP). The NECP document should include each countries' objectives and targets regarding the five dimensions of the energy union: Energy security of supply, reinforced of internal energy market, improvements in energy efficiency, strategy for decarbonizing the economy and investments in research, innovation and competitiveness [5]. Moreover, policies and measures should be implemented to reduce GHG emissions, deal with renewables deployment, and increase interconnection between bidding zones.

Therefore, thermal generation is expected to be replaced with more RES installation, thereby considerably increasing uncertainty and volatility in the electricity system that results in a need of complicated management of the balance between electricity generation and demand. This balance has been guaranteed with thermal (e.g., CCGT, OCGT, Coal), pumped hydroelectric storage and cross-border interconnections so far. Hence, the integration of new technologies that provide security to the system without carbon emissions is required to face this challenge (e.g., demand management and energy storage) as assessed in [6]. For this reason, the CEP fosters the integration of energy storage and manageable demand in the markets.

In fact, electric networks are evolving with this energy transition due to the deployment of Distributed Energy Resources (DERs), including distributed generation (DG), manageable loads such as electric vehicles (EV), and different types of energy storage systems (ESS) both on a grid operating system scale and behind the meter. Consumers with DERs are now called prosumers. They can provide a wide variety of benefits to the grid operator such as voltage and reactive power control and solve localized distribution system congestions using their energy management capabilities [7]. Despite the fact that aggregated DER participation in the wholesale market it is already allowed in The United States[8] and a few countries in Europe [9], the options this paper will analyze for prosumers participation in the market are from the'demand-side participation' due to their small generation capacity.

There is previous work explaining different ways for the demand-side to participate in the markets. To make this operational, energy management systems are necessary, which are devices prepared to centrally monitor, analyze, and control DERs performance [10]. Besides, to take advantage of the flexibility potential of DERs of small end-users and to promote their access to the retail electricity market, an aggregator [11] is required to collect relevant amounts of DG, manageable load and ESS to trade their flexibility and benefit from rewards or lower energy bills [12].

Classifications to distinguish the ways to take advantage of prosumers flexibility has traditionally considered two kinds of participation. These two types have been referred with different terms; as price-based or incentive-based programs[13]; indirect and direct demand participation [13][14]; as static and dynamic demand participation [15]; as passive or active demand response[16]; and as implicit or explicit demand participation[7] correspondingly. The ones considered in this study are the most recent ones which correspond with implicit and explicit demand flexibility. The main feature that differentiates the two of them is the way flexible demand is used. On the one side, **implicit demand flexibility** (IDF) only takes advantage of flexible demand by incentivizing prosumers with different electricity tariffs to consume or generate at certain hours. Models presented in [17] and [18] use this kind of flexible demand, and the benefits that can be obtained are assessed qualitatively in [13] and in a quantitative way in [19] for the case of Spain. On the other side, **explicit demand flexibility** (EDF), refers to committed prosumers in acting to increase or decrease load or distributed generation in response to system needs, as presented in the model used in [20]. In particular, this review is focused on the different ways of exploiting EDF potential, as it has not been detailed addressed in the literature. The IDF can still play a crucial role in the electric systems to induce consumption behavior changes, but the EDF is the one prepared to provide sudden congestion management services to solve local and national constraints in distribution and transmission networks or to participate in balancing markets to solve stability issues for the transmission network.

Furthermore, a model classification has been performed in order to provide an overview of what has been and what can be done with respect to modeling the congestion and balancing markets including demand-side management participation. Classifying electricity market models has previously been addressed considering balancing services [21][22], even considering flexible demand participation [23][24]. However, no model assessment focused on European balancing products and congestion services where EDF participates as another market party, which is the perspective this approach tackles. References [14][25][26] analyze potential flexibility products and services. Demand-response-control schemes referred in [14] are related to the different services demand could provide, but it is focused on the IDF potential and the technologies prepared to do so. In [25] a comparison between UK and USA flexible demand participation is addressed, conversely, this paper provides a holistic approach on how developed EDF integration is in all European countries. Resource [26] presents flexibility products and services from both transmission and distribution levels. However, it does not delve into the different available congestion and balancing services nor how specifically demand could be included as a market participant.

The aim of this paper is to bring clarification over demand response concept and all that surrounds it, exposing its high potential providing energy services. On this purpose, the paper contributes to organize demand response terms and involved agents for its exploitation; explains why EDF is the one that offers flexibility to the electricity system; classifies congestion management and balancing services in which EDF can bring value regarding also the main barriers found for including it as another market party in European products; identifies main weaknesses of mathematical models that include EDF participation in balancing and congestion management services; finally it analyses how integrated is EDF in European countries markets and classifies projects and initiatives being performed to develop it.

This paper is organized as follows. Section II presents the historical evolution of the terms meaning and involved agents roles in the demand flexibility framework and why it is needed. The balancing and congestion management services where EDF could participate are assessed, providing the main barriers found to include EDF as another market party. The way this participation has been modeled so far is presented in section III. How EDF participation is implemented in some European countries is analyzed in IV. Section V summarizes the paper's contributions and points out some relevant gaps of the literature on the EDF matter. Finally, conclusions are gathered in section VI.

II. EVOLUTION OF TERMS IN THE LITERATURE

This section brings clarification over the mix found in the literature when referring to demand-side flexibility terms, when they are used and how did they evolve along the years. Besides, describes the different agents required to exploit the available flexible demand in the system.

1) Electric system flexibility

The *system flexibility* is defined as the need of the electric system to adjust generation (*Generation flexibility*) or consumption (*Demand-side flexibility*) in order to maintain a secure system operation considering grid stability constraints and interruptible renewable energy sources [27]. In [25] and [26] potential flexibility products and services are analyzed mixing both generation and demand-side flexibility.

On the one hand, the conventional main sources that have been providing generation flexibility to the system are:

1) *Thermal generation*: fossil-fuels power plants can provide flexibility to the system thanks to their faster regulating advantages. The more energy is needed, the more fuel is burned and the other way round. However, the huge environmental impact together with the more restrictive policies in emissions and renewable shares, make necessary alternatives to substitute this source of system flexibility.

2) *Cross-border interconnection*: Exchanges facilitate adjusting wholesale, balancing, system support and reserve markets [27]. The Electricity Balancing Guideline (EB GL) enables Transmission System Operators (TSOs) to reserve cross-border capacity to facilitate the exchange of balancing energy. This process will be co-optimized with capacity reserved for market timeframes [28][29].

3) *Energy storage*: can adapt its electricity production and consumption to system requirements. Hydro plants have been the traditional way to do it, but the places where these plants can be built are limited. Another way to store energy is batteries, but it also presents environmental impacts, as indicated in [30].

On the other hand, demand participation started to be available through “interruptible-load tariffs” for commercial and industrial customers in the 50s [31]. In the 70s, experts began to see the potential of changing demand patterns, mentioning the future cost-effectiveness of reducing electricity demand rather than increasing supply [14]. Demand-side flexibility or demand-side management (DSM) term started in 1973[14], when electric utilities slowly started to include DSM programs in their strategic plans. In the beginning, DSM was exploited with time-based electricity tariffs such as Time of Use (ToU) tariffs[32], thus giving rise to the first demand response (DR) programs, which will not receive this name until the late 80s[33]. Later on, DSM started to provide energy or power when wholesale prices rose, when there was a shortfall of generation or transmission capacity issues or during emergency grid operating situations (load shedding) [34]. Nowadays, DSM could be used to reduce the energy bills of the prosumers responding to price signals or help the system with frequency restoration, congestion management, and voltage control support [34]. The whole DSM concept includes all DER possibilities that range from load management (which is referred to as DR) to distributed solar photovoltaic (PV) panels and storage onsite. Therefore, it is becoming possible to participate in balancing and congestion management services where regulation measures are prepared. Figure 1 summarized all the abovementioned terms evolution and some relevant events for demand-side flexibility development.

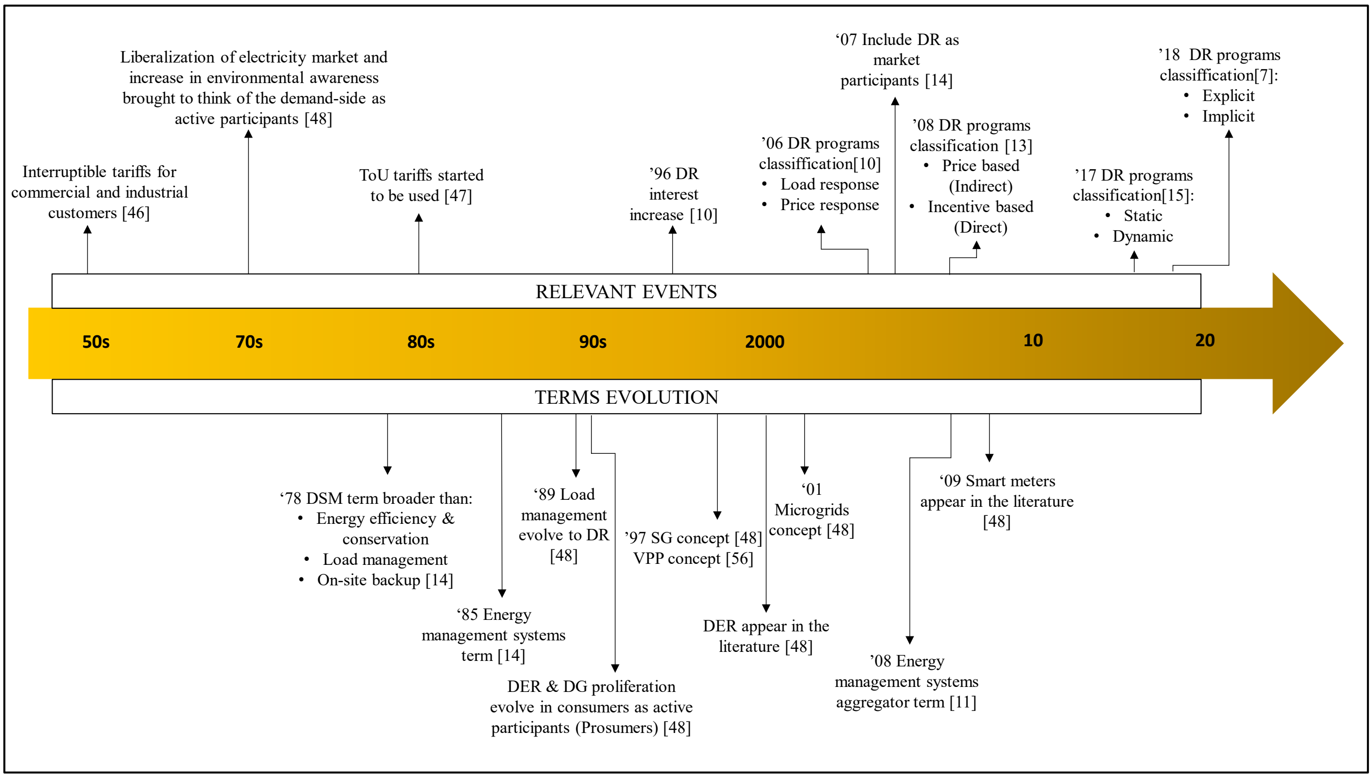

Figure 1. Evolution of demand-side flexibility related terms

The most recent way DSM is exploited leads to two types of flexibility[7] whose main difference is how the change in consumption is incentivized:

1) Load management concept evolved to DR, being defined in the literature[19][35][10] as any form of communicating to the end-user their energy consumption in order to encourage them to modify it, responding to changes in prices to reduce their bill. This is now named as **IDF** [36] which is the same concept as price-based DR [35] and indirect, static or passive demand participation, since demand is fostered to change according to price signals that sways customers consumption decisions [36] [37]. The main tools to take advantage of the implicit flexibility are the Electricity **tariffs** [15]: ToU tariffs [38], Power based tariffs or Real Time pricing [39]. All of them have a common thing, end-users see different power or energy prices during the day to be willing to consume more or less in specific periods. However, there is no guarantee that demand would follow those premises. Therefore, this type is used to flat the demand curve to avoid network reinforcement in long term, but it does not provide real-time flexibility to the system as there is no commitment from the consumer point of view since end users can freely decide whether to react to these price signals or not.

2) In the early 2000s, DR could also refer to situations where a prosumer is committed to provide a flexibility service and therefore considers a reward or a penalty for complying or not with it, it is known as **EDF**. This flexibility can also be referred to as incentive-based DR [35] and direct, dynamic or active demand participation. In this case, the incentive can be understood as an additional payment for developing a flexibility action.

   EDF usually involves all DER options, from the capacity of manageable loads to move their consumption (DR) to the generation produced by DG and storage onsite, which are also understood as part of the demand-side resources.

This approach consists on re-scheduling consumption or onsite generation with a specific strategy that can be for instance, to bring stability to the network, to avoid peak electricity prices or to deal with grid congestion problems [40] competing directly with power plants (As a Virtual Power Plant (VPP))[41][42] in the wholesale market, balancing markets, system support and reserves markets. If it is a large prosumer, then individual participation can be considered. In any other case, **aggregation** is required. The energy is committed with the system operator [36][37] to obtain a reward for the given service. The benefits of using explicit demand flexibility to efficiently manage a high RES scenario is assessed in [43].

Therefore, IDF could flat the curve and reduce expected network congestions if end users decide to follow the signal, whereas the EDF is the only one that can offer flexibility/adaptability (balancing services and sudden congestion problems) to the system in real-time since it is the one that can participate in the markets in the same conditions than traditional generators to solve specific system need. In reality, both will be present in the usual operation. As a reference of the benefits that could be achieved with combined explicit and implicit demand flexibility, [44] concludes that savings in the electricity system in the UK could be around £4.55bn/year. These savings are allocated throughout the system, 60% from avoided investment in network capacity, 16% from avoided investment in generation peaking capacity, and 22% from the reduced curtailment of renewable energy [44]. Besides, significant network investments will be reduced by 50% of the expected cost by 2050. A flexible electricity system will be crucial for ensuring that the build-out of network expansion until 2050 will be feasible [44]. Henceforth, paper is focused on the EDF type.

2) Involved agents

Although technically possible, EDF still has a long way to go. The development of an EDF framework will provide relevant advantages such as the increase of system flexibility sources to cope with the high RES scenario, savings associated to the avoided investment costs in networks and the ones associated with the avoided payments for curtailing RES to solve congestions [45]. One of the main challenges is that manageable electricity demand coming from residential buildings and small and medium size enterprises [46] need the figure of the Aggregator.

The *Aggregator* figure has appeared in the system in order to obtain enough volume to participate in ancillary services markets, joining different amounts of distributed generation and small amounts of flexible consumption (from residential or commercial customers) [47][48]. The Regulation on aggregation is still being developed. For example, the Spanish NECP is committed to promoting the aggregator role and detecting ways to encourage it: economic incentives, more efficient technologies and techniques, and influencing consumer habits [49]. The final regulation about the Aggregator should clarify the utilities and customers in terms of roles and responsibilities, guarantying a fair exchange and access to data and ensuring fair competition while protecting relevant information [49]. It should also establish the relationship between entities that provide aggregation services and other market participants, coordinating also liability for deviations [49].

Other agents are also relevant to face this new context, such as the Balance Service Providers (BSPs) and Balance Responsible Parties (BRPs). The first ones, BSPs, are market participants that can offer balancing services to TSOs in terms of capacity or energy and can provide energy bids for the market on a voluntary basis. They include generators, aggregators, and energy storage operators. The latter ones, BRPs, represent a group of BSPs being financially responsible for their portfolio's imbalances (consumption/generation deviations) [50].

If the aggregator and the utility that supplies energy to a prosumer are different entities, the Aggregator is named as *independent aggregator* (IA). In this situation, the aggregator must have the option of exploiting the prosumer EDF without signing a contract with the supplier or BRP serving the same prosumer [47]. An imbalance charge is imposed to the BRP if the scheduled sum of generation and consumption does not match the actual one in real-time [51]. In this special case, regulation should care about how to deal with imbalances and with the financial risks assumed by the associated BRP and Supplier, with the IA actions [52].

2019/944 Directive [53] clearly states how compensation should not result in a barrier to the development of the aggregator's activity. However, the IA models present some barriers in European countries' regulation related to supplier and aggregator financial compensation methodology and the imbalance volume correction methods. The main difficulties found are stated in Articles 17.3 and 17.4 of the EU proposals and are related to the 'imbalance' issue and the 'bulk energy' issue, respectively [54], that retailer would suffer from the IA actions:

1. **Bulk energy issue** is referred to the problem caused to the retailer due to the difference between actual consumption compared to the day before procured energy as supplier neglects when EDF can be activated. Hence, the retailer perimeter is modified, and as a result, the retailer will not invoice the full electricity procured cost [54].

2. **Imbalance issue** refers to how retailers would deal with electricity deviations caused by the IA when activating the reduction or increase in demand and not due to an estimation mistake. Volume correction or energy transfer is necessary for imbalance settlement [54]. Nonetheless, beyond the time of activation of the service, consumers who, due to the energy requirements in their processes, must offset the activated demand by additional / less consumption afterward, would create an imbalance problem again. This situation is called the 'rebound effect'. However, according

to the Electricity Directive [53], if the aggregator has no active role in the rebound period and the energy transfer has already been arranged between supplier and aggregator in the initial period of activation, the imbalance issue would be only supplier's responsibility during the rebound period [54], as only costs incurred during the activation of the service can be recovered through compensation.

In Europe, only France and Switzerland have defined legislation for IA [55] facing these issues. There are countries where IA can only access markets in agreement with the customers BRP, such as Finland, Germany, and Denmark. There are also cases where the aggregator is responsible of adjustments and their costs to correct imbalances caused by demand. In this case, payments to the BRP are negotiated and agreed between aggregator and the BRP as they do in France. While in other countries, TSO assumes responsibility for imbalances adjustments and costs such as Switzerland, Ireland, and Finland [48].

How aggregator operates and interacts with other system parties is known as Aggregator Implementation Model (AIM) [47]. The flow diagram shown in Figure 2 presents the options that will define the different possibilities of AIMs. In Figure 2, supplier is referred to as SUP and aggregator as AGR:

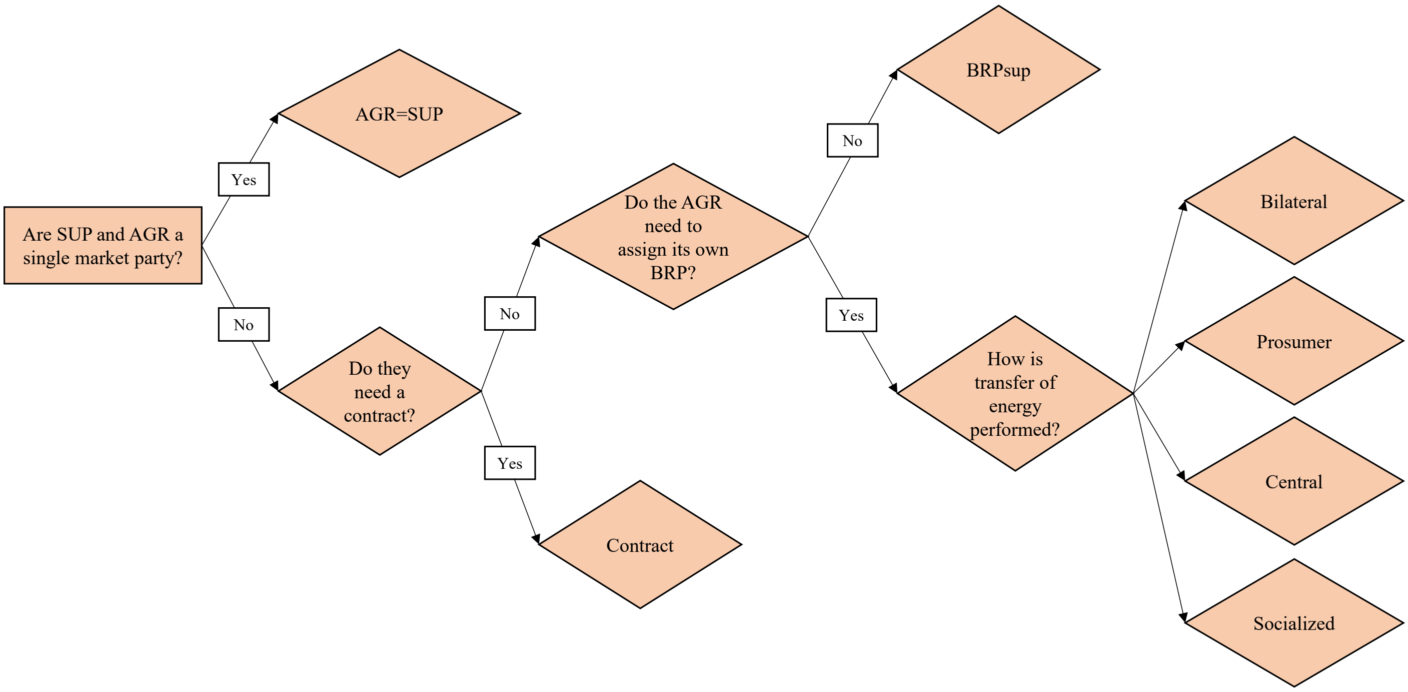

Figure 2. Aggregator Implementation Models characteristics

If besides the BRP_{SUP} there is also a BRP_{AGR}, the transfer of energy methods work as follows[47]:

I. With bilateral energy contracts, the aggregator will receive the energy ex-post from BRP_{SUP} through a hub deal. The amount of energy transferred would be equal to the difference between measurement and baseline.

II. When the energy is transferred via the prosumer, the aggregator is responsible for financially compensating the prosumer for the overcharged or undercharged energy, depending on contract conditions.

III. The centralized method uses rules to enable the responsible allocation party to transfer the energy between the BRP from the supplier and the one from the aggregator.

IV. The socialized method implies that there is no energy transfer from/toward the aggregator BRP. However, the impacted supplier is compensated through a regulated price formula by all other BRPs for the sourced but not delivered energy.

The combination of the electricity imbalance correction (Transfer of energy methods presented in Figure 2) and the financial responsibility when there is no contract between supplier and aggregator [47] result in different IA models [56][57]. According to 2019/944 directive[53], the main combination options can be summarized in three models:

- **Uncorrected model**: There is no imbalance volume correction or compensation, hence the BRP compensation is settled through the socialized energy transfer method.

- **Corrected model with no compensation**: Where there is imbalance volume correction but no compensation. Usually, the prosumer corrects the BRP's imbalance volumes based on the amount of activated flexibility. For TSO markets, the correction responsibility lies in the same TSO. However, the BRP does not receive compensation from any market participant in any case.

- **Corrected model with compensation**: Where there is imbalance volume correction and compensation with a bilateral contract. TSO corrects the BRP's imbalance volumes based on the amount of flexibility that was activated. In addition, a reference price should be agreed with the purpose that the aggregator compensates the BRP [57].

Together these features provide a common starting point for the aggregator figure that will speed up cross-border trading of EDF products, contributing at the same time to the development of a single European market for demand-side participation. Each member state has complete freedom to choose the most suitable AIM to comply with the 2019/944 directive[53].

Figure 3 is a scheme to present and clarify previous explanations, terms used, and interactions, together with the means to facilitate demand-side flexibility incorporation in the markets.

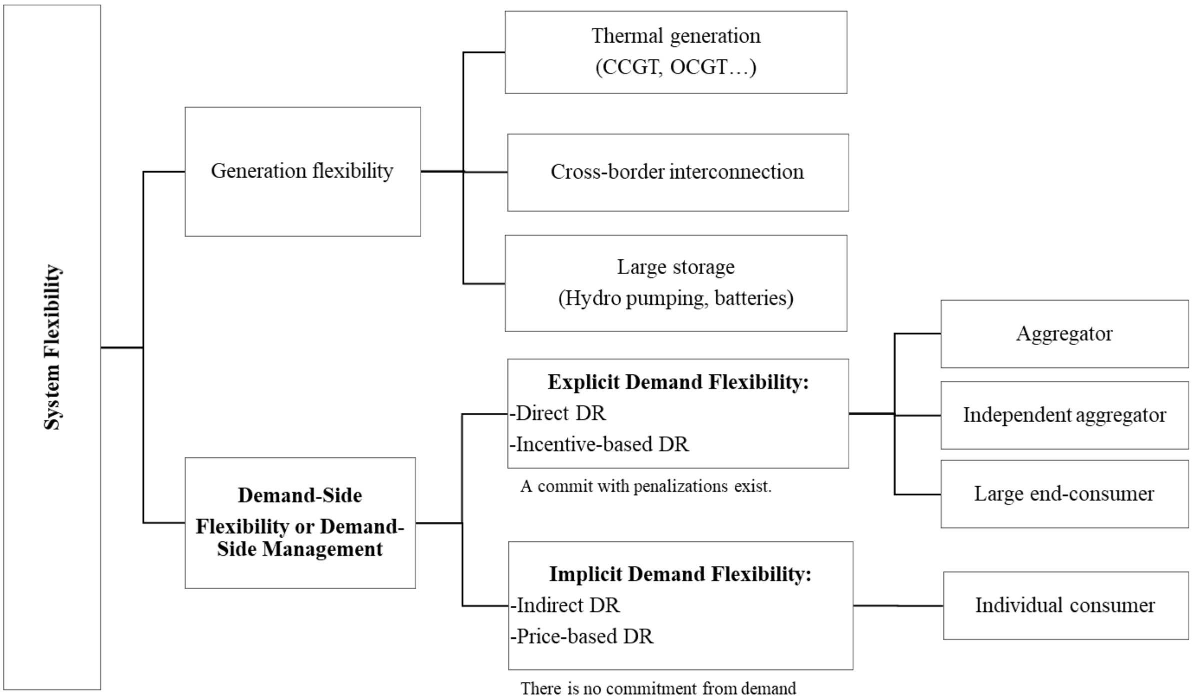

Figure 3. System flexibility clarification

III.EDF IN BALANCING SERVICES AND CONGESTION MANAGEMENT

This section contributes to highlight the possibilities of EDF participating in balancing and congestion management services working in European countries. Furthermore, the main barriers found for integrating EDF as another market party are addressed and classified. Lastly, this section contributes to gather and classify the mathematical models available in the literature, designed to include EDF in balancing and congestion management services.

The markets or services where prosumers electricity flexibility is participating differentiate between wholesale markets, adequacy management services, congestion management services, and balancing markets [7].

- Wholesale markets: flexible demand participation has been previously regarded and analyzed in detail a while ago with also recent findings and new models testing [58][59][60]and possibilities assessment. Besides, the impact of demand flexibility participating in the wholesale markets has also been analyzed from retailers' side [61]and electricity system side [62]. There are many European countries where flexible demand is already participating, such as: Denmark, Finland, France, Germany, The Netherlands, Norway, Poland, Sweeden, and Switzerland [63]. The introduction of demand flexibility in the wholesale market involves a decrease in the spot market price along the usual day peak hours [64][65]. However, these markets are out of the scope of this review.
- Adequacy management services (capacity mechanisms or strategic reserves): European Countries are cautiously allowing demand participation in this market. Directorate-General of Competition of the European Commission has recently

approved four capacity mechanisms in Poland, Italy, France, and Greece, and two strategic reserve schemes in Belgium and Germany[66]. However, that does not mean demand-side is allowed to participate. For instance, demand-side is allowed to participate in Germany, but the lack of transparency and the eligibility criteria for providers makes uncertain the actual participation[67]. France has real EDF participation [68], and Italy is working on it [63]. The demand-side flexibility potential to provide adequacy services has already been analyzed for some northern European countries: Sweden, Denmark, Finland, Norway, Estonia, Latvia, and Lithuania are assessed in [69] achieving that the peak of the system could be decreased by a 15-30% with the use of demand-side flexibility. Nevertheless, these markets are out of the scope of this review.

- Congestion management services can also be provided by EDF. Multiple models are being developed where the DSO can take advantage of demand-side flexibility to solve its own congestion problems. Some countries that are doing this are: Netherlands, Belgium, Germany, Denmark, Ireland, Norway, France and recently Spain [70]. These markets will be assessed in this review.
- EDF participation in balancing services has a vast potential presented in [71], which is still untapped in most European countries. Only a few countries have a high deployment of demand-side regulatory measures for participating in balancing services, such as Germany and Switzerland [63][72]. These are the markets that will also be assessed in this review.

Thus, this section provides a general overview of the balancing services working in European countries according to their regulation requirements and congestion management available services as they are the main EDF focus markets. These services are described and analyzed to see the EDF potential when participating as another market party. Furthermore, the main barriers found for integrating EDF are addressed. Lastly, in this section, mathematical models designed to include EDF in balancing and congestion services are classified and explained in detail.

1) Balancing Services

Balancing services aim to restore system frequency to its nominal value of 50Hz (in Europe) and maintain active power exchanges within the scheduled threshold maintaining power quality at the lowest cost. The TSO is the responsible party for dimensioning and procuring this service guaranteeing sufficient capacity and energy [28].

The different balancing services are explained in detail and how demand participation could add value to the services:

Frequency containment reserve (FCR): Primary reserves respond rapidly (within milliseconds), usually in an automated way, against frequency deviations in the grid. This fact is why only thermal power plants have traditionally supplied FCR. However, there are several types of loads (Electric heaters, heat pumps, EV…) that are prepared to supply this service although the fast ramp rate and the frequency of activation and shortages still makes it difficult for EDF to participate [39]. Remuneration can be capacity-based, activation-based, a combination of both of them, or not remunerated when it is a mandatory service for generators [73].

Frequency Restoration Reserve (FRR): it is the second step in the case that frequency has not returned within the agreed threshold, 30 seconds after the disturbance. The aim of FRR service is to replace FCR to release the capacity needed by the primary control and to restore the primary control reserves. Remuneration can be capacity based, energy based, a combination of both, and can be pay-as-bid (remunerated at the offered Price) or pay-as-cleared (price determined, for each hour, by the intersection of the demand and supply curves) [73]. Activation time is required to respond between 30 seconds up to 15 minutes after the disturbance [51].

- *Automatic Frequency Restoration Reserve (aFRR)*: Automatic service activated between 30 seconds and 15 minutes after the disturbance by the load frequency controller of the TSO.

- *Manual Frequency Restoration Reserve (mFRR)*: After the aFRR service since it has a slower ramp rate and can last longer. This service is activated manually and operates in a continuous manner to recover aFRR reserves after the frequency has been restored [7].

EDF has a high potential to participate in these services, but product requirements still need to evolve, allowing aggregation, smaller minimum bids, and asymmetrical bids [72].

Replacement Reserve (RR): the service replaces the previously activated reserves (aFRR or mFRR) to return to full operation with availability of reserves and be prepared to respond to another failure in the grid. RR has a longer duration and slower ramp rate than the previous frequency restoration services. Activation needs to last from 15 minutes up to two hours and it is manually or semi-automatically activated [51]. RR long-lasting activation periods are a barrier for EDF participation as long as aggregation is not permitted. Remuneration can be according to terms of energy provided or a mix of the energy supplied and available capacity [7].

In general, balancing services in Europe are organized in time as Table 1 summarizes [72][74]:

Table 1. Balancing Services timing

Product	Response time	Lasting time
FCR	0-30s	15min
aFRR	30s-15mins	15min
mFRR	≤15mins	15min
RR	≥15min	2h

The slowest balancing service takes 30 minutes at the most to activate it. For this reason, an efficient EDF participation design able to respond to system needs in a fast way is essential to foster its development.

2) Congestion management

Congestion management aims to avoid the thermal overload of system components [7]. There are two different congestion management categories: preventive and corrective methods[75]. Both congestion management categories are procured with market-based programs rewarding service providers (Consumer, aggregator…) with money. The reward is based on a good performance, penalizing participants who do not successfully respond to their commitment decrease in consumption. These penalties are different depending on the program terms and conditions.

On the one hand, preventive methods are based on using transmission rights and available transfer capability (ATC) considering congestion issue in a medium- or long-term basis. On the other hand, corrective methods are performed in real-time electricity markets (short-term basis) when congestion problem has already occurred. Therefore, the DSO requires a quick response complying with regulatory and networks operator rules. Corrective methods utilize the activation of flexible DSO /TSO grid assets. One traditional source is the interruptible load that some large consumers provide. Another flexible asset that can be used is EDF. To procure with it, participating prosumers are informed of the ATC in order to optimally modify their consumption pattern to alleviate the congestion taking place while, at the same time, increasing their own benefits [75]. EDF for corrective congestion management services, results a cost-effective solution [70][39].

3) Main barriers for EDF participation in balancing and congestion services

A two-level classification of existing barriers is presented to separate the first actions that must be overcome before facing the second level barriers

i. First level barriers: These ones are related to technological advances and social approval to increase the EDF potential.
   - Remote control of the demand should be developed with equipment that allow measuring asset consumption. Facing sub-metering challenges and very fast granularities for data control needs to be implemented together with the deployment of smart equipment and submetering options.
   - Larger quantities of demand (electrification) are needed to make it manageable and worthy to prepare regulatory measures.
   - Social acceptance and normalization of contributing to this matter investing in electrical devices and making the flexible consumption available to an aggregator.
   - Prepare the network to allow bidirectional power flows in order to take advantage of the increase in DER installation.

ii. Second level barriers: Subsequently, renovating regulatory measures is required in almost all the countries to enable and foster EDF participation in balancing and congestion services considering the guideline that can be found in [28]. The main regulatory barriers that prevent its inclusion could be handle by modifying the following three regulation blocks [37]:

   - The standardization of the different products allowing EDF participation: Which means that prequalification, measurement and verification protocols must be clearly defined for each service. Also, payment and penalties criteria should be based on open and fair competition. Besides, a baseline consumption calculation method should be stated, which estimates what an end-user would have consumed if EDF had not been used [76]. This methodology needs to be developed for consumers to be paid for what they provide. Lastly, clarifying service prioritization rules and forecasting where demand flexibility will be more valued will facilitate investment decisions [77].
   - Aggregators allowance: Member States must define roles and responsibilities around aggregation providers. Relationships between retailers, BRPs and IAs should be clarified and again search for fair competition. Well-defined standard procedures by the regulator and TSO are important to protect the financial interests of all parties [37]. Hence, to manage in a fair way the access to data from the different entities, a process reform is

required [77]. To guarantee security in this data exchange, cyber-security protocols should also be developed [77].

- Adjust technical requirements in line with participants' capabilities: It is important to play in a competitive framework holding auctions in a transparent manner. Hence, strong and traditional requirements for market parties, need to evolve. For instance, the bidding size requirement should be small enough to allow new entrants such as EDF and IA [53]. The duration of the call should be as short as the technical requirements of markets allow. Availability of the offer may change according to specific necessities [78], always trying to keep it as small as possible. Moreover, the frequency of activations/short recovery periods should be reasonable as some participants need time to rest between activations. Lastly, asymmetrical bids should be allowed to foster some new technologies integration in the market [37]. Table 2 summarizes the main technical barriers that the different ancillary services find to include EDF as another market party. Moreover, the potential of EDF in that particular service is assessed considering three levels: high (H), medium (M), low (L), which evaluate the economic efficiency of using EDF instead of other technologies considering the difficulty of inclusion versus benefits achieved such as avoidance of generation investment.

Table 2. Main technical market barriers for EDF participation

<table>
<tr><th></th><th>Services</th><th>EDF potential</th><th>Main barriers</th></tr>
<tr><td rowspan="4">Balancing services</td><td>FCR</td><td>L</td><td>Too fast ramping rates. Symmetrical and high min bids. Very frequent activations/Shortages</td></tr>
<tr><td>aFRR</td><td>M-H</td><td rowspan="2">High min bids. Very frequent activations/Shortages. Aggregator allowance</td></tr>
<tr><td>mFRR</td><td>M-H</td></tr>
<tr><td>RR</td><td>L</td><td>Availability of the activation offer can be too long for EDF. High min bid.</td></tr>
<tr><td>Congestion management</td><td>DSO /TSO</td><td>H</td><td>Aggregator allowance</td></tr>
</table>

4) Mathematical models that include EDF in balancing or congestion services

Two exploitation manners of demand flexibility were clearly identified in section II, are modeled in the literature. First, implicit demand flexibility has been largely addressed using price signals [79] [80][81] which foster customers to change their consumption patterns. However, the real challenge is to include EDF as a market participant in the models as the bunch of services that EDF can provide are much wider than the implicit one. Hence, models presented in Table 3 focus on EDF integration, though [82] and [83] include both.

Depending on the markets where EDF is involved, there is more or less work done beforehand. Much work has already been done in order to find the best way to model EDF participation in the wholesale markets, affecting somehow to the spot price[84][85]. However, recent work [86][87] has proven a high potential of demand participating in the ancillary services markets using their EDF capability. In this regard, it is still not fully mature the best practices to model EDF participation in ancillary markets. In this section, previous work related to models that include EDF participation in balancing services will be classified in Table 3 below to address the main weaknesses of EDF participation in balancing services.

Other models' classifications have been previously done. However, the focus of the classifications is very different. In [88], the classification is based on the changes required in power system planning models to include a high variable renewable energy integration and discuss various scenarios on a national or regional level. In addition, this classification does not necessarily include demand-side response as a source of system flexibility and the markets where EDF can participate are not analyzed. In the classification presented in [89], all kinds of approaches performed to implement demand response programs in the smart grid environment are presented. However, these approaches are not only mathematical models (Pilot projects and other type of approaches are included) and approaches are not oriented to market participation. Hence, the gap in the literature addressed in this section is a mathematical models' classification that include EDF participation in balancing and congestion management services.

The features assessed to classify the balancing models are:

- ✓ **Electricity markets modeled**: defining which balancing services are considered (FCR, aFRR, mFRR and RR) and if previous energy dispatch is considered. When referred as 'balancing services', all balancing services are included. However, the modeling treats all of them as a whole for computational simplification.

- ✓ **Time framework:** depending on the target of the model, different time frameworks for market-solving are considered. Long-term consideration usually corresponds with 'Generation expansion planning models' and can be daily or hourly scheduled (with a lot of simplifications, such as representative weeks or months for each season). For short-term planning there are three main markets: day-ahead (DA) [90], intra-day [82] and real-time (RT) [91]. For DA, hourly schedule is used, and for RT, sub-hourly timing is considered. As our interest is focused on reserve markets, energy capacity to provide these services is traded the DA and power is activated in RT. This is why all models work in a short-term schedule and classification over this feature considers DA, intra-day or RT markets.

- ✓ **Sources of flexibility:** All these models consider EDF participation. For this reason, to characterize them, it is relevant to specify which sources of flexibility are considered. Options are: DG, Energy Storage Systems (ESS) and manageable loads, such as EV, thermostatically controlled load (TCL) or shiftable load (SL) in general. The particular case of the electric vehicle to grid (V2G) acts as an ESS. Flexibility modeled can come from a specific type of loads such as EVs [92] [93], electric heating systems [90] or all types of aggregated load [94][95][96]. The way these loads are modeled can be as a linear segment that can be plugged or unplugged [97], referred to as demand blocks, or in the case where the aggregator is involved, full control is assumed over each particular load [92][93] [94]. Furthermore, when aggregator gathers DG or ESS besides load, the same criteria applies [98][99] [100] [101] [102] [103] [104] being the aggregator the full responsible to decide whether to bid in one market or another and which flexibility resources should provide it.

- ✓ **Flexibility remuneration mechanism:** In addition, to encourage EDF providers to participate in the markets, cost avoidance analysis presented in [82] [90][101] are not enough, remuneration mechanisms for flexibility products are necessary. However, they are still not well developed nor clear the best way to do so. Nevertheless, some models presented in Table 3 consider somehow demand flexibility payments. Some remuneration mechanisms can distinguish two different paid categories, band availability and utilization (in both directions) [99]. A more used remuneration mechanism only remunerates for utilization [98][92][93][105], considered as the resources that changed their dispatch. In [92] a penalization for the deviations is also considered. Another way of remuneration in an indirect way for the flexibility used is by reducing billing costs [102]. Capacity payments are considered in [94] and as an up-front payment for only availability is also considered in [103].

- ✓ **Network consideration:** the network constraints are considered or not depending on the target of the model and the accuracy of results required. Table 3 gathers models with and without network consideration. There are also different ways of considering the network. For instance, as a microgrid, which assesses local results for specific studies as presented in [101] and [104]. In case the model applies to a whole country or a bigger system, a 'national grid' is considered where the way the grid is modeled is with power limitations based on ATC [95][102][103]. Moreover, in these models, the grid is simplified as active power limits (Direct Current (DC)). On the other side, in other studies as [92] and [93] unidirectional interaction with the grid is assumed, hence network is not modeled, as congestion and allocation of loads and generators are neglected.

- ✓ **Mathematical formulation**: This classification differentiates between deterministic optimization (Det.), stochastic optimization (Sto.), or equilibrium (Eq.) model based on [22]. Optimization models are formulated as a single objective function to be optimized, subject to a set of technical and economic constraints. When an optimization model considered perfect competition dispatch, the objective function is usually focused on (as explained in [21]) maximization social welfare[82][102], maximization profit or minimization of operational costs, where most models are formulated with this last objective function [94][92][93][98][99][97][95] [96][100][101][90][103][104]. Furthermore, according to its parameters, certainty can be deterministic or stochastic. It is deterministic when parameters are known (i.e. mean value) and is stochastic if parameters are modeled as random variables with known distributions (Probabilities). In contrast, equilibrium models consider the simultaneous profit maximization of each participant competing in the market, usually using game theory approaches [22]. Models based on game-theory are adequate to assess medium and long-term strategies, as they evaluate and calculate the strategic behavior for every generation company. However, these models are generally simplified by using demand representations that do not follow a chronological sequence. Hence, when looking at reserves, these models are not appropriate as temporal constraints are not considered [21].

- ✓ **Market clearing-price calculation:** When calculating the market clearing-price it can be considered the initial investment payback which refers to the capital expenditure (CAPEX) which is not very common, the operating costs (OPEX) or consider both costs (TOTEX) to calculate the price.

Table 3 shows the abovementioned characteristics of the models with EDF participation in balancing services from the literature.

Table 3. Mathematical models for balancing services

Source/ Model	**Markets involved**	**Timing (DA, intra-day or RT)**	**Sources of EDF**	**Payment/remuneration for flexibility**	**Considers the Network (Yes,No) Type.**	**Opt.Sto, Opt.Det or Equilibrium**	**CAPEX, OPEX or TOTEX**
[82]	Energy and balancing services	DA, intra-day and RT	Aggregated load	No	No	Det	TOTEX
[83]	Energy and balancing services (FCR, aFRR, mFRR)	DA	Aggregated ESS	No	No	Sto	OPEX
[90]	Energy and balancing services (aFRR, mFRR, RR)	DA	Aggregated residential electric heating systems	No	No	Det. with stochasticity for RES generation and flexibility availability	OPEX
[91]	Balancing services	RT	Aggregated residential thermal energy storage	No	No	Det	OPEX
[92]	Energy and mFRR	DA and hour ahead	Aggregated load from EV	Yes	No	Det.	OPEX
[93]	Energy and balancing services	DA and RT	Aggregated load from EV	Yes	No	Sto.	OPEX
[94]	Energy and only upwards mFRR	DA	Aggregated load	Yes	No	Det.	TOTEX
[95]	Energy and balancing services	DA	Aggregated load	No	Yes. National. DC	Sto.	OPEX
[96]	Energy and balancing services (FCR, aFRR, mFRR)	DA	Aggregated load	No	No	Det.	OPEX
[97]	Energy,FCR, aFRR, mFRR and RR	DA	Demand blocks	No	No	Eq.	OPEX
[98]	Balancing services	DA and RT	Aggregated DG, ESS and load	Yes	No	Sto.	TOTEX

[99]	Energy and aFRR	DA and RT	Aggregated DG and load (V2G or TCL)	Yes	No	Sto.	OPEX
[100]	Energy and RR	DA and RT	Aggregated DG and load (SL, V2G or TCL)	No	No	Sto.	OPEX
[101]	Energy and balancing services	DA	Aggregated DG and load	No	Yes. Microgrid	Det.	OPEX
[102]	Energy and balancing services	DA and RT	Aggregated DG, ESS and load	Yes	Yes. Maximum power flow of lines	Sto.	TOTEX
[103]	Energy and balancing services	DA and RT	Aggregated DG and load	Yes	Yes. Maximum transmission capacity of lines	Sto.	TOTEX
[104]	Balancing services	DA and RT	Aggregated DG and load	No	Yes. Microgrid	Sto	OPEX
[105]	FCR	DA	Aggregated thermostat and heating units	Yes	No	Det	TOTEX
[106]	Balancing services	DA and RT	Aggregated ESS provided by: water heaters, pools and agriculture loads	No	No	Det	TOTEX

For congestion management models with EDF participation classification presented in Table 4, the characteristics that have been considered are similar to the ones above with some nuances:

- ✓ **Electricity markets modeled**: When the focus is placed on the markets that apply to constraint management the options are: voltage control, network loss and congestion management. When all of them are modeled, it is referred as 'All DSO services'; when there is no specification over the market modeled, it is referred as 'DSO services'. Besides, these services can apply to the TSO [81], to the DSO, or both. In [107], congestion and balancing services are modeled at the same time as an exception.
- ✓ **Time framework:** It is a relevant feature for these models whether they are designed to prevent a future congestion problem or correct an already existing one. Therefore, the timing where the congestion is solved is classified between preventive or corrective [75].
- ✓ **Sources of flexibility**: For this research, only EDF sources are considered. Therefore [81]has been neglected as only implicit demand flexibility is modeled for solving congestion problems. This classification is the same as for balancing services detailed explained above.
- ✓ **Flexibility remuneration mechanism:** As mentioned, it is still not well developed nor clear the best way to remunerate flexibility services. For solving congestion problems, some examples for remunerating this service are regarded in the models presented in Table 4. In [108], remuneration is defined by end-users according to changes in baseline consumption. In [109] a price incentive iteration method is applied to EV aggregators. In the model presented in [110], the objective is to maximize the payoff for the electricity provider which is obtained by subtracting the cost of energy purchase at the wholesale market from the sales to end-users.

- ✓ **Network consideration:** congestion can occur in the distribution or in the transmission grid, as EDF is connected to the distribution grid, all the models analyzed take the grid into account only at distribution level.
- ✓ **Mathematical formulation:** Focus on the same classification explained above, differentiating between deterministic optimization (Det.), stochastic optimization (Sto.) or equilibrium (Eq.) model based on [22].
- ✓ **Purpose:** The purpose of all these models is minimizing the costs (or maximizing the profit) of procuring with flexible sources capable of solving congestion at distribution level and minimizing also congestion problems. The optimization problem can be regarded from different entities: DSO or Aggregator.

Table 4 below shows the abovementioned characteristics of models that include EDF participation in congestion management services from the literature.

Table 4. Mathematical models for congestion management services

Source/Model	**Markets involved**	**Timing (Preventive or corrective)**	**Sources of EDF**	**Payment/remuneration for flexibility**	**Considers the Network (Yes, No)**	**Opt.Sto, Opt.Det or Equilibrium (Eq)**	**Purpose**
[75]	All DSO services	Preventive	DG and ESS	No	Distribution grid	Det	DSO
[107]	Balancing and CM for DSO	Corrective	Aggregated loads	No	Distribution grid	Det	DSO
[108]	DSO and BRP services	Preventive	Aggregated Residential loads	Yes	Distribution grid	Det	Aggregator
[109]	All DSO services	Corrective	Aggregated EVs	Yes	Distribution grid	Det	DSO
[110]	CM service for DSO	Preventive	Aggregated EVs and HP loads	Yes.	Distribution grid	Sto	Aggregator
[111]	CM service for DSO	Preventive	Aggregated industrial and residential loads	No	Distribution grid	Det	DSO

IV. EDF IN EUROPE

In this section, first, a general overview of the European countries' achievements and developments over EDF integration as another market participant in balancing services is given. Secondly, demand participation in congestion management products available in Europe is presented. The third point, contributes to organize and classify the projects and initiatives that encourage EDF integration in European countries.

1) Balancing services in Europe

There is a desire to increase harmonization in European countries, balancing services regulation and products. The more regulatory measures are unified, the easier it becomes to extend the markets internationally, reaching a more efficient system. There are three ongoing projects to redesign harmoniously European balancing platforms. Each one corresponds with a different product available to manage operation reserves [112][113][114]:

- TERRE project aims to develop a common platform for RR products, which corresponds with balancing energy with an activation time up to 30mins [112].
- MARI project aims to implement a platform for European countries to exchange balancing energy from mFRR with an activation time of less than 15min. [113]
- PICASSO project aims to establish the European platform for the exchange of balancing energy from aFRR with an activation time between 30 seconds and 15 minutes. [114]

These platforms together will facilitate the participation of all kinds of resources in the balancing services.

The progress in adapting some national BMs to integrate demand resources has been limited. Differences in existing legislation and regulatory frameworks make it difficult for some countries to cooperate on a common electricity market [51]. However, there are also countries with a high deployment of demand inclusion regulatory measures such as: Germany and Switzerland that are participating. A brief summary on EDF participation for EU countries in each market is gathered from sources [72][63] in Table 5 below:

Table 5. EU countries balancing market openness to demand participation

Demand participation	FCR	aFRR	mFRR	RR
Austria	NO	YES	YES	Doesn't exist
Belgium	YES. Load upwards	NO	YES	NO
Germany	YES	YES	YES	Doesn't exist
Denmark	YES	YES	YES. Limited to electric boilers	YES
Finland	YES	NO	YES	Doesn't exist
France	YES	NO. PICASSO project.	YES	YES
Ireland	YES	YES. Only industrial customers	YES. Only industrial customers	Only De-synchronised
Netherlands	NO	YES	YES	NO
Sweden	YES	YES	YES	YES
UK	YES	NO	NO	YES
Poland	NO	NO	NO	NO
Spain	NO	YES	YES	YES
Italy	NO	NO	NO	NO
Switzerland	YES	YES	YES	YES

Germany, Switzerland, and Sweden stand out as they have progressed quite fast regarding EDF access to the balancing markets [72][63]. All balancing services are open to all market parties and all technologies, as long as they meet the technical requirements of each service. In Germany, the definition of an aggregator framework encouraged independent entities to participate as the participation process and the contracts needed have been simplified, thus considerably fostering EDF participation. However, in Germany IA is not yet allowed as there is no regulation over this figure [55]. The main weakness in Germany is transparency. The amount of energy traded in the balancing markets that comes from the demand side is not easy to estimate, since only the prequalified capacity per technology is publicly available; therefore, Table 6 does not specify quantities for the German case.

Conversely, in France the majority of ancillary services are open to demand participation, as technical prerequisites are reasonable and easier to comply by independent parties to be able to bid into the market through pooling [72], although in RR there is no real participation as there are still some barriers. In addition, direct access to aFRR is limited as only large generators are obliged to provide it. Hence, generators procure with their required reserve through a secondary market enabling other BSPs to trade their flexibility for the system. Nevertheless, activation selection is made on a pro-rata basis and the activations period would be too long and frequent. Hence, in practice there is no EDF participating in this product. The PICCASO project tackles this barrier as it will implement merit order list activation for this secondary market [72]. Another barrier is that aggregation of flexible demand and generation in the same pool is not allowed, only a pilot project has been launched for FCR, mixing on-site generation with flexible demand. The French TSO (RTE) is also considering allowing asymmetrical product participation to enable this kind of aggregated pool. In addition, the IA framework is quite developed in France, allowing aggregators and consumers to use their flexibility without having to sign a contract with the supplier BRP. This key regulatory progress has led the French market to develop a mechanism called NEBEF, created to allow virtual pools of load to be traded in the wholesale market [115]. In November 2018, the "energy mix planification" program [72] started working, establishing the amount of EDF necessary to be bided in the markets. To achieve this required amount and to develop EDF participation in the existing products, additional exclusive tenders for EDF began to be organized. The French government is in charge of deciding beforehand the quantities of EDF that will be tendered. For 2018, 2.200 MW were originally tendered, however was not reached due to the penalties established which disincentivize participation and the falling trend in payments in this product [72]. Table 6 shows the 2017 total contracted capacity, EDF participation and aggregation allowance. Table 7describes Germany and France balancing services characteristics:

Table 6. Germany and France EDF participation in AS [53]

	Service	Country product name	Total capacity contracted [MW]	EDF access and participation	Aggregation accepted
GERMANY	FCR	Primary control reserve	830	✔	✔
	aFRR	Secondary control reserve	1.976	✔	✔
			1.907	✔	✔
	mFRR	Minute reserve	1.850	✔	✔
			1.654	✔	✔
FRANCE	FCR	Primary Control	600-700	70MW	✔
	aFRR	Secondary Control	600-1.000	Access through a secondary market	❢
	mFRR	Fast Reserve	1.000	500MW	✔
	RR	Complementary Reserve	Max. 500	Access but no participation	✔
	DSR-RR	Demand Response Call for Tender	750-1.400	730MW	✔

✔ YES ❢ HALTINGLY ✕ NO

Table 7. Germany and France AS features. Based on sources [72]**[20]**[116]

	Service	Minimum size [MW]	Symmetrical bid required?	Notification time	Activation	Utilization settlement rule	Max. Duration of activation
GERMANY	FCR	1	Yes	<30s	Automatic	Pay as bid	1 week
	aFRR	5 (1 MW if no other offer)	No	<5mins	Automatic	Pay as bid	4 h
	mFRR	5 (1 MW if no other offer)	No	<15mins	Automatic	Pay as bid	4 h
FRANCE	FCR	1	No	<30s	Automatic	Regulated price	30mins
	aFRR	1	No	<15mins	Automatic	Mandatory	30mins
	mFRR	10	No	<15mins	Manual	Pay as bid	30mins
	RR	10	No	30mins	Manual	Pay as bid	30mins
	DSR-RR	1	No	2h	Manual	Regulated price	30mins

There are also some countries like Spain that has not yet developed adequate national regulations neither for the prosumer figure nor demand aggregation. In Spain, there is only one real scheme that provides flexibility to the system, which is the interruptibility system for the electro-intensive industry. The big consumer responds to the need of the system of disconnecting from the network, enabling this way other users to be fed in scarcity circumstances. This scheme is managed by the Spanish TSO, Red Eléctrica de España (REE) [117]. However, further developments have been recently applied in regulatory measures to include demand participation in balancing services, this changes are presented in the Operation procedures (OP) [104].

2) Congestion management in Europe

European countries agree that demand flexibility should be available for solving congestions at DSOs and TSOs level, on an open flexibility market. Several initiatives and regulatory framework amendments are evolving in European countries but only at distribution level. The Expert Group 3 (EG3) push many of these modifications in its first version of the report 'Regulatory Recommendations for the Deployment of Flexibility'[118]. However, did not work on a market model. Therefore, multiple models are appearing where the DSO can take advantage of demand flexibility to solve its own congestion problems. Some countries that are doing this are: Netherlands, Belgium, Germany, Denmark, Ireland, Norway, France and recently Spain [70].

Germany and Spain models with the aim of including the use of EDF to solve congestion problems harness the 'Smart Grid Traffic Light Concept' [119], to incorporate demand flexibility into distribution grids. Localized network congestion is managed using the available distributed demand flexibility, and to trigger it there is a communication process between grid operators and market partners that procures with the different traffic light phases [70].

- Green light means no congestion predicted. Hence, demand flexibility is offered by aggregators for market and system-oriented portfolio optimization and for balancing.
- Yellow means grid congestion predicted. Hence, demand flexibility is requested by DSO (grid oriented) on a contractual basis to avoid economic inefficient network expansion.
- Red means congestion in real time. Hence, demand flexibility nodes are controlled by DSO without contractual basis to preserve a secure network operation [120].

In the German initiative 'The Proactive Distribution Grid' the DSOs request to the aggregator a list with their total flexibility requirements, including necessary types and boundary conditions in order to provide congestion management services. There are different variables such as: grid location, topology and predicted power flow of a specific area that would influence the usefulness of possible flexibilities. Therefore, the aggregator individually values the elements of their portfolio to optimize selected assets according to the congestion-specific sensitivity for each flexibility type [121]. This selection of demand flexibility options and its final activation procedure are managed through a platform which has the information at the same time of the congestion forecasts. Subsequently, aggregators are in charge of deciding the best assets to use to comply with the flexibility request while upholding existing contractual agreements with their customers. Another research project in Germany is 'Advanced Decentral Grid Control' [70] which also works in developing a process to integrate the market participants and the DSO to facilitate power flow predictions in Medium/Low Voltage grids. The main difference with the other initiative is that a contract with the prosumer is necessary [122].

There is also an ongoing project in Spain called IREMEL and is working on developing an efficient model to take advantage of DERs [123].It is necessary to allow DER participation in the existing European electricity markets for the periods where no restriction exists to achieve an efficient market model. Moreover, participation allowance in the local flexibility markets is also a must. To know when European markets have restrictions or not for DER participation, grid traffic light code is used in the same way as in Germany [124]. IREMEL involves large and small DSOs, individual DERs, aggregation companies, proactive consumers, battery producers, tech companies, Energy Associations etc. All these entities will participate in the different pilots in order to assure a correct performance of the system in case a congestion is detected at DSO level. 5 pilots will be carried out to test the proposed model in different Spanish areas. The project also includes the definition of an efficient information sharing procedure between DERs, Aggregators, Market Operator, DSOs and TSOs [123].

Conversely, in France, the main barrier comes from the established method of connecting resources to the distribution grid. In the traditional connection method, the prosumer pays most of the connection costs. Hence the DSOs not have the right to refuse connection of any medium voltage (MV) power plant to the network. To address this barrier, the Innovative Connection Offer (InnoCon) project was developed with the aim to provide an alternative to the reference connection offer to renewables power plants, facilitating the connection rapidly and less costly. The way it works is offering a connection contract providing the opportunity for the producer to produce more than the contracted quantity when technical conditions are favorable. In return, the DSO has the right to curtail their power generation at certain times of the year when network constraints are likely to occur. Thus, as the electricity generation depends on the state of the network, this would lead to an increase in the network's overall connected power, limiting at the same time the amount of energy curtailed. As a result, investment in capacity necessary with current connection rules can be avoided [70].

3) Projects and initiatives

There are many other projects, pilots, and initiatives on track involving flexible demand integration in the grid and EDF participation in markets and data management.

These projects goals are sometimes similar. Briefly, some of the objectives the projects are working on are organized as follows:

1. Proving the feasibility of a proposed solution to network congestion
2. Providing imbalances services efficiently
3. Including demand flexibility participation in a market product/service.
4. Fostering a specific technology (Solar distributed, ESS or smart grids deployment)
5. Improving aggregated demand participation framework. This means standardizing processes over involved parties' relationship and data sharing, facing barriers to aggregators participation in different markets and providing technological solutions, and everything in accordance with European regulation.

In addition, the different categories that are going to be considered according to their main aim and developments to classify all these initiatives are based on [125] and are presented in Table 8:

Table 8 Initiatives categories classification

Categories	Main aim of the initiatives
Market platform	Place where buyers and sellers of flexibility meet to trade flexibility.
TSO/DSO operational platform	Platform to operate balancing services or to manage the grid with flexible resources participation either at TSO or DSO level.
TSO/DSO coordination platform	Platform where TSOs and DSOs cooperate to carry out the tendering, trading, activation and/or settlement of EDF for their own purposes (i.e. ancillary services).
Market facilitation platform	To support the energy market well-functioning and wholesale settlement, by distributing the available data previously validated and enriched.
Technology platform/VPP	Platform to monitor and control particular features of the flexible assets in a specific portfolio or location.
Energy management progress	Work to improve control devices performance and foster the use of new appliances prepared to be controlled remotely within the home, building or factory.
Policies pusher by providing technical solutions	by analyzing a particular barrier in the market (Relationship between parties, data sharing…) aims to influence and prove a Regulatory policy that address the problem.

The types of loads that the initiatives involve are specified, distinguishing over: Residential, Commercial, Industrial, Electric vehicle (EV), Distributed Generation (DG), Energy Storage (ES), All (Which include all distributed generation and loads at TSO and DSO level) or Aggregated (Which refers to all DERs gathered by the aggregator).

Table 9, summarizes these characteristics for each project:

Table 9. EU Projects and initiatives

Project	Type/Category	Goal	Countries involved	Target loads	Active or work in progress (WIP)	Source
Invade	DSO operational platform	1	BG, DE, ES, NO, and NL	EV and ES	Finalice by 2019 ACTIVE	[126][127]
FUSION-TRANSITION	DSO operational platform	3	UK	All	2018-2023 WIP	[128][129]
InterFlex - Enexis	DSO operational platform	5	NL	ES and EV. Commercial aggregators	2017-2019 ACTIVE	[128]
MADE	Energy management progress	5	UK	Residential	2019-2020 WIP	[130][131]
Future Flex	Energy management progress	1	GB	Residential	2019-2021 WIP	[132]
EnergieKoplopers	Energy management progress	3	NL	Residential	2016 ACTIVE	[128][133]
Cordis	Energy management progress	5	EU	Residential	2020-2023 WIP	[134]
Cordinet	Energy policies pusher	5	ES, SE and GR	All	2019-2022 WIP	[135]
Smart Solar Charging	Market and DSO operation platform	4	NL	Residential and commercial	Jan 2020 ACTIVE	[128]
DRIvE	Market facilitation and DSO operational platform	5	EU	Residential and commercial	2017-2020 WIP	[128]
Flex4Grid	Market facilitation platform	5	EU	All	2015-2018 ACTIVE	[136]

Fskar	Market facilitation platform	5	EU	All	2019-WIP	[137]
CATALYST	Market facilitator platform	5	EU	All	2017-2020 WIP	[128]
DRES2MARKET	Market facilitation platform	2	ES, FR, NL, GR, AT and NO	DG	2020-2023 WIP	[138]
OneNet	Market facilitation platform	3	EU	All	2020-2022 WIP	[139]
IDCONS	Market platform	1	NL	All	2019 ACTIVE but still WIP	[125][140][141]
Piclo Flex	Market platform	5	UK	All	1st phase active since 2018. 2nd phase WIP	[123][142]
DYNAMO	Market platform	1	NL	Aggregated	2016-2019 ACTIVE	[128][143][144]
FlexLab	Market platform	1	NO	All	2020-WIP	[145]
IREMEL	Policies pusher by providing technical solucitions	5	ES	DG	2019-WIP	[123][124]
Smart Grids Task Force – EG3	Policies pusher by providing technical solutions	4	EU	All	2018 ACTIVE	[128][146][40]
ebIX distributed flexibility project	Policies pusher by providing technical solutions	3	EU	All	2020 ACTIVE	[128][147][148]
ENGENE	Technology platform	4	NO	All	2018 ACTIVE	[125] [145]
NorFlex	Technology platform	3	NO	Residential, commercial and industrial	2019-2021 WIP	[149]
DOLFIN	Technology platform	5	EU	Industrial	2013-2020 WIP	[150] [151]
Hoog Dalem	Technology platform	4	NL	Residential	2017 ACTIVE	[128]
Smart Energy Isles	Technology platform	5	UK	Residential	2019 ACTIVE	[128]
REDREAM	Technology platform	5	ES, BE, IT, HR, UK, GR, FR, DE	Residential, commercial and industrial	2020-2023 WIP	[152]
MOMEBIA	Technology platform	1	ES	Aggregated	2020-2022 WIP	[153]
ENERA	TSO operational and coodination platform and also market facilitation platform.	5	GR,FR,UK, NL, BE,AT,LX, SW	Aggregated	2018-2020 WIP	[125][154]
International Grid Control Cooperation (IGCC)	TSO/DSO operational platform	2	AT, BE, CH, CZ, DE, DK, EL, FR, HR, IT, NL, PL, PT, RO, RS, SI and ES	All	2019 ACTIVE	[155]

Danish Market Models	TSO/DSO coordination & market platform	2	DK	All	2018-2020 WIP	[128]
GOPACS	TSO/DSO coordination platform	1	NL	All	Jan 2019 ACTIVE	[123][156]
Intra Flex	TSO/DSO operational platform	2	UK	All	2019-2021 WIP	[157][158]
Interreg CvvP	VPP	5	EU	DG	2017-2020 WIP	[128] [159]

V. CRITICAL ANALYSIS ON EDF

From a technical point of view the deployment of EDF as another market party for balancing services or congestion management is possible as the needed technology and devices exist. However, there is much work to be done to make this really happen. In order to face the main social and regulatory barriers for EDF development and integration in the different electricity markets, a significant economical investment is required and a strong commitment is necessary from the different countries' governments to develop policies that foster EDF deployment and exploitation in the short term. In addition, to design and analyze the EDF participation in markets, mathematical models are required. For this reason, an analysis is performed over the already existing models capable of counting on the participation of EDF in the markets.

From the assessed models able to include EDF as a participant in the balancing services, some weaknesses identified include:

- Models do not separate between the different balancing services, only [97] distinguishes among the ancillary markets, but a demand block simplification is applied. Requirements for the different services are not the same nor remunerations. Therefore, treating them as a whole can limit EDF participation, as a supplier cannot be prepared to provide all of them. Thus, neglecting some technologies possibilities.

- There is a lack of models that consider how EDF participating in balancing services can influence in long-term planification of generation expansion. A key factor to face the energy transition it is to include EDF as another market participant, being necessary to develop long-term analysis models that take it into account to take consistent investment decisions.

- Type of loads considered are still limited. General modeling of aggregated DG, ESS and load is only presented in [98][102] and the rest of the models do not consider the three categories at the same time.

- From the models above, it is not yet clear which is the best flexibility remuneration mechanism to incentivize flexibility sources participation in balancing markets.

- Very few models consider the whole system network[95] [102] [103] being an essential part when DER is considered to assess bidirectional flows.

Conversely, the most relevant weak points found in the congestion management models analyzed in the literature that include EDF participation are:

- Lack of mixture of preventive and corrective models, as usually both are complementary one with the other.

- No clarification on which remuneration mechanisms are more efficient and fairer.

- Sources of EDF are still limited. Most aggregators only include loads. There is no congestion solving models aggregating DG, ESS and loads at the same time.

- Including stochasticity in preventive models may improve these models' results.

Furthermore, each country is planning their deployment of regulatory measures and policies. In this regard Netherlands and Great Britain are the most advanced European countries in active initiatives. Additionally, there are plenty of projects from a European perspective that are relevant to unify the market as much as possible. According to the Network Codes [160] all three European platforms (TERRE, MARI & PICCASO) that allow for EDF participation in the balancing markets should be deployed by the end of 2022.

All these findings raise some questions for future research:

1. Estimation of EDF integration costs: for the TSO, the aggregator, or the individuals.
2. How to manage all distributed energy resources (DG, ESS and manageable load) at the same time for operation optimization.
3. Define the most appropriate and fairest remuneration mechanism for EDF participation in the different markets.
4. How EDF participation in all other markets besides balancing and congestion services could be addressed. Always taking into account a non-discriminatory market, in which participation is allowed regardless of the DER technology (storage, generation or demand) and the size of the consumer.

VI. CONCLUSIONS

This paper contributes to clearly define the term of EDF in future electric systems. To the authors' best knowledge, it is the first time an exhaustive EDF review has been performed in different parts: clarifying the difference between system flexibility and demand flexibility terms, the potential of the markets where EDF can participate, what are the current barriers, what is being studied and what is done in Europe. The outcomes of the analysis and review performed at each part is suitably summarized and classified in Tables and Figures enabling a comprehensive outlook of the main options and relevant issues involved in each part.

Thus, the article starts understanding the different types of demand flexibility. It can be assured that EDF is the only type of demand flexibility that really provides system flexibility, aggregated or not. One way to take advantage of its possibilities is participating in the balancing and congestion management services as another market party. Then, the main barriers for EDF integration as another market participant have been identified and classified in two different levels. In addition, mathematical models where EDF participates have been studied and classified, identifying the main weaknesses these models have and where should be work on.

Then, some European countries have been gathered and analyzed regarding their current status of the EDF integration in the balancing markets explaining Germany and France in more detail. Besides, a summary of the most relevant projects and initiatives that are working to improve the EDF participation framework and how they are doing it is provided.

Finally, the next research lines, questions to be solved and current gaps have been outlined taking into account the review done in each of the previous parts.

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