Critical evaluation of European balancing markets to enable the participation of demand aggregators

Mattia Barbero[1]*, Cristina Corchero[1,2], Lluc Canals Casals[1,2], Lucia Igualada[1] and F.-Javier Heredia[2]

[1] Catalonia Institute for Energy Research (IREC), Jardins de les Dones de Negre 1, 2, 08930 Sant Adrià de Besòs, Barcelona, (Spain); mbarbero@irec.cat; ccorchero@irec.cat; lcanals@irec.cat; ligualada@irec.cat

[2] Universitat Politecnica de Catalunya - BarcelonaTech (UPC), Jordi Girona, 1-3, 08034 Barcelona, (Spain); f.javier.heredia@upc.edu

* Correspondence: mbarbero@irec.cat;

Declarations of interest: none

Abstract: European Directives are incentivizing consumers to play an active role in the electricity system and to collaborate to maintain its stability, which has been historically provided by large generation power plants. However, it is not easy for the System Operator to handle the coexistence of consumers and generators in the same markets. Under these circumstances, a new actor allows small residential and commercial consumers to participate in flexibility markets: The Demand Aggregator. However, balancing markets opened to Demand Aggregators still present several barriers that do not allow their practical participation. This study analyzes barriers and enablers of four European electricity markets and proposes a new market framework that would enhance Demand Aggregators' participation. To validate the proposed market and to understand the economic potentials of aggregated small tertiary buildings, a Demand Aggregator is simulated using real building's consumption data. Results show that technical requirements to participate in balancing markets such as the minimum bid size, the symmetricity of the offer and the product resolution strongly affect incomes for Demand Aggregators. However, neither in the proposed market, the creation of a Demand Aggregator whose business model is focused on small tertiary buildings does not seem realistic due to low incomes in comparison to the fixed costs necessary to enable Demand Response, especially if only the air conditioning system is considered.

Keywords: Demand Aggregator; Regulatory framework; Ancillary Services; Demand Response; Tertiary building management.

---

1. Introduction

The higher penetration of Renewable Energy Sources (RES) and its inherent stochasticity is changing the way in which electricity is traded and managed in the electricity system. The old paradigm in which production is adapted to consumption is no longer feasible (Khan, Verzijlbergh, Sakinci and De Vries, 2018). In this new framework, energy production is not directly controllable and forecasts are not fully accurate. In addition, an increase in the energy consumption implies higher demand peaks and grid congestions, which could increase grid reinforcement needs (Spiliotis, Ramos Gutierrez and Belmans, 2016). Considering that nowadays grid balancing is vastly done by big power generation plants, which tend to be less reliable, flexibility offered by end-consumers through Demand Response (DR) mechanisms is crucial.

There are two DR types: implicit DR where the end-users consumption is expected to react to a price signal and explicit DR where flexibility offered by end-users is traded in energy markets (SEDC, 2016). This study immerses in the latter type to improve the use of energy resources and energy processes involved in the grid balancing services.

The latest advances in smart grid and building technologies promise to unlock the participation in DR programs and to transform passive consumers into active consumers, also called "prosumers". Prosumers are able to modify their energy consumption depending on external signals, i.e. economic or environmental among others. Smart buildings, having to manage their energy flows of generation from renewable power sources and consumption, may include solutions to evaluate their flexible loads. This means that technical barriers are no longer significant on the automation side. The main challenge is to transform these functionalities into products that consumers can trade in electricity markets (Iria, Soares and Matos, 2018) to reduce their electricity bill while helping the energy transition toward a 100% renewable energy system. Currently, although commercial services and residential consumer represent the major share of electricity consumption, according to the International Energy Agency (Energy in Buildings and Communities Programme, 2016), their flexibility potential remains untapped.

Demand Aggregator (DA) has emerged as a new market agent necessary to manage demand-side flexibility (Bertoldi, Zancanella and Boza-Kiss, 2016). Its role is to aggregate different flexibility providers (loads and/or Distributed Energy Resources (DER)), allowing them to participate in electricity markets (Behrangrad, 2015). DA is able to manage its client portfolio directly through contracts (unconditional delivery) or indirectly (conditional delivery) through price incentives (Richter and Pollitt, 2018). Literature is full of optimal DR strategies for participation in the wholesale market (Abapour, Mohammadi-Ivatloo and Tarafdar Hagh, 2020). Moreover, DA could participate in Frequency Containment Reserve (FCR) (Yuen, Oudalov and Timbus, 2011), in Frequency Restoration Reserve (FRR), that is divided in manual (mFRR) and automatic (aFRR), and in the Replacement Reserve (RR) (Heleno, Matos and Lopes, 2016). Centralized power plants have historically provided these frequency regulation services. For this reason, existing markets are strongly oriented towards generators and, in majority of cases, they do not allow a real participation of demand side resources. In a high renewable penetration scenario, it is fundamental to reassess these markets considering the participation of small consumers and renewable resources, which have completely different characteristics compared to large thermal power plants (Borne, Korte, Perez, Petit and Purkus, 2018).

To improve energy processes and use, the Energy Efficiency Directive 2012/27/EU states that barriers for DR participation have to be removed and that DR has to be encouraged, including the participation of aggregators (European Parliament, 2012). Moreover, the EU winter package "Clean Energy for All Europeans" previews faster markets, where the energy is traded close to real-time and intraday and balancing markets gain even more importance. The package suggests to incentivize the use of demand side flexibility and storage resources, strengthening the role of the aggregator (European Commission, 2016). Although some countries have already opened the market to DA, they still maintain several technical requirements strongly oriented to classical centralized generation sources, reducing potential participation of consumers in the system (Sweco, Ecofys, Tractbel Engineering and PWC, 2015). A recent study (Poplavskaya and de Vries, 2019), which analyzed balancing markets in Austria, Germany and Netherlands, found key differences among the countries of study and presented some examples of how the markets' design is not yet aligned with the EU policy objectives. Moreover, various countries, such as Spain, have not yet transposed European Directives having their balancing markets closed to prosumers (SEDC, 2017).

Nonetheless, industry, residential and tertiary buildings can become potentially eligible for participating in DR programs. Although the majority of existing aggregators deal with large consumers as industries (Shoreh, Siano, Shafie-khah, Loia and Catalão, 2016), literature is focusing on residential and tertiary buildings as well because they represent about 40 % of the global energy consumption (Lindberg, 2017). Such buildings have several energy consumption systems, such as Heating, Ventilating and Air Conditioning (HVAC), that can be controlled to provide demand-side flexibility services (Ding, Cui, Zhang, Hui, Qiu and Song, 2019). The services these prosumers may offer depends on the elements installed in the building. Stationary batteries (Malhotra, Battke, Beuse, Stephan and Schmidt, 2016) and electric vehicles (EV) (Peng, Zou, Lian and Li, 2017) are also considered important devices for balancing the grid.

This study critically examines current European markets framework regarding DA and DR. Section 2 analyzes the existing business models in Europe, differentiating third-party aggregators and aggregators as retailers. Then, the section analyzes the market requirements to understand how they could act as a barrier for consumer's participation distinguishing among regulatory, technical and economic barriers. To have a clear picture of the situation in Europe, some of the most relevant markets opened to DA in Europe (SEDC, 2017) (Belgium, Finland, France and UK) are analyzed, highlighting principal enablers and barriers. After that, the section examines technologies currently used and the markets in which aggregators are operating, to understand the connection between market configuration and flexibility provided by aggregators.

Then, with the main objective to propose a possible frequency regulation market that enables DR participation, Section 3 proposes an aggregator owned by the local administration due to the fact that public buildings represent a high share of tertiary buildings in cities and they suppose an important potential source of flexibility. This Section, within the framework of the REFER project (*REFER*, 2018), shows how a tertiary building DA would operate in the proposed market based on the information gathered from the libraries in the Metropolitan Area of Barcelona (AMB, from the Spanish acronym). Flexibility sources from libraries are HVAC and self-consumption solutions with storage systems. The flexibility of the aggregator portfolio is quantified under three different scenarios: the first one considers libraries having air conditioning as the only flexibility resource; the second one considers that 30 % of libraries have installed a self-consumption solution with storage system; the third one includes participation in different markets at the same time. Finally, the study performs an economic simulation of the DA participation in the proposed market to evaluate costs and benefits of offering balancing services and analyzes the effect of different technical requirements on the DA business model. Conclusion and final remarks are presented in the last section.

2. Materials and Methods

This section presents an overview on DA in Europe. After a brief overview of the DA business models emerging in Europe, possible barriers to spread DA are discussed. Then, this section analyzes principal European markets that are already open to DA and, finally, this section presents the current situation in Spain and the case study analyzed.

2.1. Market models for demand response aggregation

DA business models consist in trading the flexibility of their clients to one or more actors through market mechanisms or through bilateral contracts. The DA can participate in frequency regulation services or help to solve grid congestions by selling flexibility to the Transmission or Distribution System Operator (TSO/DSO). Another option for the DA is to help balancing the Balance Responsible Parties (BRP) and/or retailers' portfolio. The DA could operate outside the conventional chain of energy supply i.e. is neither BRP nor retailer (Third-Party Aggregator) (Nordic TSOs, 2017), or it can be the same BRP/retailer acting as DA (Ikäheimo, Evens and Kärkkäinen, 2010), as shown in Figure 1.

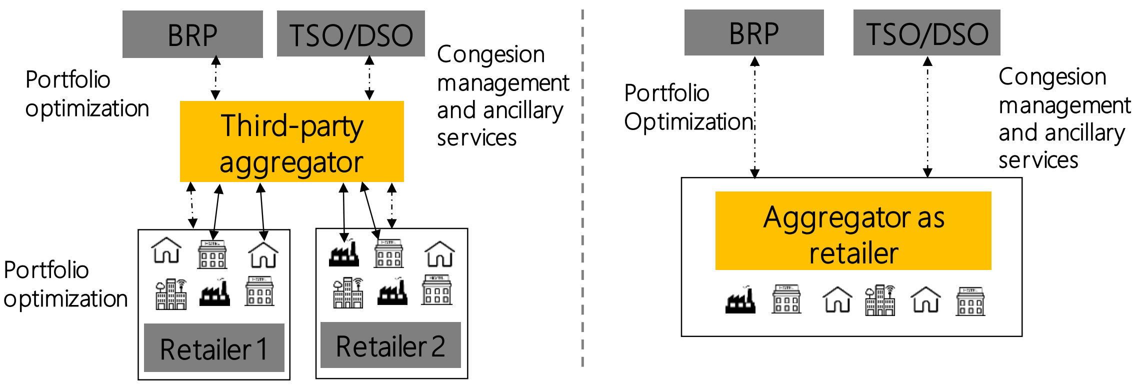

Figure 1. Comparison between "Third party aggregator" and "aggregator as retailer" business model

In the case of a Third-Party Aggregator, consumers contract the energy provision from different retailers and the DA takes advantage of the consumer's flexibility by selling the aggregated flexibility to different actors. In this case, consumers do not buy energy from the DA, its role is to trade and manage the consumer's flexibility. The DA can either provide frequency regulation services and congestion management to the TSO/DSO or balance external BRP/retailer's portfolio by trading the shifted energy in intraday markets. The main drawback of this business model is that the flexibility activation from part of the DA could create unbalances in the consumer's BRP/retailer/DSO portfolio. Without clear rules about the unbalances created by the DA, the consumer's BRP/retailer/DSO could be penalised unfairly (Bertoldi, Zancanella and Boza-Kiss, 2016) or the DA could be indebted for the unbalance created.

In the case in which the DA is the same as the retailer, its main business is to sell energy to its clients. However, in Europe, there are retailers that act as DA, since they offer special tariffs to consumers that are able to shift part of their consumption when it is necessary. Usually, they are retailers that own renewable generation assets and are able to take advantage from the flexibility of their clients to reduce the unbalances costs by balancing their own portfolio. Complementary, a competitive retailer will use DR in order to reduce the risk of being exposed to high prices in the spot market (Paterakis, Erdinç and Catalão, 2017). If retailers have enough flexibility, they could also provide frequency regulation services and congestion management to TSO/DSO or balance external BRP's portfolio. The main drawback of a retailer as DA is that it can raise some conflicts of interest.

In our case of study, an innovative public aggregator as retailer is proposed. The AMB has already started one of the first municipal retailers, called "Barcelona Energia" (*Barcelona Energia*, 2020), and could expand its business model with DA. In this case, the DA, a part from being a retailer, could also be the owner of the buildings and offer frequency reserves to the TSO, taking advantage of its building's flexibility. The advantage of the business model proposed is that DA benefits are not shared with the final users, allowing keeping more profitable a business with low margins.

2.2. *Frequency markets and barriers*

Different type of barriers have been analyzed for DR in frequency regulation markets (Good, Ellis and Mancarella, 2016). This study follows the idea presented in (Borne, Korte, Perez, Petit and Purkus, 2018), which grouped possible barriers for DA to entry in frequency regulation markets in three types: regulatory, technical and economic barriers.

Regulatory barriers refer to all those barriers that can appear due to the market regulated and not-regulated framework, that are:

- Restriction on demand aggregation: Although Demand aggregation is allowed, there can be still restrictions on the type, the size or the voltage connection of the load (Borne, Korte, Perez, Petit and Purkus, 2018).
- Inappropriate or incomplete regulation defining roles and responsibilities between market's participants (Smart Energy Demand Coalition, 2014): TSOs should clearly define the balance responsibility in case of flexibility activation from part of a DA. If the TSO does not exclude the activated flexibility from the retailer/BRP's balancing area, a DA can cause unfair purchasing and balancing risks to retailers, BRPs and DSOs (Bertoldi, Zancanella and Boza-Kiss, 2016).
- Number of contracts needed for DR (Paterakis, Erdinç and Catalão, 2017): The need for DA to sign a contract also with the consumer's BRP/retailer/DSO can be a strong barrier as they are potential competitors. In case of incomplete regulation on balancing responsibility's BRP, retailers and DSOs are not incentivized to allow any DA trade their consumer's flexibility since DA can create additional costs to them.

Regulatory barriers can forbid or limit the participation of DA in the markets. If the regulatory framework is organized to exclude DAs, aggregators' revenues will be null (Borne, Korte, Perez, Petit and Purkus, 2018).

Technical barriers are imposed by functional requirements needed to participate in frequency regulation markets that have been historically defined for generation units and should be updated for allowing the participation of DA (Sweco, Ecofys, Tractbel Engineering and PWC, 2015). Tertiary or residential buildings participating in DR programs have characteristics completely different from generators and their major constraint is to assure their occupants' comfort. It is worth to remember that a market agent can deliver ancillary services to the TSO only if it is prequalified (Bondy, Gehrke, Thavlov, Heussen, Kosek and Bindner, 2016), demonstrating the capability to respect all technical requirements. For this reason, it is very important that prequalification is made at the DA portfolio level. If prequalification is made at an asset level, each consumer has to be able to respect all the market's technical requirements on their own (Smart Energy Demand Coalition, 2014). The requirements are:

- Minimum bid size: indicates the MW necessary to participate in the market. If this requirement is lower, than the DA needs fewer customers to participate (Cappers, Macdonald and Goldman, 2013).
- Maximum number of activations: indicates the maximum number of time that a flexibility resource can be activated during a certain period. DA consumers have restrictions about the maximum number of activations during a period to maintain comfort constraints.
- Symmetricity of the offer: flexibility can be in two directions, upward or downward regulation. If the offer needs to be symmetric, the number of consumers that can participate in DR is lower, given that some consumers can offer flexibility just in one direction (Cappers, Macdonald and Goldman, 2013).
- Notification time: indicates the maximum reaction time of the flexibility source. Short notification time can give raise to problems due to the communication delay between the DA and the consumers' reaction time, apart from increasing automation costs (Cappers, Macdonald and Goldman, 2013).
- Duration of delivery: Shorter the maximum duration of the flexibility activation, more consumers are able to participate in the service, since most of residential and tertiary consumers can activate flexibility as maximum during 1 or 2 hours (Katz, 2014).
- Product resolution: Indicates the minimum time during which a unit has to offer its flexibility. If it is very long, e.g. one day, it can limit DR participation, since different consumers could offer their flexibility just during some hours a day (Katz, 2014).
- Tender period: Indicates how often the market opens. If there is not a daily auction it could be difficult for the DA to predict the flexibility of its clients (Katz, 2014).

Technical requirements can limit the available reserve of DAs in the market and can limit the type of consumers that can participate in the DA portfolio, reducing their profitability.

Economic barriers occur when the DA business model is not viable due to costs exceeding benefits from participation of DR in balancing markets (Rious, Perez and Roques, 2015). These barriers are:

- Low prices in frequency regulation markets.
- High technical costs: smart meter installation, communication and control technologies, automation, etc... can reach high costs if very high performances are demanded to participate in the markets (Piette, Schetrit, Kiliccote, Cheung and Li, 2015).
- High penalization costs: Market costs such as penalization for not dispatching the committed energy should be reduced to incentivize demand side participation (Good, Ellis and Mancarella, 2016).
- Subsidies to peak power plants: they can create an unfair competition; peak power plants are the direct competitors in provide balancing services to the grid. The absence of direct incentives to DR technologies could decrease revenues for DA.

Economic barriers due to the market design affect the way in which the same reserve will be remunerated. A good market design should assure a fair remuneration to DA and give incentives to provide services to the network.

The barriers presented have different links among them, as represented in Figure 2, which should be taken into account to improve the balancing market design. At first, regulatory barriers should be avoided to allow DA participation. Then, technical requirements need to assure participation to the largest pool of flexible loads to maximize their availability. Finally, a good market design is necessary to allow a sufficient remuneration to DA and reduce their financial risks.

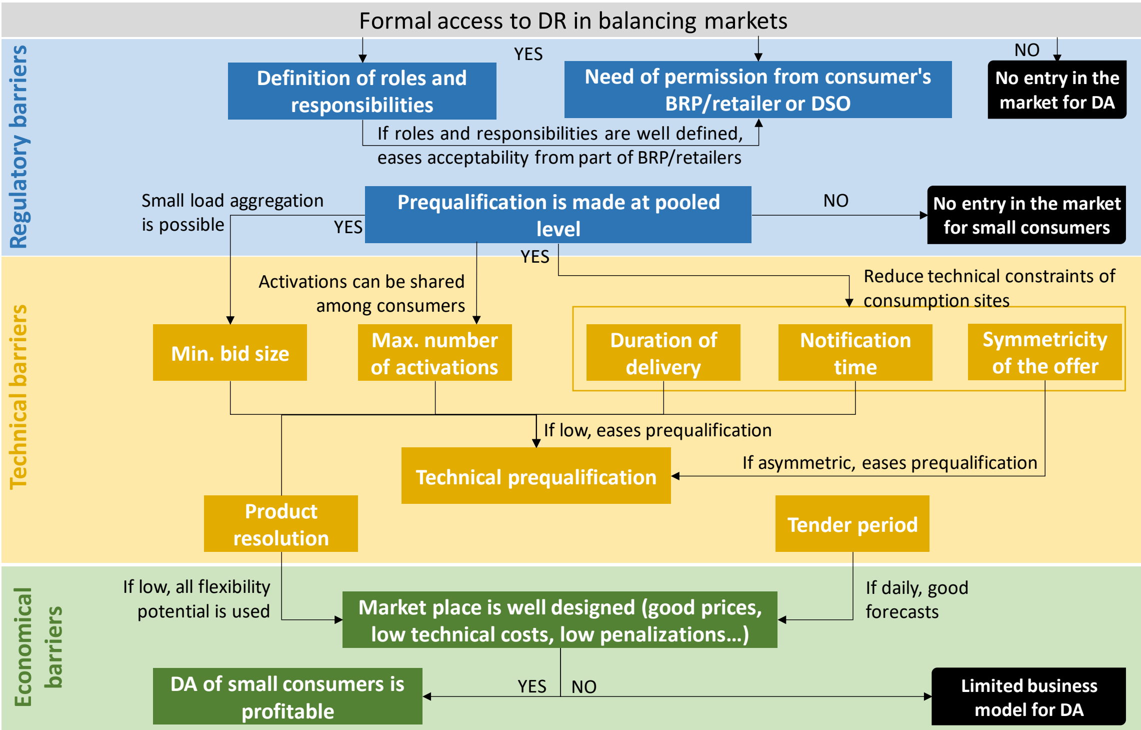

Figure 2 Links between barriers for DA in balancing markets in hierarchical order of importance

2.3. *Market analysis*

Taking into account the previous market description and barriers, this section presents an overview on frequency markets opened to DA in Belgium, Finland, France and UK. Prices come from the ENTSOE's transparency platform (ENTSO-E, 2020).

2.3.1. Belgium

Belgium increased DR programs after important capacity shortages due to technical issues of some nuclear power plants in the country in the last years. Moreover, the planned closure of some conventional power plants and nuclear power plants and the increase of renewable capacity (De Clercq, 2015) makes DR a vital source for the system.

- Principal enablers:
  - Third-party aggregators can participate in the market.
  - Offers do not need to be symmetrical in FRR and RR.
  - The minimum time between two successive activations is 8 hours in the mFRR market.
  - Prequalification takes place at pool level.
  - For FCR and FRR penalties are proportional to the payments, with a multiplication factor of 1.3.
- Principal barriers:
  - DSOs can block the consumer participation in DR programs without taking responsibility for the costs incurred by the consumer, DA and TSO.
  - Contracts are made on yearly basis for RR.

Table 1 illustrates technical requirements described by Elia, the Belgian TSO (*Elia - Keeping the Balance*, 2019).

Table 1. Summary of balancing markets open to demand aggregators in Belgium

[1]Market	Min.	Not.	Max.	Product	Symm.	Duration	Tender	Energy	Capacity

open to DA	bid size [MW]	time	number of activations	resolution		of delivery	period	payment €/MWh	payment €/MW/h
Symmetric FCR 200 mHz ENTSO-E	1	15 s (50 %) 30 s (100 %)	Continuous activation	4 hours	YES	10 minutes maximum	1 day	NO	8.6 on average
R3 (mFRR)	1	15 min	Minimum 8 hours from the last activation	4 hours	NO	2 hours	1 day	145 on average	11.2 on average
Strategic reserve (RR)	1	Several hours before activation	40 times/y 20 times/y	1 winter	NO (+)	4 hours 12 hours	1 year	At least 10,500	N/A

[1] Dark cells represent that the requirement should be improved to increase DR participation

2.3.2. Finland

Finland has the necessity to add flexibility in its grid as currently the major part of the Finnish reserves are bought from its neighboring countries such as Estonia, Sweden, Norway and Russia (Energy Market Authority, 2013). DA can help Finland to be more independent from these countries.

- Principal enablers:
  - Unbalances created by the DA in a BRP area does not increase costs for the BRP, as the TSO corrects the BRP curve after the DA flexibility activation.
  - Prequalification takes place at portfolio level.
  - Smart meters are widely used.
  - The minimum bid size is 0.1 MW for FCR-N.
  - Product resolution is 1 hour for all services.
- Principal barriers:
  - DA needs the agreement of the consumer's retailer/BRP.
  - Aggregating sources from different BRP's areas is only allowed in FCR market.
  - The minimum bid size is 5 MW for FRR and 10 MW for RR services.

Table 2 illustrates technical requirements described by Fingrid, the Finnish TSO (Fingrid, 2019).

Table 2. Summary of balancing markets open to demand aggregators in Finland

Market open to DA	Min. bid size [MW]	Not. time	Max. number of activations	Product resolution	Symm.	Duration of delivery	Tender period	Utilization payment €/MWh	Capacity payment €/MW/h
FCR-N	0.1	3 min	Continuous activation	1 hour	YES	No stop	Yearly or daily	Yes if yearly reserved	13.5
FCR-D	1	Piece-wise linear regulation or 5 s if f*<=49.7 3 s if f<=49.6 1 s if f<=49.5	Several times per day	1 hour	NO (+)	Until the freq. has been 49.9 Hz for 3 minutes	Yearly or daily	50 on average	2.4
aFRR	5	30 sec - 5 min (100%)	Several times per day	1 hour	NO	No stop	daily	50 on average	0

mFRR	5	15 min	Depends on the bids, several times per day/per year	1 hour	NO	15 minutes	No later than 45 minutes before the hour of use, or weekly	50 on average	3.3
Strategic reserve (RR)	10	15 min	Rarely	1 hour	NO (+)	NA	Every 2-3 years	NO	Pay as bid

2.3.3. France

France is possibly the European country with the longest tradition in DA, along with the UK. The massive presence of nuclear power plants and the wish to increase renewable generation resulted in a great interest of the country in DR programs. However, prices of balancing markets are dropping in last years, making more difficult the business for DA.

- Principal enablers:
  - DA can access consumers directly without the permission of the BRP/retailer.
  - The *"appel d'offres Effacement"* (RR) is appositively thought for consumers (EnergyPool, 2018).
  - Prequalification takes place at pool level.
  - The duration of delivery is well suited for consumers for all services.
- Principal barriers:
  - Aggregation of DR and generation in the same bid is not allowed.
  - Generators are obligated to deliver a-FRR services, however they can subcontract DR services through secondary markets.
  - Participation in aFRR market is limited to that consumers connected at the TSO level.
  - The minimum bid size for mFRR services is 10 MW.
  - FRR and RR are tendered on yearly basis.

Table 3 illustrates technical requirements described by RTE, the French TSO (*RTE ancillary services*, 2019).

Table 3. Summary of balancing markets open to demand aggregators in France

Market open to DA	Min. bid size [MW]	Not. time	Max. number of activations	Product resolution	Symm.	Duration of delivery	Tender period	Utilization payment €/MWh	Capacity payment
Symmetric FCR 200 mHz (ENTSO-E)	1	15 s (50%) 30 s (100%)	Continuous activation	4 hours	YES	15 min	2 days	NO	8.6 €/MW/h on average
Réglage secondaire de fréquence (aFRR)	1	400 s	Unlimited	Depending on the plant's scheduling	YES	No limit	Obligation for generator	NO	18 €/MW/h
Réserves rapidez (mFRR)	10	15 min	2/day	1 week (labor days and week-end)	NO (+)	2 hour	Year	41 on average (Balancing market price)	0.6 €/MW/h
Réserve compléme-ntaire (mFRR)		30 min				1.5 hour			0.4 €/MW/h
Appel d'offres Effacement	0.1	2 hours	20 days/year	1 hour	NO (+)	2 hours	Year	Spot price	30000 €/MW/y max

2.3.4. UK

Although UK was one of the first countries to incorporate DR solutions in Europe, the market is yet immature and the capacity of DR is decreasing each year, risking to disappear in the future (Bertoldi, Zancanella and Boza-Kiss, 2016).

- Principal enablers:
  - DA can access consumers directly without the permission of the BRP/retailer.
  - Prequalification takes place at pool level.
  - The maximum RR (STOR for the national TSO) activations per day is agreed with the TSO.
  - The system used for counting grid charges to consumers can help DA business model (TRIAD system).
  - A part from utilization and capacity payment, balancing service providers get also the nomination payment, which consist in a holding fee for each hour (£/h) used within nominated windows.
  - In 2018, UKPN presented their Flexibility Roadmap, an ambitious plan to develop market-based solutions to procure flexibility for its network where DA can participate (Venegas and Petit, 2019).
- Principal barriers:
  - Tender period can be a barrier in all markets.
  - The minimum bid size in the aFRR market is 25 MW.
  - Demand Turn Up service did not take place in 2019.

Table 4 illustrates technical requirements described by NationalGrid, the UK TSO (Nationa Grid, 2019).

Table 4. Summary of balancing markets open to demand aggregators in UK

<table>
<tr><th>Market open to DA</th><th>Min. bid size [MW]</th><th>Not. time</th><th>Max. number of activations</th><th>Product resolution</th><th>Symm.</th><th>Duration of delivery</th><th>Tender period</th><th>Utilization payment £/MWh</th><th>Capacity payment £/MW/h</th></tr>
<tr><td>Primary response (FCR)</td><td rowspan="5">1</td><td>2 s (5 %)
10 s (100%)</td><td>Continuous</td><td rowspan="4">4 h</td><td rowspan="4">NO</td><td>20 s</td><td rowspan="4">Month</td><td rowspan="4">NO</td><td rowspan="4">8.6 On average</td></tr>
<tr><td rowspan="2">Secondary response (FCR)</td><td rowspan="2">30 s</td><td>Continuous</td><td rowspan="2">30 min</td></tr>
<tr><td>Discrete</td></tr>
<tr><td>High frequency response (FCR)</td><td>10 s</td><td>Continuous</td><td>Indefinite</td></tr>
<tr><td>Enhanced frequency response (FCR)</td><td>1 s</td><td>Continuous</td><td>4 years</td><td>YES</td><td>Minimum 15 min</td><td>Sporadic-ally</td><td>NO</td><td>9.4 on average</td></tr>
<tr><td>Fast reserve (aFRR)</td><td>25</td><td>2 min</td><td>10/day on average</td><td>1 month</td><td>NO (+)</td><td>15 min</td><td>Month</td><td>102 on average</td><td>N/A</td></tr>
<tr><td>STOR (RR)</td><td>3</td><td>As max. 240 min</td><td>Indicated by the service provider</td><td>1 h</td><td>NO (+)</td><td>2 h</td><td rowspan="2">Tendered 3 times a year</td><td>167 on average</td><td>1.8 on average</td></tr>
<tr><td>Demand Turn Up (RR)</td><td>1</td><td>6 h on average</td><td>Several times per week</td><td>Some hours</td><td>NO (-)</td><td>On average 4 h and 36 min in 2018</td><td>67 on average</td><td>1.5 on average</td></tr>
</table>

Table 5 summarizes some of the current business models in the countries analyzed. France, UK and Finland are the only countries were some residential consumers are aggregated in Europe. In general, the great majority of DA works with industrial or large energy consumers, Voltalis is the only DA that works exclusively with households. In UK, where consumers are charged depending on their consumption during the three peaks power of the country during the year, all DA analyzed try to reduce grid charges. However, strict requirements for FRR in UK block the entrance of DA in that market. In Finland, all DA analyzed participate in FCR markets because they are well suited for consumers. All DA having industries in their portfolio participate in RR markets because they are the best suited for large energy consumers.

Table 5. Analysis of the main European Demand Aggregator business model

	Aggregator	FCR	FRR	RR	Wholesale/ intraday market	Reduction of grid charges	Portfolio balancing	Client target	Act as retailer
Belgium	Restore (*REstore*, 2020)	X	X	X			X	Industries, tertiary buildings	
	Yuso (*Yuso*, 2020)				X		X	Renewables, batteries, industries	X
Finland	Seam (*SEAM group*, 2020)	X		X	X			Large energy consumers	
	Fortum (*Fortum*, 2020)	X					X	Households batteries, EVs, renewables	X
France	Smart Grid energy (*Smart Grid Energy*, 2020)		X	X		X		Industries, generators	
	Energy Pool (*Energy Pool*, 2020)	X	X	X	X		X	Industries, DER	
	Voltalis (*Voltalis*, 2020)	X				X	X	Households	
UK	Open Energi (*Open energi*, 2020)	X		X	X	X	X	Industries, generators, batteries.	
	Kiwi Power (*Kiwi Power*, 2020)			X		X		Industries, tertiary buildings, batteries and CHP	
	Flexitricity (*Flexitricity*, 2020)	X		X	X	X	X	CHP, consumers, batteries, back-up generators, renewables	

2.4. *Current framework in Spain*

The case study of this work is located in Spain; therefore, a specific analysis of the Spanish framework is required. In Spain the day-ahead, intraday and future electricity markets are managed by OMIE (*OMIE*, 2020), while ancillary services are managed by the national SO, REE (*Red Electrica de España*, 2020). Nowadays, DR is allowed just to large energy consumers (5MW) through the interruptibility services (Ministry of Energy, 2018). This program has not been activated for several years raising questions whether it is a genuine interruptible load program or a form of subsidy to the national industry (Bertoldi, Zancanella and Boza-Kiss, 2016). Furthermore, the only market mechanism for trading flexibility is the national a-FRR, while the other flexibility mechanisms are an obligation for all generation plants. Power plants are paid for their availability during peak hours and the cost is a bit more than 10000 €/MW per year, representing about the 5 % of the electric tariff in Spain. This is not an efficient system from an economic point of view; in addition, it does not accomplish the guidelines of the Energy Efficiency Directive 2012/27/EU and of the Winter Package. For these reasons, the analysis performed through European markets already opened to DA is useful to formulate a proposal that can be used for the Spanish one.

In Spain, 49 % of power installed in the country comes from renewable sources, being the 30 % from solar and wind (entsoe.eu, 2018). The high share of stochastic sources in the generation mix means high needs for flexibility in the grid. Today, to assure that the generation can cover all the demand, there are 108 MW installed of power plants against the historical maximum demand registered of 45 MW. DR could be a cheaper and more environmental-friendly solution to reduce payments to peak power plants and decommission the older ones. Moreover, wind curtailment grew exponentially from 2008 to 2013 with an economic impact of around 85 M€ (Koraki and Strunz, 2017) due to a mismatch between generation and demand. The addition of DR sources in the system is a necessity for the country to hold a transition toward a 100 % renewable electricity system.

2.5. Case study

The case study considers a DA of tertiary buildings based on the characteristics of the 61 libraries of the AMB, in order to simulate the behavior of a public DA in the market framework proposed for Spain. AMB has recently started one of the first municipal retailers in Spain (*Barcelona Energia*, 2020). The possibility to take advantage of the flexibility of its own buildings as libraries, schools and offices is a great opportunity for the AMB. DA could help to accomplish local climate and energy targets set by the Covenant of Mayors (*Convenant of Mayors for Climate&Energy*, 2018) and at the same time innovate the retailer business models, possibly increasing revenues through a public DA/retailer.

Data are gathered from the library situated in Montgat (Spain) from October 2017 to October 2018 (Barbero, 2020), while the other libraries are simulated depending on their real characteristics. Flexibility sources in the Montgat library are the HVAC and a self-consumption solution composed by a PV panel and a second life electric vehicle battery. The accuracy in electric measurements responds to the characteristics determined by the IEC (International Electrotechnical Commission) Standard 62053-11 (IEC, 2015) for Class 0.5, which is 0.5% under full load conditions.

The HVAC installed in the library is a Neptuno 125 by Ferroli, with a power peak of 39 kW and able to produce 126 kW of heat and 116 kW of cold. The HVAC behavior is simulated with a multi zone building that calculates the hourly consumption of the library using external temperature, solar irradiation and the set-point temperature. Knowing that the range of comfortable temperatures is the set-point temperature ± 1 ˚C, it is possible to calculate the flexibility of the library by changing the set-point temperature in the allowed range. The simulation uses Type 56 (Klein, Duffie, Mitchell, Kummer, Thornton, Bradley, *et al.*, 2007) of TRNSYS® and, although it is a simplified model, results are coherent with other studies (Chang, Zhang, Lian and Kalsi, 2013). To validate the model, a flexibility activation from 15:00 to 15:45 was simulated during the 15/07/2019 in Montgat library. From the simplified model, in July the library can reduce its HVAC consumption of 10.8 kWh when it is open during one hour. Figure 3 shows the behavior of the library during the activation: the HVAC consumption (grey line) is reduced with respect to the baseline (yellow line), calculated as the interpolation of the consumption between the start and the end of the flexibility activation. The estimated up flexibility (orange line) represents the expected minimum consumption that the library could have, which is very close to the reached value.

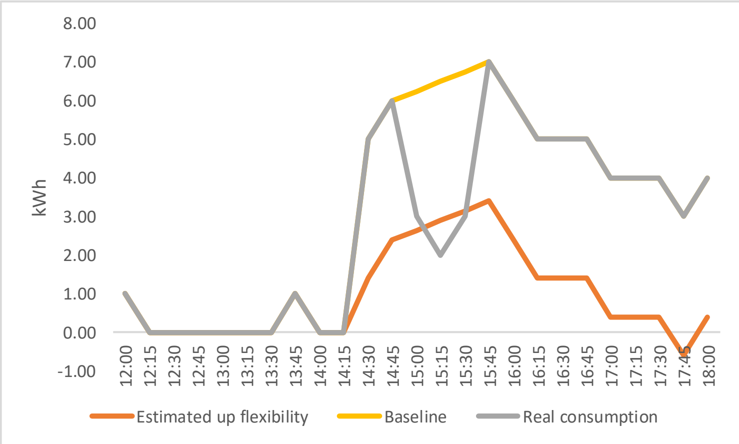

Figure 3. Simulation of a flexibility activation in July in the library

The storage system installed in the library is a second life EV battery, with capacity of 18.4 kWh and the power is limited to 10 kW by the converter. The strategy used in the building is to charge the battery during the night, when the energy is cheaper, to use that energy during the day, from 11h on. Therefore, the battery can offer downward regulation during the day and upward regulation during the night.

The HVAC system and the battery, due to their physical characteristics are suitable for participating in FRR services, while they could not participate in the RR market due to the large duration of delivery. The battery can also participate in the FCR market by continuously injecting or consuming energy from the grid whenever the frequency is lowing or increasing respectively (Canals Casals, Barbero and Corchero, 2019).

To estimate the flexibility of each one of the 61 libraries of the AMB the ratio between the power contracted by the Montgat library and each one of the other libraries is used, assuming that the same proportion corresponds to the flexibility available at libraries. Then, using the timetable of each library, the DA portfolio flexibility was calculated. Notice that the study takes into account that the flexibility is available since one hour before the opening of the library, as the building can be pre-heated or pre-cooled during that period.

The case study considers three different scenarios:

1. Libraries as they are. All buildings have HVAC but just one library has a battery. In this scenario, all the flexibility is traded in the FRR market.
2. 30 % of the libraries have electric batteries. As shown in Table 5 storage systems are often expected in the DA business models. Again, all the flexibility is traded in the FRR market.
3. Participation in FCR and FRR markets. Based on the specifications of Scenario 2, this 3rd Scenario considers that 20 % of the flexibility offered by batteries is traded in the FCR market, while the remaining 80 % is traded in the FRR market.

Figure 4 represents upward and downward flexibility for a typical day in January for Scenario 1 and 2.

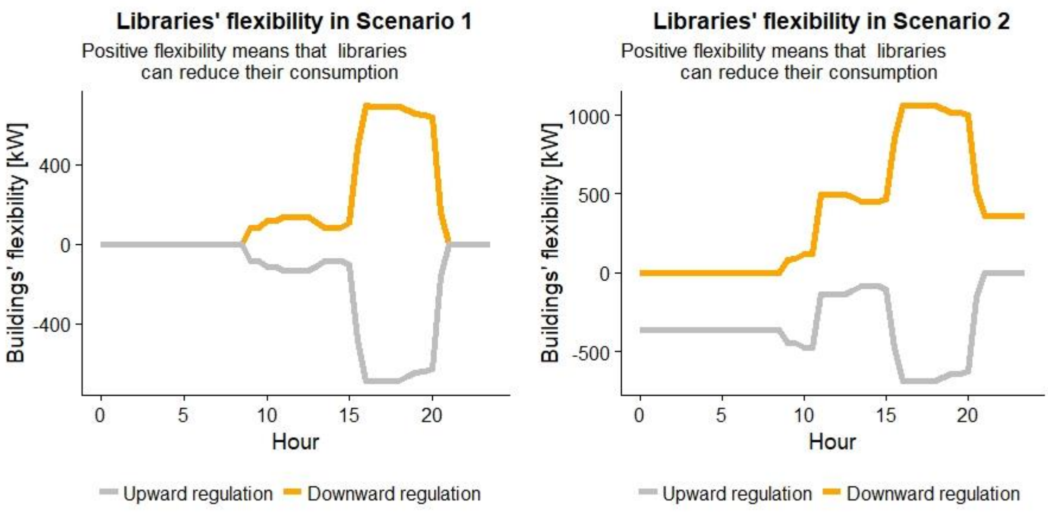

Figure 4. Libraries' flexibility in Scenario 1 and in Scenario 2 during 22th January

To calculate benefits from DR participation, the TSO calls to the DA are simulated using Matlab®, following the market characteristics described in Section 3.1. In detail, the number of calls per each day and direction comes from the round of a Normal distribution with an average equal to the average number of activations and a standard deviation equal to 0.7. Similarly, the duration of the activation varies randomly between the minimum and the maximum duration of delivery. The prices for utilization of the upward and downward regulation are those from the current FRR market in Spain during 2019 (*Red Electrica de España*, 2020). Regarding the capacity payment for FRR, the study assumed a price of 3.3 €/MW, according to the average price in the Finland market during 2019. Regarding capacity payments in the FCR market, it has been assumed the average price of the European symmetric FCR 200 mHz during 2019, that is 8.6 €/MW/h, where France and Belgium are participating. Finally, the hours activated are the hours with the highest price in the current market for two reasons: 1) The hours with the highest prices are the hours in which the grid is more stressed, so it is when a service that is activated just few times a day would be used; 2) This allows to keep into account eventual spike prices in the market.

To calculate the DA's benefits, it is assumed that the flexibility offered to the markets is the 80 % of the actual flexibility calculated, to ensure that the committed capacity is delivered by the DA even when some individual consumers may not be able to perform in order to avoid penalizations (SEDC, 2017). In this study the DA is considered as a price taker that uses hourly marginal prices and, thus, the formulation of an optimal bidding strategy is out of the scope

3. Discussion and results

According to the qualitative analysis of best practices, enablers and barriers from existing markets in Europe, this section proposes a national frequency energy market followed by an economic simulation of the functionality of a tertiary buildings' DA in the market.

3.1. Proposed frequency market

In order to allow participation of small consumers in frequency markets, it would be desirable that the prequalification takes place at pool level, as in Finland, UK and France. Otherwise, just large energy consumers will be able to be prequalified and DA would not increase the number of consumers that could participate in frequency markets. Taking Belgium, France and UK as example, it would be better if DA does not sign any contract with BRP/retailers and DSOs but directly with prosumers. In addition, the TSO should automatically adjust the BRP/retailer's curve when flexibility is activated from part of the DA, as it is done in Finland, to avoid to increase BRP/retailer unbalances costs due to the DA action.

FCR, due to the nature of the service, is the most similar market among countries. It is a very rapid regulation, for this reason the notification time is between 2 and 15 seconds and it is activated continuously. The Finnish case is a great example of how, at least in FCR markets, the minimum bid size can be 0.1 MW. As in Finland, a product resolution of 1 hour is proposed with daily auctions. Capacity payments are necessary for this type of service and should be higher than in other markets, as it is a more sophisticated service. Figure 5 represents qualitatively the FCR market proposed in respect to the four markets analyzed.

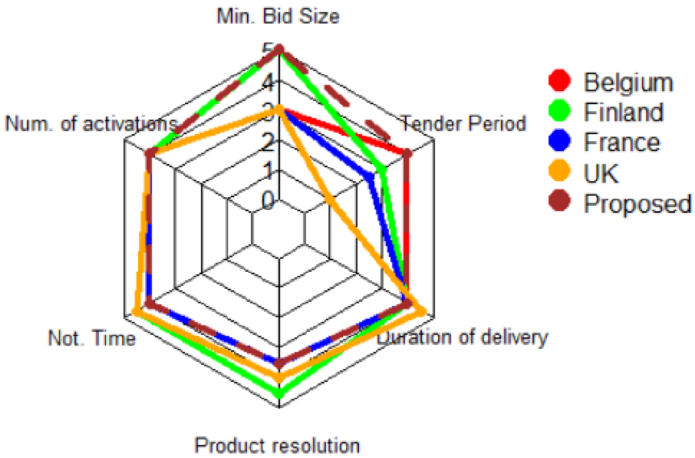

Figure 5. Comparison among countries and the proposed market for FCR balancing services

Regarding mFRR, the notification time recommended is 15 minutes, in line with all markets analyzed. Taking the Belgian example, it is proposed a minimum bid size of 1 MW, because higher minimum bid sizes could be difficult to reach for a tertiary building DA. In order to allow tertiary building DR, the average number of activations per day recommended is two, as in France. 30 minutes product resolution is suggested, as a longer product resolution would reduce the number of clients able to deliver the service using HVAC or batteries. In all countries analyzed, mFRR is not a symmetrical service and the duration of the service is between 15 minutes and 2 hours. Duration of delivery between 15 minutes and 1 hour are well suited for tertiary buildings. Regarding the tender period, in all countries apart from Finland, where it is contracted until 45 minutes before the hour of use, FRR is tendered monthly or yearly. The Finnish case demonstrates that shorter tender time is possible, a daily tender can be a good trade-off for allowing participation of DR in the market, taking into account that it could be very complicated for the DA to predict the flexibility one month or one week ahead. Marginal price for capacity payments and bid price for utilization payments should reflect costs and ensure revenues to all market participants, as already happens in France and Finland. Figure 6 represents qualitatively the FRR market proposed in respect to the four markets analyzed.

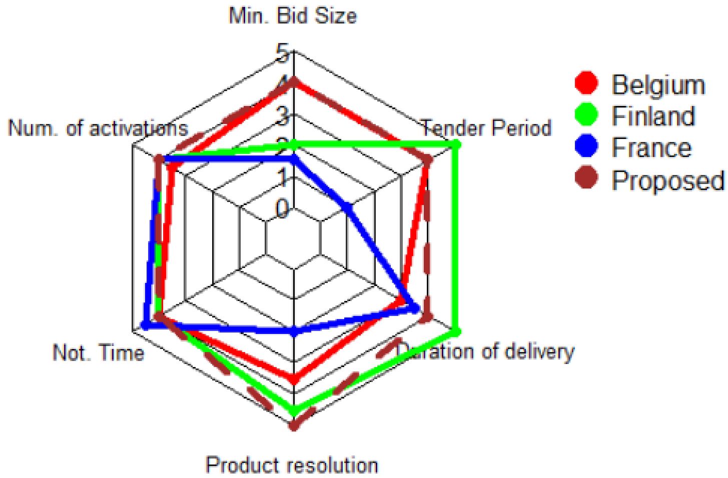

Figure 6. Comparison among countries and the proposed market for FRR balancing services

Regarding RR, the notification time varies significantly among countries; it goes from 15 minutes to 8 hours. DR sources usually can react relatively fast, a minimum notification time of 2 hours as in France or less can be enough for DA. The minimum bid size should be fixed to 1 MW as in Belgium and UK to boost DA participation. UK is a great example of how the maximum number of activations can be agreed with the DR source. The duration of delivery should be fixed to 2 hours, as in France. In France, Finland and UK the product resolution of 1 hour allows catching DR potentials, the same product resolution is proposed here. In all markets analyzed these reserves are contracted yearly or seasonally. A daily tender period would facilitate flexibility forecast for the next period, and indeed, it would enhance consumer's participation. Finally, in the market proposed there should be both capacity and utilization payments as in UK, France and Belgium. Figure 7 represents qualitatively the RR market proposed in respect to the four markets analyzed.

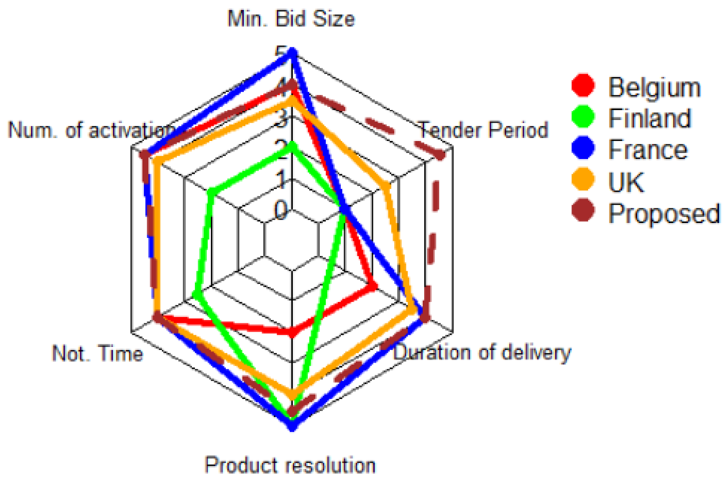

Figure 7. Comparison among countries and the proposed market for RR balancing services

Table 6 shows the summary of the technical requirements proposed for the different services.

Table 6 Proposed balancing market open to Demand Aggregators

Market	Min. bid size [MW]	Not. time	Max. number of activations	Product resolution	Symm	Duration of delivery	Tender period	Utilization payment	Capacity payment
FCR	0.1	15s 50% 30s 100%	Continuous activation	1 hour	YES	No stop	Daily	0	Marginal price
mFRR	1	15 min	2/day on average	30 minutes	NO	15 minutes to 1 hour	Daily	Bid price	Marginal price

RR	1	2 hours	Indicated by the service provider	1 Hour	NO	2 hours	Daily	Bid price	Marginal bid price

3.2. DA profits

This section shows the possible profits that the DA would have in the proposed FCR and FRR markets for our case study and the total energy shifted due to the balancing services offered. In addition, the study evaluates both the number of calls accepted by the DA and the minimum number of libraries needed to assure profits to the DA's clients. The number of calls accepted represents how many times the DA has flexibility available and it is activated by the TSO. Notice that if the DA has no flexibility available it will not do any bid to the market and the TSO will use other flexibility providers to restore the frequency in the grid. The number of libraries needed are calculated to reach the 95 % of the profits, taking into account just the hours in which the flexibility offered is higher than the minimum bid size. From the Matlab® simulation, the number of downward and upward FRR activations was 668 and 665 times respectively, with an average duration of the activation of about 38 minutes.

In the first scenario, libraries can respond to 531 calls out of 1333 from the TSO to the DA. It is assumed that during these hours the DA can activate other clients and, if not, it would not have offered flexibility into the market. Revenues from utilization and capacity are 5323 € and 5835 € respectively, which make a total amount of 11158 €. The total energy shifted to provide balancing services is respectively 65 MWh and 44 MWh for downward and upward regulation.

With these market conditions, the DA would need at least 596 libraries to assure its participation in the market. With less libraries, the DA would not reach the minimum bid size required.

In Scenario 2, libraries can respond to 985 calls thanks to the contribution of batteries, considerably more than in Scenario 1. This is because batteries are available also when the library is closed, while the HVAC is available just when the library is open. In this case total revenues would rise to 27929 €, of which 13699 € comes from utilization and 14230 € from capacity. The total energy shifted increases when batteries are considered. In this scenario 162 MWh and 114 MWh for downward and upward regulation respectively where used. This result shows how batteries increase substantially the flexibility of buildings, reducing also the number of buildings needed by the DA to reach the minimum bid size. In this case, at least 168 tertiary buildings would be necessary to reach the minimum bid size, assuring the 95 % of the benefits described.

In Scenario 3, libraries can also respond to 985 calls. In this third scenario, revenues come from two markets, resulting in 12025 € from utilization and 12550 € from capacity payments from FRR services, 4375 € from capacity payment from the FCR market, generating a total income of 28950 €. In Scenario 3 DA provides 143 MWh and 100 MWh for downward and upward regulation respectively for FRR services. As buildings participate in two markets at the same time, the flexibility needed to reach the minimum bid size for both services at the same time is higher and, consequently, at least 210 tertiary buildings would be necessary. Note that as FCR services pay just for capacity, energy revenues are lower than in Scenario 2. However, capacity payments in FCR are higher than in all other cases, making Scenario 3 the most suitable one, as benefits are 1020 € higher than in Scenario 2.

Table 7 resume the main results of each Scenario.

Table 7 Results by Scenario in the proposed balancing market

	Scenario 1	**Scenario 2**	**Scenario 3**
Number of calls accepted	532	985	985
Utilization Payments [€]	5323	13699	12025
Capacity Payments [€]	5835	14230	16925
Total energy shifted for FRR service [MWh]	109	276	243
Number of buildings needed to reach the minimum bid size	596	168	210

Average yearly revenue by scenario are 182, 457 and 475 € for each library. The estimated investment cost for DA client is about 134 € per consumer and per year to cover costs for automation, telecommunication and monitoring, according to (Rious, Perez and Roques, 2015). This means that total benefit per library per year are respectively 48, 323 and 341 €. Considering that the average annual bill of the libraries analyzed is about 30000 €, possible revenues represent a very low percentage of the total bill. Figure 8 shows the results.

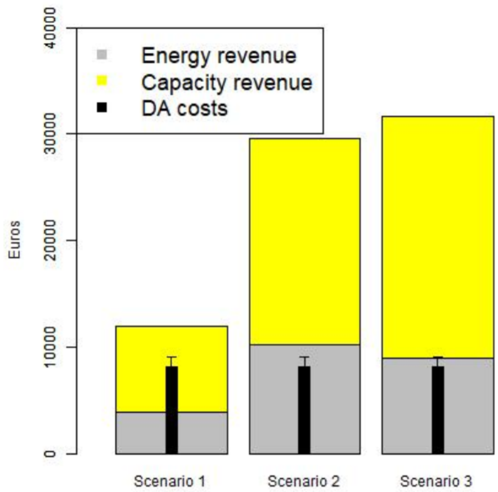

Figure 8. DA costs and profits by Scenario in the proposed balancing market

Notice that in this study costs and benefits are considered as an overall and that taxes are not counted. If from these results taxes and the share of the profits among all clients should be subtracted from the DA profits, the business model would not probably be viable. However, hardware costs for DR could be amortized by the reduction in the energy bill due to the monitoring and the consumption optimization of the building. Including batteries in the study substantially increases the brut profit of the DA. However, although the investment costs for batteries and inverters are not considered due to the inherent complexity of battery ageing according to its working conditions (Canals Casals, Lluc, Amante García Beatriz, González Benítez, 2017) and, thus, the amortization period, this profit is expected not to be enough to guarantee the payment of a battery replacement, as shown in a recent study from the same authors that already analyzed costs and benefits of using second life batteries for DR in balancing markets here (Canals Casals, Barbero and Corchero, 2019).

In order to better understand the impacts of the technical requirements on the DA business model, Table 8 shows benefits and total number of buildings needed for Scenario 2 under tuned market conditions. Values for the base case come from the market conditions represented in Table 6.

The minimum bid size of the offer has no impact on the revenues generated. However, it has a strong influence on the number of libraries needed by the DA to assure that revenues. There is almost a linear correlation between the number of libraries needed and the minimum bid size of the offer. This means that if the minimum bid size is higher, the DA needs a larger portfolio to participate in the frequency regulation market.

The average number of activations mostly influence revenues. While there is a fixed part (capacity payments) that does not depend on the total number of activations, the variable part (utilization payments) does. By increasing the number of activations, revenues per each library grow. However, the comfort of the building's occupants is affected more times per day and buildings' managers would be less willing to take part of the DA portfolio.

It is found that the symmetricity of the offer is a very important parameter in the DA business model. By putting this condition, the DA is forced to offer ever the lower available flexibility between the upward and the downward, reducing the total flexibility offered to the system.

Revenues are dramatically reduced (divided by three) and the number of buildings needed to assure the participation in the frequency regulation market is multiplied by four.

The product resolution affects both revenues and the number of libraries needed. Increasing the product resolution to 4 hours forces the DA to offer the minimum upward and downward flexibility available in the 4 hours' block. In this case, revenues are reduced to 316 € and the number of libraries needed is more than doubled. In the case of a product resolution of 24 hours, the business model would not be possible, because, as represented in Figure 4, the upward or the downward flexibility are equal to 0 in many occasions.

Table 8 Revenues and number of libraries needed under tuned technical requirements

Tuned Parameter	Revenues per library [€]	Number of libraries needed
Base case	457	168
Minimum bid size = 5 MW	457	841
Minimum bid size = 0.1 MW	457	17
Average number of activations = 4	614	171
Average number of activations = 1	351	168
Symmetric offer	160	671
Product resolution = 4 h	316	366
Product resolution = 24 h	0	NA

From the analysis performed, even though regulatory and technical barriers to participate through small aggregated tertiary buildings in frequency regulation markets are avoided using the market proposed, it can be difficult for DA to find a valuable business model by aggregating small tertiary buildings. Economic barriers are yet strong, as prices are too low to face actual costs in communication and automation needed to participate in these markets. However, it is highlighted the importance to facilitate the entrance of small tertiary buildings DA in the frequency regulation market, as they can be an important resource for the grid. Moreover, the impact of the technical requirements on the DA business model is quantified.

4. Conclusions

This study identifies the main barriers for small tertiary buildings' Demand Aggregators to participate in frequency regulation services. In particular, regulatory, technical and economic barriers are identified in hierarchical order. These barriers are reinforced when prequalification is made at the asset level and when there is a lack of regulation for determining the effect of Demand Aggregator on the Balance Responsible Party or retailer's portfolio balancing. With the aim to avoid all these barriers, the study proposes a possible market framework.

Economic results from the simulation of a Demand Aggregator aggregating public libraries in the proposed market shows that possible revenues are relatively low, especially when only air conditioning system is used for Demand Response services. Results highlight that batteries can substantially increase revenues for Demand Aggregators and reduce the number of clients necessary to reach the minimum bid size required although the amortization costs of these batteries might significantly reduce this economic advantage. From the simulation also emerges that Demand Aggregators can increase their revenues offering flexibility in different markets at the same time. In addition, the study analyzes the effect of technical requirements in the Demand Aggregator's business model. It is found that the symmetricity of the offer and the product resolution are the most important requirements to evaluate possible revenues and the number of buildings needed by the Demand Aggregator.

If revenues should be divided among clients and subtracting taxes, the creation of a business model for small tertiary buildings Demand Aggregator does not seem possible and a great flexibility potential would be blocked. In order to reduce costs, municipalities that already participate in electricity markets through a municipal retailer, as it is the case in Barcelona with "Barcelona Energia", could consider to extend their operations to Demand Aggregation. For this reason, this study proposes an innovative public Demand Aggregator, which is also the owner of the flexible buildings. In Barcelona, the municipal retailer can act as Demand Aggregator using the flexibility of its buildings to balance its own portfolio and selling services to the grid. There is a big potential considering the great number of public buildings that public institutions manage. Probably it is the only way to take advantage of the flexibility of these small tertiary buildings, also considering that public administration does not need to respond just to market forces, as they also need to respect environmental targets and be an example for citizens.

Acknowledgment

The authors gratefully acknowledge the project REFER (COMRDI15-1-0036), funded by ACCIÓ and the European Regional Development Fund (FEDER) under the RIS3CAT Energy Community. This research has also been financially supported by the research and innovation programme Horizon 2020 of the European Union under the grant agreement nr. 731211 SABINA. C. Corchero work is supported by the grant IJCI-2015-26650 (MICINN). Prof. F.-Javier Heredia was supported by the grant RTI2018-097580-B-I00 of the Ministry of Science, Innovation and Universities of Spain.

All researchers have been partially supported by the Generalitat de Catalunya (2017 SGR 1219). The authors also acknowledge the suggestions from the Energy Pool team.

References

Abapour, S., Mohammadi-Ivatloo, B. and Tarafdar Hagh, M. (2020) 'Robust bidding strategy for demand response aggregators in electricity market based on game theory', *Journal of Cleaner Production*. Elsevier Ltd, 243, p. 118393. doi: 10.1016/j.jclepro.2019.118393.

[dataset] Barbero, M. (2020) 'Montgat library consumption and temperatures'. Mendeley Data. doi: 10.17632/ftwbtw9nmx.2.

Barcelona Energia (2020). Available at: http://energia.barcelona/es/barcelona-energia-la-electrica-publica-metropolitana (Accessed: 5 February 2020).

Behrangrad, M. (2015) 'A review of demand side management business models in the electricity market', *Renewable and Sustainable Energy Reviews*. Elsevier, 47, pp. 270–283. doi: 10.1016/j.rser.2015.03.033.

Bertoldi, P., Zancanella, P. and Boza-Kiss, B. (2016) *Demand Response status in EU Member States*, *Europa. eu: Brussels, Belgium*. doi: 10.2790/962868.

Bondy, D. E. M., Gehrke, O., Thavlov, A., Heussen, K., Kosek, A. M. and Bindner, H. W. (2016) 'Procedure for validation of aggregators providing demand response', *19th Power Systems Computation Conference, PSCC 2016*. doi: 10.1109/PSCC.2016.7540997.

Borne, O., Korte, K., Perez, Y., Petit, M. and Purkus, A. (2018) 'Barriers to entry in frequency-regulation services markets: Review of the status quo and options for improvements', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 81(July 2016), pp. 605–614. doi: 10.1016/j.rser.2017.08.052.

Canals Casals, Lluc, Amante García Beatriz, González Benítez, M. M. (2017) 'Aging Model for Re-used Electric Vehicle Batteries in Second Life Stationary Applications', in *Project Management and Engineering Research. Lecture Notes in Management and Industrial Engineering*. Springer, Cham, pp. 139–151. doi: https://doi-org.recursos.biblioteca.upc.edu/10.1007/978-3-319-51859-6_10.

Canals Casals, L., Barbero, M. and Corchero, C. (2019) 'Reused second life batteries for aggregated demand response services', *Journal of Cleaner Production*. Elsevier Ltd, 212, pp. 99–108. doi: 10.1016/j.jclepro.2018.12.005.

Cappers, P., Macdonald, J. and Goldman, C. (2013) *Market and Policy Barriers for Demand Response Providing Ancillary Services in U.S. Markets*, *Lawrence Berkeley National Laboratory*. doi: 10.1016/j.enpol.2013.08.003.

Chang, C. Y., Zhang, W., Lian, J. and Kalsi, K. (2013) 'Aggregated Modeling and Control of Air Conditioning Loads for Demand Response', *IEEE Transactions on Power Systems*, pp. 1–10. doi: 10.1109/ISGT.2013.6497895.

De Clercq, B. (2015) 'Electricity security crisis in Belgium - Role of Elia System Operator', *Elia*, (January).

Convenant of Mayors for Climate&Energy (2018). Available at: https://www.eumayors.eu/ (Accessed: 6 August 2018).

Ding, Y., Cui, W., Zhang, S., Hui, H., Qiu, Y. and Song, Y. (2019) 'Multi-state operating reserve model of aggregate thermostatically-controlled-loads for power system short-term reliability evaluation', *Applied Energy*. Elsevier, 241(November 2018), pp. 46–58. doi: 10.1016/j.apenergy.2019.02.018.

Elia - Keeping the Balance (2019).

Energy in Buildings and Communities Programme (2016) 'EBC Annex 67 Energy Flexible Buildings, http://www.iea-ebc.org/projects/ongoing-projects/ebc-annex-67/'.

Energy Market Authority (2013) 'National report 2013 to the Agency for the Cooperation of Energy Regulators and to the European Commission. Finland', pp. 1–68. Available at: http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/NATIONAL_REPORTS/National Reporting 2013/NR_En/C13_NR_Finland-EN.pdf.

Energy Pool (2020). Available at: https://www.energy-pool.eu/en/technology/ (Accessed: 5 February 2020).

EnergyPool (2018) *Lancement de l'appel d'offresis Effacement*. Available at: https://www.energy-pool.eu/fr/lancement-de-lappel-doffres-effacement-2018/ (Accessed: 14 June 2018).

ENTSO-E (2020) *ENTSOE's transparency platform 2020*. Available at: https://transparency.entsoe.eu/balancing/r2/balancingVolumesReservationPrice/show (Accessed: 12 February 2020).

entsoe.eu (2018) *Installed Capacity per Production Type*. Available at: https://transparency.entsoe.eu/generation/r2/installedGenerationCapacityAggregation/show?name=&defaultValue=false&viewType=TABLE&areaType=BZN&atch=false&dateTime.dateTime=01.01.2017+00:00%7CUTC%7CYEAR&dateTime.endDateTime=01.01.2017+00:00%7CUTC%7CYEAR&are (Accessed: 11 July 2018).

European Commission (2016) *Clean Energy for All Europeans*. Available at: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans.

European Parliament (2012) 'Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency', *Official Journal of the European Union Directive*, (October), pp. 1–56. doi:

10.3000/19770677.L_2012.315.eng.

Fingrid (2019) *Reserves and balancing power*. Available at: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/ (Accessed: 24 December 2019).

Flexitricity (2020). Available at: https://www.flexitricity.com/en-gb/ (Accessed: 5 February 2020).

Fortum (2020). Available at: https://www.fortum.com/ (Accessed: 5 February 2020).

Good, N., Ellis, K. A. and Mancarella, P. (2016) 'Review and classification of barriers and enablers of demand response in the smart grid', *Renew. Sustain. Energy Rev.* doi: 10.1016/j.rser.2017.01.043.

Heleno, M., Matos, M. A. and Lopes, J. A. P. (2016) 'A bottom-up approach to leverage the participation of residential aggregators in reserve services markets', *Electric Power Systems Research*, 136, pp. 425–433. doi: 10.1016/j.epsr.2016.03.025.

IEC (2015) *Electricity metering equipment (a.c.) – Particular requirements – Part 11: Electromechanical meters for active energy (classes 0,5, 1 and 2)*.

Ikäheimo, J., Evens, C. and Kärkkäinen, S. (2010) 'DER Aggregator Business: the Finnish Case', p. 38.

Iria, J., Soares, F. and Matos, M. (2018) 'Optimal supply and demand bidding strategy for an aggregator of small prosumers', *Applied Energy*. Elsevier, 213(September), pp. 658–669. doi: 10.1016/j.apenergy.2017.09.002.

Katz, J. (2014) 'Linking meters and markets: Roles and incentives to support a flexible demand side', *Utilities Policy*. Elsevier Ltd, 31, pp. 74–84. doi: 10.1016/j.jup.2014.08.003.

Khan, A. S. M., Verzijlbergh, R. A., Sakinci, O. C. and De Vries, L. J. (2018) 'How do demand response and electrical energy storage affect (the need for) a capacity market?', *Applied Energy*. Elsevier, 214(July 2017), pp. 39–62. doi: 10.1016/j.apenergy.2018.01.057.

Kiwi Power (2020). Available at: https://www.kiwipowered.com/ (Accessed: 5 February 2020).

Klein, S. A., Duffie, J. A., Mitchell, J. C., Kummer, J. P., Thornton, J. W., Bradley, D. E., *et al.* (2007) 'Multizone Building Modelling with Type 56 and TRNBuild', *Trnsys 16-a Transient System Simulation Program*, 6, pp. 1–11.

Koraki, D. and Strunz, K. (2017) 'Wind and Solar Power Integration in Electricity Markets and Distribution Networks Through Service-centric Virtual Power Plants', *IEEE Transactions on Power Systems*, 33(1), pp. 1–1. doi: 10.1109/TPWRS.2017.2710481.

Lindberg, K. B. (2017) *Impact of Zero Energy Buildings on the Power System - A study of load profiles , flexibility and system investments*. Available at: http://hdl.handle.net/11250/2450566.

Malhotra, A., Battke, B., Beuse, M., Stephan, A. and Schmidt, T. (2016) 'Use cases for stationary battery technologies: A review of the literature and existing projects', *Renewable and Sustainable Energy Reviews*, 56, pp. 705–721. doi: 10.1016/j.rser.2015.11.085.

Ministry of Energy (2018) 'Boletón Oficial del Estado', *Boletín Oficial del Estado*, pp. 61561–61567. Available at:

https://transparencia.gob.es/servicios-buscador/contenido/normativaordenministerial.htm?id=NORMAT_E0492160119036&lang=es&fcAct=2019-03-15T08:25:41.875Z.

Nationa Grid (2019) *Balancing services*.

Nordic TSOs (2017) *Unlocking flexibility Nordic TSO discussion paper on third-party aggregators*. doi: 10.1109/MPE.2016.2625218.

OMIE (2020). Available at: http://www.omel.es/inicio (Accessed: 10 February 2020).

Open energi (2020). Available at: http://www.openenergi.com/ (Accessed: 5 February 2020).

Paterakis, N. G., Erdinç, O. and Catalão, J. P. S. (2017) 'An overview of Demand Response: Key-elements and international experience', *Renewable and Sustainable Energy Reviews*. Elsevier, 69(September 2015), pp. 871–891. doi: 10.1016/j.rser.2016.11.167.

Peng, C., Zou, J., Lian, L. and Li, L. (2017) 'An optimal dispatching strategy for V2G aggregator participating in supplementary frequency regulation considering EV driving demand and aggregator's benefits', *Applied Energy*. Elsevier Ltd, 190, pp. 591–599. doi: 10.1016/j.apenergy.2016.12.065.

Piette, M. A., Schetrit, O., Kiliccote, S., Cheung, I. and Li, B. Z. (2015) *Costs to Automate Demand Response – Taxonomy and Results from Field Studies and Programs*. Available at: https://gig.lbl.gov/sites/all/files/drrc_final_report_taxonomy.lbnl-1003924.pdf.

Poplavskaya, K. and de Vries, L. (2019) 'Distributed energy resources and the organized balancing market: A symbiosis yet? Case of three European balancing markets', *Energy Policy*. Elsevier Ltd, 126(November 2018), pp. 264–276. doi: 10.1016/j.enpol.2018.11.009.

Red Electrica de España (2020). Available at: http://www.ree.es/es/ (Accessed: 5 February 2020).

REFER (2018). Available at: https://refer.upc.edu/ca (Accessed: 31 July 2018).

REstore (2020). Available at: https://restore.energy/en/homepage (Accessed: 5 February 2020).

Richter, L. L. and Pollitt, M. G. (2018) 'Which smart electricity service contracts will consumers accept? The demand for compensation in a platform market', *Energy Economics*. The Authors, 72, pp. 436–450. doi: 10.1016/j.eneco.2018.04.004.

Rious, V., Perez, Y. and Roques, F. (2015) 'Which electricity market design to encourage the development of demand response?', *Economic Analysis and Policy*. Economic Analysis and Policy, pp. 128–138. doi: 10.1016/j.eap.2015.11.006.

RTE ancillary services (2019).

SEAM group (2020). Available at: http://www.seam-group.com/en/ (Accessed: 5 February 2020).

SEDC (2016) 'Explicit and Implicit Demand-Side Flexibility Complementary Approaches for an Efficient Energy System Explicit and Implicit Demand-Side Flexibility: Complementary Approaches for an Efficient Energy

System', (September). Available at: http://www.smarten.eu/position-papers-reports/.

SEDC (2017) 'Explicit Demand Response in Europe Mapping the Markets 2017', pp. 1–223. Available at: http://www.smarten.eu/wp-content/uploads/2017/04/SEDC-Explicit-Demand-Response-in-Europe-Mapping-the-Markets-2017.pdf.

Shoreh, M. H., Siano, P., Shafie-khah, M., Loia, V. and Catalão, J. P. S. (2016) 'A survey of industrial applications of Demand Response', *Electric Power Systems Research*. Elsevier B.V., 141, pp. 31–49. doi: 10.1016/j.epsr.2016.07.008.

Smart Energy Demand Coalition (2014) 'Mapping Demand Response in Europe Today', *SEDC. Smart Energy Demand Coalition*, (April), p. 92. Available at: http://www.febeliec.be/web/infosession strategic demand reserve _ 16_5_2014/1011306087/list1187970122/f1.html%5Cnhttp://sedc-coalition.eu/wp-content/uploads/2014/04/SEDC-Mapping_DR_In_Europe-2014-04111.pdf.

Smart Grid Energy (2020). Available at: https://www.smartgridenergy.fr/ (Accessed: 5 February 2020).

Spiliotis, K., Ramos Gutierrez, A. I. and Belmans, R. (2016) 'Demand flexibility versus physical network expansions in distribution grids', *Applied Energy*. Elsevier Ltd, 182, pp. 613–624. doi: 10.1016/j.apenergy.2016.08.145.

Sweco, Ecofys, Tractbel Engineering and PWC (2015) 'Study on the effective integration of demand energy recourses for providing flexibility to the electricity system', *Final report to The European Commission*, (April), p. 179.

Venegas, F. G. and Petit, M. (2019) 'Can DERs fully participate in emerging local flexibility tenders ?', *Eem 2019*. IEEE, pp. 1–5.

Voltalis (2020). Available at: https://www.voltalis.com/business#header (Accessed: 5 February 2020).

Yuen, C., Oudalov, A. and Timbus, A. (2011) 'The provision of frequency control reserves from multiple microgrids', *IEEE Transactions on Industrial Electronics*, 58(1), pp. 173–183. doi: 10.1109/TIE.2010.2041139.

Yuso (2020). Available at: https://yuso.be/en/ (Accessed: 5 February 2020).