Financial Viability of the Aggregators Participation in the Regulation Reserve Market

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***Abstract*—There is an urgent need to reduce the combustion of fossil fuels and replace these sources with renewable energy sources. The two major renewable energy resources, solar PV and wind generation, are variable. This variability makes balancing the electrical system more difficult. One way to manage this volatile system is to use markets for ancillary services to ensure that the electrical grid can operate in a safe, efficient and reliable manner. This paper proposes a methodology for a group of smaller consumers to be aggregated together so that they can effectively bid into markets for ancillary services. The methodology is tested on the Portuguese reserve regulation market and the financial viability of such aggregation is explored. Results show that aggregating consumer bids for downward regulation services can be financially viable in the Portuguese market. Reducing the minimum bid size increased the participation of the consumers thus increasing revenues.**

Keywords—Aggregators, Ancillary services, Electricity market, Renewable energy, Reserve regulation.)

I. Introduction

A. Motivation, Aims and Background

Many countries are beginning to recognize the full risks associated with climate change due to the burning of fossil fuels. These countries are introducing legal and regulatory proposals to transform their power system away from fossil fuels and towards the use of more renewable energy technologies [1].

This is the case in the European Union which has introduced numerous proposals to accelerate the energy transition. These proposals include the Clean Energy for all Europeans' package [2].

This EU wide legislative package has been transposed to the national level in Portugal through the National Energy and Climate Plan for 2030 [3]. This plan aims to increase the use of renewable energy technologies to 47% of gross energy consumption by 2030 and reach carbon neutrality by 2050.

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The greater use of renewable energy is expected to bring about some extra challenges related to forecasting and matching the electricity demand across the day [4], [5].

There are market-based solutions to these challenges which typically include ancillary services to help maintain the reliability, quality and efficiency of the power system in real-time [6]. Regulators and system operators have realized the importance of ancillary services and as such have created competitive markets for the delivery of these services [7].

Generally, these services are provided by non-renewable generators and the revenue from providing these services can help replace part of the revenue lost in the conventional energy markets [6]. This is the context behind the development of this work which seeks to analyze the impacts of an aggregator of consumers in Portugal to gather enough generation to participate in the ancillary markets, namely participating in the reserve regulation market. This aggregator can thus assist in balancing the supply and demand of energy within Portugal.

B. Literature review

The participation of consumers in energy markets has been studied by several authors. For example, the optimal bidding strategy of an aggregation of residential consumers participating in the secondary and reserve markets within MIBEL was developed by [8].

The authors found that the preferences of the consumers significantly affect the cost borne by both the aggregator and the prosumers and that consumer-owned EVs offer the greatest source of flexibility for the aggregator.

An optimization model for the aggregation of residential consumers is developed in [9]. The residential consumer has several distributed energy devices such as PV systems, battery energy storage systems and thermal energy storage systems and the aggregator can schedule the residential load to participate in the day-ahead energy market as well as local flexibility markets.

The optimization of the participation of an aggregator in the wholesale power market as well as the regulation reserve market was proposed by [10]. The model investigated the impacts of a group of Norwegian electricity consumers on the flexibility of the system. Results showed a 4% cost reduction for the group of consumers during the study period.

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A business model for an aggregator operating in ancillary markets was analyzed by [11]. Various scenarios were created to investigate the impact of increasing flexible resources on the financial outcomes of the aggregator agents. The functionality and technical barriers to implementation were highlighted and discussed.

The business model and financial viability of a DR aggregator in a regulated power market were investigated by [12]. The authors found that DR aggregation is profitable in regulated power markets but the specific market designs play a significant role in the financial performance of the aggregator. The authors investigated a general form of DR and did not consider specific ancillary services which may be more profitable.

Reserve provision by an aggregation of interconnected microgrids was analyzed in [13]. The authors propose a three-stage framework that takes into account both active and reactive power requirements and the framework ensures that the technical constraints of the test case are not exceeded. The financial viability of the proposed aggregator framework was not considered.

C. Contributions and Paper Organization

In this paper, the financial feasibility of aggregator's participation in the Portuguese regulating reserve market is explored. This paper has the following main contributions:

- Analyze the financial feasibility of aggregating consumption offers in the Portuguese Regulatory Reserve Market. This is done by aggregating the consumption of different consumers and then increasing or decreasing consumption in a certain time and by a certain amount.
- The developed model allowed for different levels of minimum bid sizes that allowed for the level of participation from the consumers to change.
- Evaluate the impact that this type of bid will have on the regulatory reserve market, specifically through the price offered.

The rest of the manuscript is organized as follows: Section II contains the methodological approach. Section III contains the results obtained from the model as well as a discussion of these results. Conclusions drawn from these results are presented in Section IV.

II. Methodology

The main objective of this manuscript is to investigate the feasibility of aggregators participating in the reserve regulation market. This was done by combining various consumer's demand and submitting bids into the downward regulation reserve market through an increase in the consumers' consumption.

A. Aggregation model

Initially, an ideal aggregation model was developed to submit bids directly to the Iberian energy market. This will be done through the aggregation of demand profiles from several consumers across a day.

The possibility of aggregating the consumers based on their geographical proximity is investigated, Fig. 1, and additionally an in the case where the consumers are not located nearby Fig. 2, the amount of energy bid into the market is increased to account for the increased losses. The bids submitted for aggregation can follow one of two paradigms relating to the quantity of power offered:

- Minimum bid size of 1 MW and increasing the bids by 1 MW increments.
- Minimum bid size of 0.1 MW and increasing the bids by 0.1 MW increments.

These two paradigms were chosen according to existing market rules as well as [14]. The smaller size of the bids allows a larger number of smaller consumers to participate.

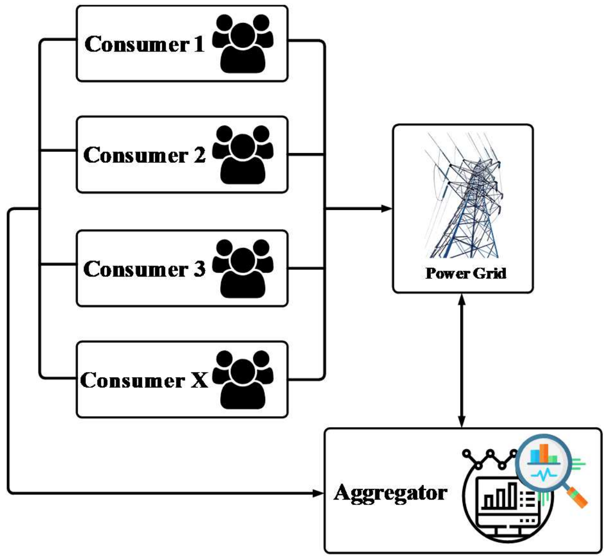

Figure 1 - Aggregation scheme of the different consumer customers under the same transformer.

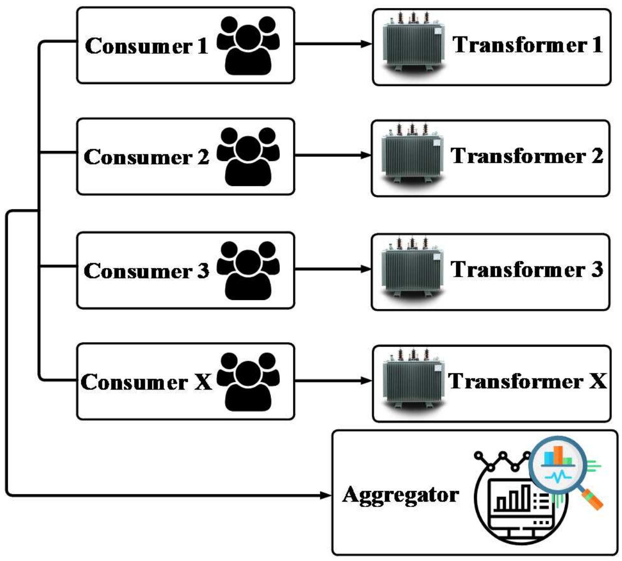

Figure 2 - Aggregation scheme of the different consumer customers bidding at various transformers.

B. Remuneration model

The remuneration model for the provision of downward reserve regulation services by the consumers is divided into two parts. First, the aggregator submits and is rewarded for the provision of the ancillary services. Second, the clients receive their remuneration after increasing the consumption to meet the needs of the bid. The energy provided for the reserve regulation is valued at the marginal price of the regulation market at the time of contract delivery.

Thus, for each period, the reward for regulation services is dependent on the price paid for the marginal unit of energy in either the upward or downward regulation markets.

Moreover, the total remuneration due to the aggregator is given in (1) which shows that the remuneration is dependent on the marginal price at that time multiplied by the amount of downward reserve provided to the system operator:

$$VRR = \sum (PRR \cdot ERR) \qquad (1)$$

where VRR is the revenue for the downward regulation reserve service in €, PRR is the marginal price of the regulation reserve market to be lowered (€/MWh), and ERR is the amount of energy sold into the downward regulation reserve market in MWh.

The consumers' revenue is dependent on the income provided by the reserve regulation market less the cost of increased consumption of energy bought on the spot market of the day-ahead energy market. This is shown in (2):

$$G_0 = \sum (PRR \cdot ERR) - \sum (PM \cdot ERR) \qquad (2)$$

where, G_0 is the consumer's gross revenue in €; PM is the Daily Market price (€/MWh); PRR is the Regulation Reserve Market price (€/MWh) and ERR is the amount of energy transacted in MWh. Once G_0 is calculated, it is necessary to subtract the percentage owed to the aggregator agent in return for the services provided. This is expressed in (3).

$$G_0 = G_X + G_A \qquad (3)$$

Where G_X is the net consumer gain and G_A is aggregator's gain, both given in Euros. Thus, the full revenue for the aggregator for over the group of consumers can be given by multiplying a factor α, which represents a percentage of each of the consumer's revenue. Thus, the total value of the economic result of the aggregating agent is given by the expression (4).

$$G_A = \sum_{x \in \Omega^X} (G_X \cdot \alpha_X) \qquad (4)$$

III. Analysis and Results Discussion

When submitting bids for inclusion in the aggregators offer, bids of 1MW were considered as well as bids of multiples of 0.1MW. This was done as 0.1MW is the minimum bid size for energy markets in certain European countries [14]. This allowed the smaller consumers to participate while still meeting the stated thresholds. In this paper, the aggregation was carried out using different scenarios of bid sizes. These scenarios are:

- Aggregation of all customers, with offers of 1MW and allowing offers of multiples of 0.1 MW
- Aggregation of the customers with the highest consumption, with offers of 1MW and allowing offers of multiples of 0.1 MW
- Aggregation of a group of domestic customers, with allowed bids of multiples of 0.1 MW.

In this manuscript, the bids into the regulation reserve market were made in 5494 hours of the 8760 hours of 2019, corresponding to 62.7% of the available hours.

These hours were during the working days of the year with some additional hours removed which did not have data recorded.

A. Data and Assumptions

The consumer data is presented in Table I and can be divided into two groups. The first group comprises of the consumption of 12 different domestic consumers (represented by the code DOM1-12 in the table). The second group comprises 15 commercial customers, eight of which are contracted to receive medium voltage energy (represented by the code MV1-8 in the table) while the remaining seven are connected to the low voltage distribution network under special low voltage energy contracts (represented by the code LV1-8 in the table).

For the economic study carried out in this paper, the data from the day-ahead energy market and the Regulation Reserve Market were also analyzed and these were obtained from [3], [4]. The data analyzed were for the year 2019. Regarding the downward Regulation Reserve Market, the data were treated and investigated using MATLAB.

Through this, the average amount of the regulation reserve negotiated throughout 2019 was obtained. Specifically, various representative days were derived from the data. Firstly, an average day for the whole year was derived, then representative days for various seasons were developed, and finally, representative profiles for each of the days of the week were constructed.

Figure 3 show the power and average price of the regulation reserve during the average day, respectively. Analyzing the downward regulation reserve prices, the average price for this service is calculated as 32.66 €/MW.

TABLE I - CONSUMERS' CODE AND THEIR CONTRACTED POWER AND AVERAGE DAILY ENERGY CONSUMPTION.

Consumer	Contracted Power (kW)	Daily Aver. Energy Consumed (kWh)	Consumer	Contracted Power (kW)	Average Energy Consumed Daily (kWh)
LV 1	50.00	12.0	MV 8	186.00	6.2
LV 2	55.00	13.6	Dom1	39.60	1.7
LV 3	67.00	24.5	Dom2	23.25	3.4
LV 4	120.00	60.3	Dom3	187.49	26.4
LV 5	195.00	74.9	Dom4	23.25	0.4
LV 6	177.00	67.9	Dom5	47.00	8.0
LV 7	70.00	6.2	Dom6	46.50	12.2
MV 1	146.48	65.0	Dom7	65.00	9.2
MV 2	130.67	47.5	Dom8	41.41	3.7
MV 3	465.85	119.4	Dom9	46.00	4.9
MV 4	292.95	81.2	Dom10	41.41	3.3
MV 5	50.00	5.1	Dom11	74.40	13.2
MV 6	689.00	63.0	Dom12	93.00	12.4
MV 7	292.95	50.2			

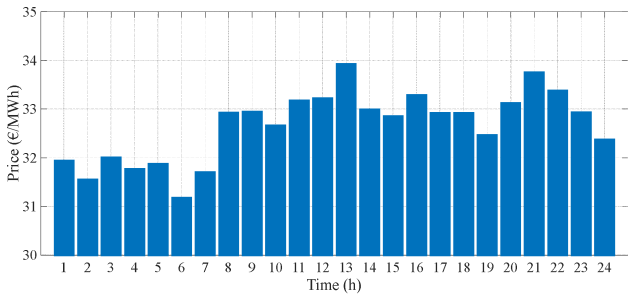

Figure 3 – Average hourly downward regulation reserve price in MIBEL during 2019.

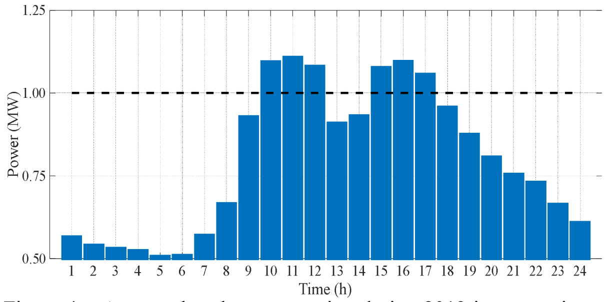

Figure 4 – Average hourly consumption during 2019 in comparison to the 1MW bid size.

A detailed analysis of each consumer's demand profile was undertaken to better estimate their potential to contribute to downward reserve regulation. Also, detailed investigations were carried out regarding the variation in demand profiles across the various days in the week as well as how the demand profiles fluctuated during the differing seasons.

B. *Proposal 1*

The first bidding proposal involved aggregating and offering 1MW of regulation reserve flexibility but only when the customers' load profiles allowed. This constituted a significant portion of the consumer's load and thus this threshold was rarely met making this proposal unfeasible.

Figure 4 shows the total consumption of the aggregated consumers. The Figure shows that the consumption rarely crosses the 1MW threshold, in fact, the consumption only crosses this threshold between the hours of 10:00 and 12:00 and then again between 15:00 and 17:00.

This is mainly due to the low consumption of the consumers. Further analysis showed that the aggregate consumption only crossed the 1MW level for 1420 hours of the total 5494 hours available. If the 1MW aggregate load was bid into the daily market at the marginal price, the energy would cost €48 943.5. The same amount of energy bid into the downward regulation reserve market would generate €73 624.32 which would leave a gross result of €24 680.82 for the consumers without deducting the percentage due to the aggregator for services rendered.

C. *Proposal 2*

To obtain an analysis with a similar number of customers, but with higher consumption, a group of consumers with similar consumption was chosen. The 13 consumers selected in this proposal are those present in Table II. This proposal investigates an increase of consumption of 10% for various hours in proposal 2.1 and an increase of consumption by 20% for various hours in proposal 2.2.

1) *Proposal 2.1*

In this proposal, the bidding offers were in the range of 0.1MW to 0.3MW. These bid sizes allowed the aggregator to bid into the regulating reserve market for 826 of the 5494 hours available, representing 15% of the period.

Table II shows the consumers that participate in this proposal, the respective percentage of consumption and the profit relative to the offer. Thus, the combined revenue generated by this proposal was €2 835.13 for 2019. The total amount of energy in these bids is 165.7 MWh but only 81 MWh are accepted. Increasing consumption through the day ahead market has a cost of €5 676.48 while revenue from participating in the Reserve Regulation Market was €8 511.61.

TABLE IV - RESULTS OF PROPOSAL 3.1

	Percentage consumption on offer (%)	Energy traded (MWh)	Total Profit (€)	Consumer Profit (€)	Aggregator Agent Profit (€)
dom2	1.03	0.36	3.07	2.92	0.15
dom5	1.63	0.57	4.84	4.59	0.24
dom7	3.69	1.29	10.97	10.42	0.55
dom8	1.35	0.47	4.02	3.82	0.20
dom9	3.68	1.29	10.92	10.38	0.55
dom10	1.15	0.40	3.42	3.25	0.17
dom11	4.38	1.53	13.00	12.35	0.65
dom12	16.42	5.75	48.78	46.34	2.44

TABLE V - RESULTS OF PROPOSAL 3.2

	Percentage consumption on offer (%)	Energy traded (MWh)	Total Profit (€)	Consumer Profit (€)	Aggregator Agent Profit (€)
dom2	1.17	3.4	33.24	31.57	1.66
dom5	2.47	7.19	70.22	66.71	3.51
dom7	5.24	15.22	148.68	141.24	7.43
dom8	1.45	4.23	41.28	39.21	2.06
dom9	3.52	10.22	99.86	94.87	4.99
dom10	1.21	3.15	34.27	32.56	1.71
dom11	6.48	18.82	183.90	174.71	9.2
dom12	11.79	34.25	334.55	317.82	16.73

TABLE VI - COMPARISON OF PROPOSALS 3.1 AND 3.2

	Percentage of consumption in the proposal 3.1 (%)	Percentage of consumption in the proposal 3.2 (%)	Profit on the proposal 3.1 (€)	Profit on the proposal 3.2 (€)
dom2	1.03	1.17	3.07	33.24
dom5	1.63	2.47	4.84	70.22
dom7	3.69	5.24	10.97	148.68
dom8	1.35	1.45	4.02	41.28
dom9	3.68	3.52	10.92	99.86
dom10	1.15	1.21	3.42	34.27
dom11	4.38	6.48	13.00	183.90
dom12	16.42	11.79	48.78	334.55

TABLE VII - COMPARISON OF THE DIFFERENT PROPOSALS

Proposals	Consumers' Total Profit (€)	Aggregator Total Profit (€)	Energy Exchanged (MWh)	Min. Power Auctioned (MW)	Number of Hours Traded
Proposal 1	23446,78	1234,04	1420.0	1	1420
Proposal 2.1	2693.37	141.76	165.7	0.1	826
Proposal 2.2	18159.25	955.75	1112.4	0.1	4034
Proposal 3.1	282.18	14.85	35.0	0.1	352
Proposal 3.2	2696.08	141.90	290.5	0.1	2557

2) *Proposal 2.2*

In this proposal, the bid sizes ranged from 0.1MW to 0.5MW according to the varying consumption patterns of the consumers. This allowed bidding to take place in 4034 of the 5494 hours available. This represents 73.4% of the period under study.

Based on Table III, 885.51 MWh of energy was traded resulting in a profit to the consumers of €19 115. This was due to revenues from the regulating reserve market of €56 703 and costs from the daily market of €37 587.72.

Thus, the use of divisible offers to reflect the technical characteristics of the consumers' consumption flexibility allows a more varied set of consumers to access the market through the provision of ancillary services, increasing both the profit for the consumer and the aggregator.

D. Proposal 3

This bidding proposal focused on domestic consumers with similar contracted power levels and energy consumption over 2019. This consisted of 24 demand profiles being aggregated for submission to the reserve regulation market.

This proposal was subdivided into two groups. One group offered energy consumption increases of 25% of total consumption (proposal 3.1) while the other group offered a 50% increase (proposal 3.2) in total consumption. The hours available to bid into the reserve market from these two groups were 352 and 2557 which corresponds to 6.4% and 46.5% of the total hours respectively.

1) Proposal 3.1

In this proposal, the group of consumers were able to bid on a total of 35 MWh of energy. This resulted in a profit of €297.03 from marginal costs from the daily energy market of €635.97 and reserve regulation revenues of €933 for the lowering of energy costs. Table IV shows the effects of the various consumers.

2) Proposal 3.2

In proposal 3.2, which consisted of allowing bids into the reserve regulation market for a 50% increase in consumption from the consumers, the energy bid into the reserve market reached a total of 290.5 MWh. This corresponds to a profit of €2 839.98 after costs from the day-ahead energy market of €5 679.35 and revenue from the regulation reserve market of €8 517.33 were considered. The individual profit figures of the proposal for each consumer can be seen in Table V.

Both proposals 3.1 and 3.2 considered the same consumers and the only difference was the total amount of consumption that could be bid into the reserve market. Proposal 3.2 had twice the amount of energy bid into the reserve market and this meant that the consumer's profit in proposal 3.2 was about ten times as much as proposal 3.1.

This result shows the importance of conducting prior research into the amount of potential load reduction offered by each client to maximize their savings through participation in such a program.

E. Financial Feasibility Assessment

From the comparison between proposals 2.1 and 2.2 it is shown that increasing the amount of aggregate consumption from 10% to 20% results in an increase in gains for the consumers and the aggregator by nearly nine-fold.

An increase from 20% to 30% of aggregate consumption increases doubles the profit. However, the absolute amount of profit in Euros between the two proposals is quite similar

Table VI compares proposals 3.1 and 3.2. The increase in the percentage of consumption in proposal 3.2 increases the profit of the consumers as it increases their interactions with the regulation reserve market.

Table VII shows a comparison of the profit, energy traded, and the number of hours traded from the consumers in five proposals. Both proposal 2.2 and 3.2 show a significant increase in the number of hours traded compared to proposals 2.1 and 3.1 respectively. Also, Table VII shows an analysis of the financial viability of the aggregator agent across all five proposals.

It should be noted that the increase in the amount of energy traded increases the need for flexibility from the aggregator agent to adjust and respond to the more profitable bids from the consumers.

This work has assumed that the aggregator agent is a price-taking agent It should also be noted that smaller minimum bids (0.1 MW) increase the number of available bids from a collection of consumers. This is an important result if the goal of the future energy system is to have more consumer engagement. Devising regulations with low minimum bid sizes increases the ability of consumers to participate and thus increase the liquidity and viability of aggregating agents. Across the various proposals, the marginal revenue for the aggregator is approximately 5% for each consumer. This marginal revenue will need to cover the aggregator's cost of operations, such as staffing and consumer acquisition. Whether this revenue is sufficient to ensure the financial viability of the aggregator depends on numerous factors which still need to be investigated.

IV. Conclusions

In this paper, a methodology was presented for the aggregation of a group of smaller consumers so that they can jointly bid into ancillary services markets. The Portuguese reserve market was used to test the methodology and the financial viability of such aggregation was explored. The results of this study will be increasingly important to the transmission system operators who are responsible for managing the system. These results show that consumers, through aggregator agents, can increase the flexibility of the electricity system. The inclusion of smaller offers can allow for very precise market balancing actions and will reduce the need to engage in other, potentially more expensive, grid balancing actions. Also, the results show that consumer welfare was improved by participating in ancillary markets through the aggregator agent. The services identified in this paper add value to the existing energy system. Consumers can lower their energy bills by being rewarded for the provision of much needed ancillary services. The inclusion of the aggregator agent can be an important step in increasing consumer engagement. According to various plans and directives, the energy system will become more electrified in the future and the need for flexibility will increase. Thus, increased participation of consumers through aggregators can contribute to flexibility requirements for future energy systems. Lowering the minimum bid size increased the participation of the consumers and allowed them to enjoy increased revenues. Smaller minimum bid sizes may allow further aggregation of the consumers but will involve increased difficulty in managing these groups of consumers. This tradeoff can be explored in future research. The marginal revenue for the aggregator from each consumer is quite low and thus business models which focus on reducing costs such as consumer acquisition costs and minimizing barriers to entry for consumers should be prioritized. Different business models will be investigated in future research.

References

[1] K. Hansen, C. Breyer, and H. Lund, "Status and perspectives on 100% renewable energy systems," *Energy*, vol. 175, pp. 471–480, 2019.

[2] European Commission, "Clean energy for all Europeans package," *Energy - European Commission*, Oct. 20, 2017. https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en (accessed Nov. 09, 2020).

[3] Ministry of environment and climate change, "National Energy and Climate Plan 2030." [Online]. Available: https://www.portugal.gov.pt/pt/gc22/comunicacao/comunicado?i=plano-nacional-energia-e-clima-2030-aprovado-em-conselho-de-ministros (accessed Nov. 09, 2020).

[4] G. J. Osório, J. N. D. L. Gonçalves, J. M. Lujano-Rojas, and J. P. S. Catalão, "Enhanced Forecasting Approach for Electricity Market Prices and Wind Power Data Series in the Short-Term," *Energies*, vol. 9, no. 9, Art. no. 9, 2016.

[5] S. D. Ahmed, F. S. M. Al-Ismail, M. Shafiullah, F. A. Al-Sulaiman, and I. M. El-Amin, "Grid Integration Challenges of Wind Energy: A Review," *IEEE Access*, vol. 8, pp. 10857–10878, 2020.

[6] M. R. M. Cruz, D. Z. Fitiwi, S. F. Santos, S. J. P. S. Mariano, and J. P. S. Catalão, "Multi-Flexibility Option Integration to Cope with Large-Scale Integration of Renewables," *IEEE Transactions on Sustainable Energy*, vol. 11, no. 1, pp. 48–60, 2020.

[7] N. G. Paterakis, O. Erdinç, and J. P. S. Catalão, "An overview of Demand Response: Key-elements and international experience," *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 871–891, 2017.

[8] J. Iria, F. Soares, and M. Matos, "Optimal bidding strategy for an aggregator of prosumers in energy and secondary reserve markets," *Applied Energy*, vol. 238, pp. 1361–1372, 2019.

[9] C. A. Correa-Florez, A. Michiorri, and G. Kariniotakis, "Optimal Participation of Residential Aggregators in Energy and Local Flexibility Markets," *IEEE Transactions on Smart Grid*, vol. 11, no. 2, pp. 1644–1656, 2020.

[10] A. Roos, S. Ø. Ottesen, and T. F. Bolkesjø, "Modeling Consumer Flexibility of an Aggregator Participating in the Wholesale Power Market and the Regulation Capacity Market," *Energy Procedia*, vol. 58, pp. 79–86, 2014.

[11] M. Agostini, F. Bignucolo, M. Coppo, R. Turri, and J. M. Schwidtal, "Ancillary services provision by aggregators and impact on distribution network operation," in *2019 54th International Universities Power Engineering Conference (UPEC)*, Sep. 2019, pp. 1–6.

[12] C. Fang, B. Fan, T. Sun, D. Feng, and J. Chen, "Business models for demand response aggregators under regulated power markets," *CIRED - Open Access Proceedings Journal*, vol. 2017, no. 1, pp. 1614–1617, 2017.

[13] A. L. Bella, M. Farina, C. Sandroni, and R. Scattolini, "Design of Aggregators for the Day-Ahead Management of Microgrids Providing Active and Reactive Power Services," *IEEE Transactions on Control Systems Technology*, vol. 28, no. 6, pp. 2616–2624, Nov. 2020.

[14] REN *et al.*, "Trans European Replacement Reserves Exchange," ENTSO-E, Brussels, Belgium, 2016.