A Survey on the Participation of Distributed Energy Resources in Balancing Markets

Mana Farrokhseresht, Nikolaos G. Paterakis, Madeleine Gibescu, Yaser Tohidi, J. G. Slootweg
Electrical Energy Systems, Eindhoven University of Technology
Eindhoven, the Netherlands
{m.farrokhseresht, n.paterakis, m.gibescu, y.tohidi, j.g.slootweg}@tue.nl

***Abstract*—Distributed Energy Resources (DER) participation in the conventional balancing market operated centrally by the Transmission System Operator (TSO) presents challenges such as neglecting the operational constraints of Distribution System Operators (DSO) and increased communication requirements from many small units. Participation of DER in a DSO-operated local balancing market can mitigate these challenges to some extent. However, in such a market model, if operated independently from the central balancing market, individual costs for the TSO and the DSO might be higher. Therefore, the coordination between the TSO and the DSO is important to ensure that the global cost to the system is minimized. Apart from the market design, there are other issues related to the participation of DER in balancing markets such as minimum bid size, which can be mitigated through the use of aggregators, and the imbalance settlement process, which involves penalizing or rewarding participants through various pricing mechanisms. This paper reviews most of the features necessary for a successful participation of DER in balancing markets, including different market architectures, the role of aggregators and pricing mechanisms in balancing markets.**

***Index Terms*—Aggregator, Balancing market, Distributed Energy Resources, TSO-DSO coordination.**

I. INTRODUCTION

The increasing penetration of renewable energy sources (RES) makes balancing supply and demand more challenging for system operators. RES with nearly zero operational cost will be dispatched before conventional generators [1]. This means that a large portion of on-line generators with a predictable power output will be replaced by RES with uncertain power outputs [2]. In addition, the central balancing and congestion management processes for TSOs will be more difficult in systems where there is an increased share of Distributed Energy Resources (DERs) such as solar and wind generation, combined heat and power and energy storage units at the distribution level [3]. Unlike traditional generation units connected at the transmission grid, DERs generally have small capacity and are connected to the low and medium voltage distribution grids [4]. Traditionally, balancing has been the responsibility of the TSO and is provided by large conventional generators connected to the transmission level. However, in addition to supplying electricity, DERs can also deliver balancing services and consequently increase the stability of the grid and security of supply [5].

A key factor that incentivizes provision of balancing services by DERs is their exposure to market signals [6]. Balancing markets can be an effective transaction platforms for small DERs to actively provide balancing services [1][2]. However, one of the main challenges of balancing markets is establishing an efficient mechanism for DERs to enable their participation in market transactions [7].

Traditionally, the TSO operates the central balancing market where all resources with balancing responsibility at transmission or distribution grids participate and sell their balancing services [8]. In this market process, the DSO is not involved when (aggregated) DERs are activated by the TSO in the balancing market and this can cause problems such as congestion and voltage violations for the distribution system [9]. As a result, in addition to this TSO-operated balancing market, there might be a need for a similar market but operated by the DSO [10]. In this paper, this market is called a DSO-operated local balancing market. New roles and responsibilities have to be defined for the DSO in order to extract the most value from DERs [11][12].

Moreover, these two markets influence each other and consequently there should be a coordination between the TSO-operated central balancing market and the DSO-operated local balancing market [13]. Coordination makes it possible for the TSO and all connected DSOs to balance supply and demand system-wide while resolving voltage and congestion issues locally [14][15]. Furthermore, this coordination provides opportunities to use DERs for the provision of balancing services, not only for the distribution grid, but also for the benefit of the entire power system [16]. In this paper, different market frameworks for the TSO-operated central balancing market and the DSO-operated local balancing market are explained in detail. The pros and cons of each model are provided subsequently.

The contribution of this paper is to classify different balancing market frameworks introduced in the literature. Our classification gives an overview about possible market structures for participation of DERs in central or local balancing markets; based on the existence of a local balancing market for DERs or lack thereof. In case of existence of a local balancing market, the classification is complemented with the coordination mechanisms linking local and central balancing markets.

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The rest of the paper is organized as follows. In section II the aforementioned balancing market frameworks are explained. In addition to market frameworks, for a successful participation of DERs in local balancing market, aggregtaor plays an important role. Moreover, price signal acts as an incentive mechanism for aggregator who participates in balancing markets. Therefore, section III and IV present roles of aggregator and pricing mechanisms in balancing markets respectively. Conclusions are provided in section V.

II. Balancing market models for DERs

In the current balancing market structure, the TSO contracts directly with DERs, possibly via an aggregator, for their balancing services. Participation of DER in the balancing market, however requires a different market structure; a local balancing market where DERs' services could be procured and DSO involved as an active player to cope with the problems related to a TSO-operated central balancing market [9]. Generally speaking, balancing market structures for participation of DERs can be split into: the global balancing market model, the independent local balancing market model, and the local balancing market with TSO-DSO coordination model. These models are discussed further in more details.

A. Global balancing market model

In this model, there is no local balancing market in the distribution level. Instead, there is only one TSO-operated central balancing market for both resources connected at transmission (i.e. flexibility assets which can provide balancing services and are connected at the TSO level directly such as large generator, large flexible loads, etc.) and distribution levels (i.e DERs). It means that the TSO is the only buyer of balancing services from both large and DERs. The TSO contracts DERs directly from the distribution grid, possibly via an aggregator. The role of the DSO is limited to impose pre-qualification, i.e. a process to ensure that activation of resources from DERs by the TSO doesn't jeopardize the security and stability of the distribution grid [17]. In this scheme, there are two submodels as explained below.

1) Centralized balancing market: There is only one TSO-operated balancing market. The TSO is the only entity which has the access to all the resources at the distribution and transmission system to be used for the entire power system balancing [18]. In the market clearing process of this setup, distribution network constraints are not taken into account and the DSO is not involved in the procurement of balancing services from DERs. The advantage of this model is the relatively simple process of its market clearing. Since the distribution grid constraints are not taken into account during market clearing, the pre-qualification has to be imposed by the DSO in order to secure the distribution grid.

2) Common TSO-DSO balancing market: This setup could be seen as an extension of the centralized TSO-operated balancing market. The difference is that in this model, in the market clearing process, a common optimization is considered, which satisfies the needs for both distribution and transmission grids and minimizes the total cost of procuring balancing services. Therefore, distribution constraints are simultaneously taken into account during central balancing market clearing. Collaboration and sharing of data between TSO and DSO is necessary for this market model to be implemented in practice. However due to the combination of all constraints of the whole system in one optimization, the market clearing involves a heavy computation process. In [19] this model is used. This model is shown in Fig. 1.

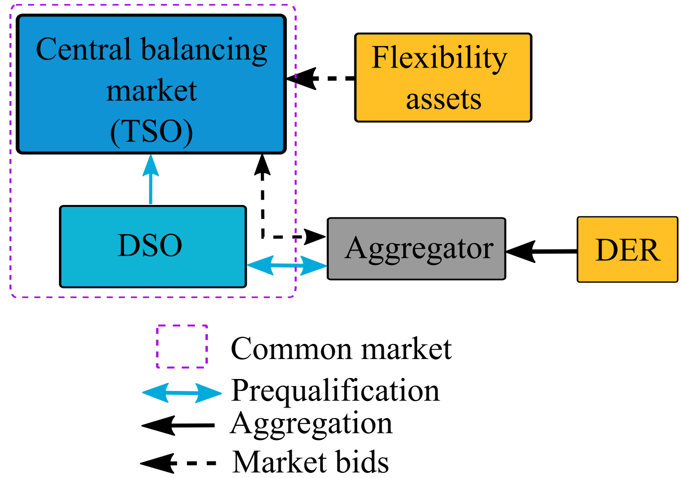

Fig. 1: Common TSO-DSO balancing market

B. Independent Local Balancing Market

In this market setup, there is a local balancing market which is operated by the DSO and the TSO is the operator of the central balancing market. However, unlike previous market models, the TSO cannot access DERs and utilize their balancing services for its own purpose. As in this model the balancing responsibility of the distribution grid is transferred completely to the DSO, this model is called Shared Balancing Responsibility in [17]. The efficiency of resource allocation is relatively low and Balance Responsible Parties (BRPs) may face a higher balancing cost in this model, as both TSO and DSO have limited access to resources outside their jurisdiction area. However, the operational process of market clearing is relatively less complicated. In [20] this market architecture is applied. In Fig. 2, this model is shown schematically.

C. Local balancing market with TSO-DSO coordination

In this setup there is a local balancing market which is operated and cleared by the DSO. DERs offer their balancing services first to this local balancing market. DSO is the buyer of their services and its priority is to solve its own balancing problems, by activating DERs connected to its jurisdiction area. The remaining non-used balancing capacity from DERs can be aggregated and transferred to the TSO grid. Depending on whether or not the DSO participates in the TSO-operated central balancing market with these non-used aggregated DERs, there can be two types of local balancing markets which are in coordination with the TSO: non-strategic DSO and strategic DSO schemes.

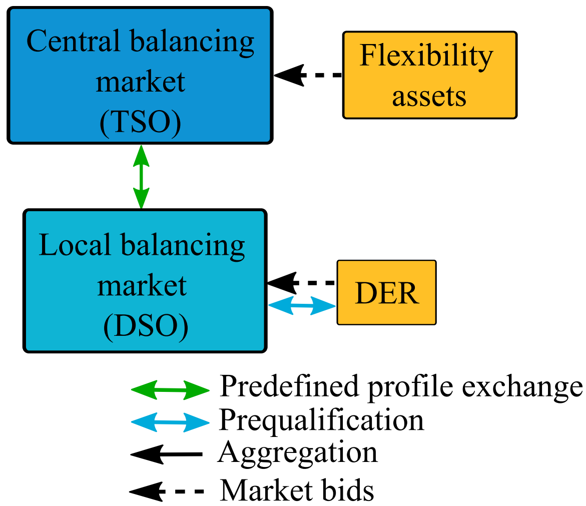

Fig. 2: Independent local balancing market

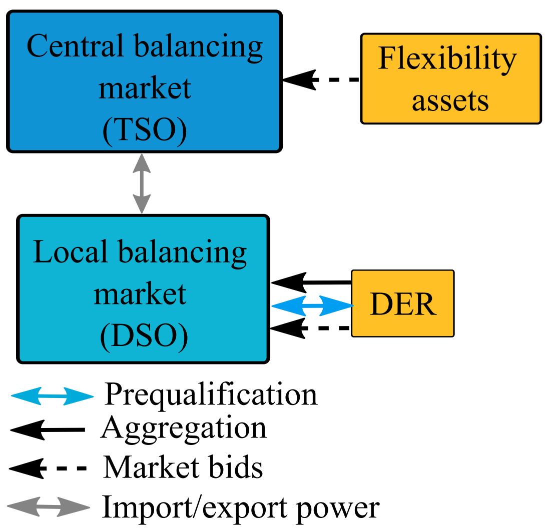

Fig. 3: Local balancing market with non-strategic DSO

1) Non-strategic DSO: In the approach proposed in [21][22], the DSO clears the local balancing market first. Then, if the demands cannot be fulfilled by local resources, or supply is not completely consumed, the DSO imports or exports electricity from higher voltage grid levels. Similarly, in the local ancillary service market model proposed in [23], DSO has the priority over the TSO for the allocation of DERs from the distribution grid. After solving local grid constraints, DSO aggregates and offers the remaining bids to the TSO. This corresponds to Fig. 3. The concern about non-strategic DSOs is that there is no guarantee that the resources are used efficiently throughout the whole system.

2) Strategic DSO: [24] proposes a methodology to optimize the trading strategies of a profit maximizing proactive distribution company (PDISCO) in the balancing market by mobilizing the demand response. While this is not in line with EU regulation, a separate entity from the DSO could take on the role of PDISCO to manage the DERs, and coordinate with the DSO to respect network constraints and provide congestion management services. PDISCO submits continuous

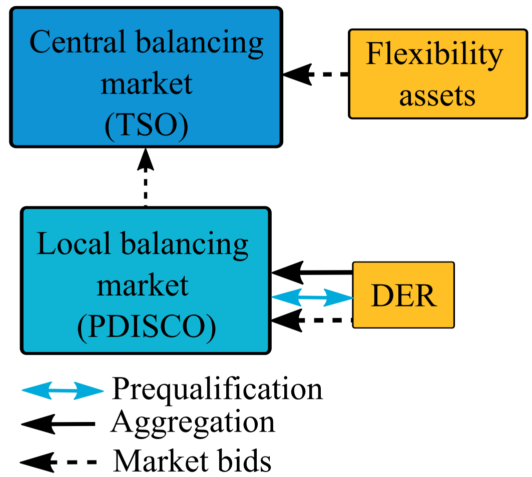

Fig. 4: Local balancing market with strategic DSO

offers and bids strategically to the transmission-level balancing market. Modelling of PDISCO together with profit maximizing distributed generation (DG) is presented in [25]. PDISCO in this framework is basically an aggregator that acts in the wholesale market by finding the best aggregated offer based on the offers received from the DGs and the network constraints. Thus, the upper level problem should have been DGs profit maximization and the lower level problem the PDISCOs offers to day-ahead and balancing markets. However, it is modelled the other way around in [25]. This model corresponds to Fig. 4.

In Table I, all these balancing markets with their sub-models and characteristics are summarized.

III. Role of Aggregators

There is usually a minimum bid size for market participants in balancing markets [4]. Often, DERs are not able to participate in the balancing market due to this restriction. Therefore, to accumulate balancing services from small-scale DERs and sell them to a BRP, the DSO or the TSO, an aggregator can play a key role in the balancing market [26]. The aggregator can optimize the value of balancing services from DERs by selling it to the entity which has the most immediate need for those services, and hence is prepared to pay competitively [27]. Moreover aggregators can mitigate the risk of non-delivery of balancing services from a single DERs by aggregating a large number of them and consequently guaranteeing the provision of balancing services [28]. The aggregator and DERs should agree on commercial terms and condition for procuring balancing services [27]. Accordingly, aggregators in balancing markets can be categorized into three types:

1) Production aggregator: aggregates small generators to enable them to access the balancing market [29]. An example is the Virtual Power Plant. The aggregator builds a flexible portfolio as part of its business model. Other market players in the balancing market can also utilize these aggregated services [28].
2) Demand aggregator: acts as an arbitrator between small resources and other market players in balancing markets.

TABLE I: A summary of different balancing market architectures

	Role of DSO/ respecting distribution network	Role of TSO /Interaction between DSO&TSO	Costs / resources allocation efficiency	Mathematical algorithm/ computational complexity
Non-strategic DSO	- Local market operator - Buyer of services from DERs - Provide security and stability of the grid	- Central market operator - DSO imports/exports power to/from TSO - Extensive communication between the TSO-operated balancing market and the local DSO-operated balancing markets.	- Local markets might create lower entry barriers for small scaled DERs - In strategic DSO model due to participation of DSO in TSO wholesale market the cost of DSO and the total system is minimized - High resources allocation efficiency in both TSO and DSO	- Heavy operational process (manual and iterative) - Deadline for finishing the market clearing process might be endangered in strategic DSO model - Could create uncertainty in the market as it is unclear on which base DSOs might block activations
Strategic DSO	- Local market operator - Aggregates the DERs - Provide security and stability of the grid	- Central market operator - DISCO can maximize its profit by participating in TSO balancing market		
Independent local market	- Local market operator - Provide congestion management and grid balancing - DSO grid constraints are respected.	- Central market operator - Clear boundaries between TSO and DSO. - Defining a pre-defined schedule methodology agreed by both TSO/DSO might be challenging	- Total amount of balancing services to be procured by TSO and DSO will be higher - BRPs might face higher costs for balancing - Small local markets might be not provide sufficient resources for the DSO	- Operationally less heavy - Privacy and confidentiality of data are guaranteed
Centeralized market	- No real involvement of DSO - Provide system pre-qualification	- System market operator - Only the TSO is a buyer for the service	- Low in operational costs	- Practically DSO constraints might not be respected - Need for accurate forecasts of future grid load - In order to secure the grid, safety margins taken by the DSO might be very conservative
Common market	- DSO grid constraints are respected - Provide system pre-qualification	- System market operator - TSO and DSO collaborate closely making optimal use of the available DERs - Need for sharing data between DSO and TSO	- Total system costs of balancing service for the TSO and local services for the DSO are minimized - Individual cost of TSO and DSO might be higher compared to other schemes - Allocation of costs between TSO and DSO could be difficult	- Heavy mathematical process

For example, they can have agreement with residential or commercial electricity consumers to aggregate their capability for shifting the loads and building a Demand Response Service [26]. Therefore, they make a single resource of many small active loads and sell their services in the balancing market.

3) Commercial aggregator: acts as a balance responsible entity and monitors its own power balance in order to be sure that the power purchased and generated matches the power sold and consumed within its portfolio. This type aggregator has to pay imbalance charges in case of deviation from a submitted programme [30].

Depending on the these different roles, aggregators can bring different added value for the system; small-scaled DERs can access the marketplace, balance responsible parties can optimize their portfolios to mitigate risks of deviating from their day-ahead schedules, and finally DSOs and TSOs have more options to balance the system [31].

IV. Imbalance pricing schemes

Price signals can play an important role in incentivizing efficient interactions from actors in the balancing market [32]. In this section, different imbalance pricing schemes are explained briefly. There are two approaches for imbalance prices in Europe: single and dual pricing. The production surplus of a BRP is referred to as the long imbalance price and its production shortage is referred to as the short imbalance price. Under a single pricing approach the long and short imbalance prices are identical [33]. It means that DERs or aggregators receive the imbalance price if they have generation surplus and have to pay this same price if they have shortage in the balancing market. However, in the dual pricing approach, the long and short imbalances have different prices, which also depend on the direction of the market party's imbalances with respect to the direction of the net system imbalance. In other words, if DER's or aggregator's imbalance is in the opposite direction of the system imbalance, they usually have to pay the price equal to the day-ahead price. But if they are in the same direction with the net system imbalance, they have to pay the price based on the marginal cost of the last balancing unit deployed, which is usually higher than the day-ahead price. Germany, Belgium and UK are countries which apply a single pricing scheme [34]. Dual pricing approach is applied in the Netherlands, France, Spain and the Nordic countries [32]. The dual pricing approach creates more incentive for an aggregator to net its imbalance among different DERs. In the single pricing approach, however, DERs will always have to pay its marginal cost whether or not this activated DERs is in the aggregator's portfolio [28].

V. Conclusion

This paper presented a review of different balancing market structures where Distributed Energy Resources (DERs) can provide balancing services. The focus of this paper was on the introduction of local balancing markets operated by the DSO and its coordination with the TSO-operated central balancing market. A summary of the balancing market structures was given in Table I. Finally this paper, reviewed tools and mechanisms to facilitate and incentivise DERs to participate in balancing markets, such as the role of aggregators and pricing mechanisms.

References

[1] C. Fernandes, P. Frías, and J. Reneses, "Participation of intermittent renewable generators in balancing mechanisms: A closer look into the Spanish market design," *Renewable Energy*, vol. 89, pp. 305–316, 2016.

[2] J. P. Chaves-Ávila and C. Fernandes, "The Spanish intraday market design: A successful solution to balance renewable generation?" *Renewable Energy*, vol. 74, pp. 422–432, 2015.

[3] B. Nyamdash, E. Denny, and M. O'Malley, "The viability of balancing wind generation with large scale energy storage," *Energy Policy*, vol. 38, no. 11, pp. 7200–7208, 2010.

[4] "Study on the effective integration of demand energy recourses for providing flexibility to the electricity system," Sweco, Ecofys, Tractbel Engineering and PWC, Final report to The European Commission, 2015.

[5] N. Paterakis, O. Erdinc, and J. Catalao, "An overview of demand response: key-elements and international experience," *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 871–891, 2017.

[6] C. Eid, P. Codani, Y. Perez, J. Reneses, and R. Hakvoort, "Managing electric flexibility from distributed energy resources: A review of incentives for market design," *Renewable and Sustainable Energy Reviews*, vol. 64, pp. 237–247, 2016.

[7] L. Vandezande, L. Meeus, R. Belmans, M. Saguan, and J. M. Glachant, "Well-functioning balancing markets: A prerequisite for wind power integration," *Energy Policy*, vol. 38, no. 7, pp. 3146–3154, 2010.

[8] C. Eid, P. Codani, Y. Perez, J. Reneses, and R. Hakvoort, "Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design," *Renewable and Sustainable Energy Reviews*, vol. 64, pp. 237–247, 2016.

[9] M. Zipf and D. Möst, "Cooperation of TSO and DSO to provide ancillary services." European Energy Market (EEM), 2016 13th International Conference on the.

[10] F. Hvelplund, "Renewable energy and the need for local energy markets," *Energy*, vol. 31, no. 13, pp. 2293–2302, 2006.

[11] E. Rivero, D. Six, and H. Gerard, "evolvDSO: Assessment of the future roles of the DSOs, future market architectures and regulatory frameworks for network integration of DRES," *International Conference on Electricity Distribution*, June 2015.

[12] L. N. Ochoa, F. Pilo, A. Keane, P. Cuffe, and G. Pisano, "Embracing an adaptable, flexible posture: Ensuring that future european distribution networks are ready for more active roles," *IEEE Power and Energy Magazine*, vol. 14, no. 5, pp. 16–28, Sept.-Oct. 2016.

[13] Antony Zegers (AIT), Helfried Brunner (AIT), A. Zegers, and H. Brunner, "TSO-DSO interaction : An Overview of current interaction between transmission and distribution system operators and an assessment of their cooperation in Smart Grids," no. September, p. 35, 2014.

[14] S. Ruester, S. Schwenen, C. Batlle, and I. Prez-Arriaga, "From distribution networks to smart distribution systems: Rethinking the regulation of european electricity DSOs," *Utilities Policy*, vol. 31, pp. 229–237, 2014.

[15] P. B. Andersen, J. Hu, and K. Heussen, "Coordination strategies for distribution grid congestion management in a multi-actor, multi-objective setting." Innovative Smart Grid Technologies (ISGT Europe).

[16] "Towards smarter grids: Developing TSO and DSO roles and interactions for the benefit of consumers," ENTSO-E, Tech. Rep.

[17] "Basic schemes for TSO-DSO coordination and ancillary services provision," SmartNet project, VITO/EnergyVille, Technical Report.

[18] S. Ahn, S. Nam, J. Choi, and S. Moon, "Power scheduling of distributed generators for economic and stable operation of a microgrid," *Utilities Policy*, vol. 4, no. 1, pp. 398–405, Mar. 2013.

[19] M. C. Caramanis, E. Ntakou, W. Hogan, A. Chakrabortty, and J. Schoene, "Co-optimization of power and reservesin dynamic t&d power markets with nondispatchable renewable generation and distributed energy resources," *Proceedings of the IEEE*, vol. 104(4), pp. 807–836, April 2016.

[20] A. Papavasiliou and I. Mezghani, "Coordination Schemes for the Integration of Transmission and Distribution System Operations." [Online]. Available: http://smartnet-project.eu/wp-content/uploads/2017/05/CoordinationSchemesDispatchPSCCV2.pdf

[21] D. Ilic, P. G. D. Silva, S. Karnouskos, and M. Griesemer, "An energy market for trading electricity in smart grid neighbourhoods," *6 th International Conference on Digital Ecosystems Technologies*.

[22] H. Gerard, E. I. R. Puente, and D. Six, "The costs of privacy in local energy markets," *Business Informatics (CBI)*, 2015.

[23] H. Gerard, E. I. Rivero Puente, and D. Six, "Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework," *Utilities Policy*, 2017.

[24] C. Zhang, Q. Wang, J. Wang, M. Korpås, and M. E. Khodayar, "Strategy-making for a proactive distribution company in the real-time market with demand response," *Applied Energy*, vol. 181, pp. 540–548, 2016.

[25] Q. Wang, C. Zhang, J. Wang, P. Pinson, and J. Ostergaard, "Real-Time Trading Strategies of Proactive DISCO with Heterogeneous DG Owners," *IEEE Transactions on Smart Grid*, vol. 9, no. 3, pp. 1688 – 1697.

[26] A. Roos, S. O. 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, no. 1876, pp. 79–86, 2014.

[27] S. Rahnama, S. E. Shafiei, J. Stoustrup, H. Rasmussen, and J. Bendtsen, *Evaluation of aggregators for integration of large-scale consumers in smart grid*. IFAC, 2014, vol. 19, no. 3.

[28] C. B. S. Burger, J. P. Chaves-vila and I. J. Prez-Arriaga, "The value of aggregators in electricity systems," MIT Center for Energy and Environmental Policy Research, Technical Report.

[29] M. Heleno, M. A. Matos, and J. A. Lopes, "A bottom-up approach to leverage the participation of residential aggregators in reserve services markets," *Electric Power Systems Research*, vol. 136, pp. 425–433, 2016.

[30] "Existing business models for renewable energy aggregators," BestRES, Tech. Rep.

[31] S. Burger, J. P. Chaves-Ávila, C. Batlle, and I. J. Pérez-Arriaga, "A review of the value of aggregators in electricity systems," *Renewable and Sustainable Energy Reviews*, vol. 77, no. February 2016, pp. 395–405, 2017.

[32] J. P. Chaves-Ávila, R. A. Hakvoort, and A. Ramos, "The impact of European balancing rules on wind power economics and on short-term bidding strategies," *Energy Policy*, vol. 68, pp. 383–393, 2014.

[33] R. A. C. van der Veen, A. Abbasy, and R. A. Hakvoort, "Agent-based analysis of the impact of the imbalance pricing mechanism on market behavior in electricity balancing markets," *Energy Economics*, vol. 34, no. 4, pp. 874–881, 2012.

[34] M. Bueno-Lorenzo, M. Á. Moreno, and J. Usaola, "Analysis of the imbalance price scheme in the Spanish electricity market: A wind power test case," *Energy Policy*, vol. 62, pp. 1010–1019, 2013.