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Aggregator of Demand Response for Renewable Integration and Customer Engagement: Strengths, Weaknesses, Opportunities, and Threats

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Abstract: The world is progressing towards a more advanced society where end-consumers have access to local renewable-based generation and advanced forms of information and technology. Hence, it is in a current state of transition between the traditional approach to power generation and distribution, where end-consumers of electricity have typically been inactive in their involvement with energy markets and a new approach that integrates their active participation. This new approach includes the use of distributed energy resources (DER) such as renewable-based generation and demand response (DR), which are being rapidly adopted by end-consumers where incentives are strong. This paper presents the role of the DR aggregator to effectively integrate DER technology as a new source of energy capacity into electricity networks using information communication technology and industry knowledge., Based on DR aggregators, this framework will efficiently facilitate renewable energy integration and customer engagement into the electricity market. To this aim, advantages and disadvantages of DR aggregators are discussed in this paper from political, economic, social, and technological (PEST) points of view. Based on this analysis, a strengths, weaknesses, opportunities, and threats (SWOT) analysis for a typical DR aggregator is presented.

Keywords: aggregator; demand response; distributed energy resource; information communication technology; renewable energy; SWOT; PEST

1. Introduction

The power system is in a state of transition due to the increased amount of renewable-based distributed energy resources (DERs) emerging on the demand-side of the grid [1]. DERs include renewable technology such as solar photovoltaic systems, wind generations, and electric vehicles, but also encompass other resource capacities such as demand response (DR) programs, batteries, microgrids, and small generators [2]. Integrating these new technology resources into existing infrastructure and energy markets pose massive challenges for power systems worldwide as operators usually do not have the appropriate mechanisms for monitoring or controlling low voltage networks, which is typically where these resources are connected [2]. What makes the situation worse is that renewable DERs are intermittent in nature and unlikely able to detect overall frequency and voltage change, which have the potential to jeopardize system stability and power quality [3]. High penetration levels of renewables connected to the grid requires system operators to secure larger reserves of dispatchable capacity from more traditional sources of energy, which increases the cost of energy delivery [2,3]. Furthermore, these balancing sources must bear the loss of life caused by the constant cyclic readjustments needed to mitigate the variations caused by renewables [4].

In order to promote investment on renewable-based technologies, the incentives through DR programs and the associate electricity pricing schemes can be effective [5]. Another approach for enhancing renewable penetration is the joint investment by several players on energy storage of renewable energy in a form of electricity [6,7] or hydrogen [8,9]. Battery energy storage systems (BESSs) and hydrogen storage can play vital role in smoothing renewable energy generation and then contribute to energy supply, reliability, and grid investment. Also, customer engagement in the operation of these technologies including participation in the associated markets is a promising approach to tackle the issues regarding high penetration of DERs [1]. This engagement through DR programs brings many benefits for those participated customers and the network side as well, as described in Section 2. One of the most effective platforms for customer engagement is participating in the electricity market [10]. However, most end-consumers, especially in residential areas, have not generally had access to dynamic price signals of electricity and therefore have been limited to their participation in energy markets. Having said that, commercial and industrial end-consumers have had an easier time gaining a foothold in markets through the use of DR programs [11]. However, the coordination of commercial and industrial customers to maximize benefits to them and to other players such as utilities. Some studies also show the effectiveness of coordinating distributed DR and flexibilities from consumers as a potential resource for reducing total energy cost of consumers [1,12–14] or improving the efficiency of grid operation [1,15–18] and investment on energy delivery system [19–21]. To this aim, a DR aggregator helps manage these objectives.

DR aggregators play a fundamental role in tapping into the end-consumer market, by creating customized, automated controls for consumer loads and appliances that enable remote access, while taking into consideration preferences and behavioral patterns [15,22]. These aggregators have the ability to bridge the information and technology gap that is currently being faced by power networks. Simultaneously, DR aggregators can provide operators with a cost-effective mechanism for reducing the need for grid infrastructure and a tool for integrating renewable energy technology [23]. DR aggregators are emerging power market participants that also facilitate the integration of demand side technologies by capitalizing on current advances in information communication technology (ICT) along with advanced metering infrastructure (AMI) to develop new products that engage and encourage end-consumers to participate in electricity markets [1].

In this context, energy storage systems and electric vehicles (EVs) can also be participating in a DR program as a flexible load or a source of energy [24]. Some of DR programs usually integrate DERs such as rooftop solar photovoltaics (PVs) with a BESS and seeks to charge the battery storage during times of cheap electricity price or high surplus energy generation of DERs [6]. The discharge of BESS during a congestion or peak price of electricity is considered by an aggregator to secure its contractual obligation of lowest price guarantee while making a profit from the higher energy price. The research also demonstrates that end-consumers can obtain better benefits from their solar PV systems, with the assistance of an aggregator [6]. In addition, aggregators can engage with owners of EVs and vehicle-to-grid (V2G) systems for the purpose of capitalizing off of their available power and storage abilities, which can be categorized as a DR aggregator or as a V2G aggregator [25]. Although V2G aggregators are only in the pilot stage of development and are yet to be physically implemented in the market, they represent a very useful asset to the power system due to their flexible power outputs and storage abilities and are therefore set to be major players in the future [25]. Aggregators of EVs should consider the nature of EVs' operation which inherently means that they can 'ramp-up' and 'ramp-down' at high rates and quick response times. Furthermore, EVs by design can connect and disconnect from the grid for charging purposes [26]. This paper outlines the role of a DR aggregator and highlights the advantages and disadvantages of this new market participant from different aspects such as political, economic, social and technological, which is referred as the PEST analysis in literature [27]. Based on the provided PEST analysis, a strengths, weaknesses, opportunities, and threats (SWOT) for a sample DR aggregator is presented. SWOT is an organized planning framework that assesses the mentioned four components of a business or project. This analysis evaluates the internal and external aspects that are advantageous and unfavorable to satisfying the objectives of that business [28].

The rest of paper is organized as follows. Section 2 provides a review on DR programs. The applications of DR aggregators are explained in Section 3. The technical, economic, social, and political considerations of such aggregators are analysed in Section 4 to Section 6. Section 7 provides SWOT of a sample aggregator. Relevant conclusion is revealed in Section 8.

2. Demand Response Programs

Demand response (DR) programs are used by operators in power networks to maintain system affordability and stability in times of peak demand, peak DER generation, or peak electricity price [29]. These programs use the ability of end-consumers to respond to operator signals by curtailing or shifting specified loads or generations in exchange for an incentive or reward [29]. The benefits from managing these loads or generations include: bill savings and rewards for end-consumers; stabilized market volatility; grid infrastructure savings; energy efficiency; improving the reliability and stability of the grid whilst reducing marginal cost during peak events; and providing system flexibility that can be used to integrate renewable energy technology [29,30]. A conventional method for categorizing DR programs is to separate them into "incentive-based" or "price-based" programs [12], as depicted in Figure 1 including enabling technologies. Price-based programs communicate high electricity prices to end-consumers who can then choose whether or not they want to respond to those signals [31]. Incentive-based DR programs are those in which the end-consumer receives a defined reward for a specified load/generation curtailment or shift [12]. Price-based programs are only able to participate in energy markets as system operators do not have the ability to control their outcome, whereas incentive-based DR programs tend to be pre-defined contracts which enable a level of control and can, therefore, participate in energy, capacity and ancillary service markets when appropriate [30,32]. Some markets allow DR to participate in wholesale energy markets through the use of demand-side bidding, where large end-consumers or aggregators of DR can directly bid large quantities of manageable load into energy auctions as a replacement for traditional generation supply. If the bid for DR is successful, it is then dispatched by the system operator upon the requirement to bring down the cost of energy supply [1]. Demand-side bidding through DR has the ability to effectively displace traditional generators out of wholesale energy markets, as the operating costs of enabling DR is a lot less than the costs of running a power generating plant [1].

Ancillary services (AS) are used by system operators in real-time to maintain grid stability and reliability in case of unexpected outages and supply–demand variations that cause reliability issues. These services can be provided by DR programs if they are able to meet the AS requirement, and hence can be used to smooth the variations caused by intermittent renewable energy technology [15]. Capacity markets allow DR programs to be entered as a type of energy procurement that is separate from the wholesale energy market and can be used to reserve capacity for future demand forecast or in response to an emergency event. These markets increase the efficiency of the grid and also allow the cost of energy to be lowered as DR programs used for capacity reserves are able to provide competitive pricing strategies against traditional energy supply [1].

Typically, only large commercial and industrial end-consumers have participated in DR programs as they are seen to be more economically viable for enabling DR and have larger scales of controllable load [33]. Industrial participants can reduce loads such as lighting, heating ventilation and air-conditioning (HVAC), but their potential for load curtailment is also characterized by their specific industrial processes, which may permit some operations to be shut down [15]. Commercial participants are able to manipulate lighting, washing machines, dryers, HVAC, refrigeration systems, water heaters, and pool pumps in order to fulfil the requirements of a DR signal [16]. Some residential consumers have participated in DR programs through the use of direct load control over HVAC, water heaters and pool pumps [34]. Figure 2 illustrates the potential parts and appliances of different end-consumers for participation in a DR program.

Domestic participation has been limited as the enabling cost of DR for these consumers is higher, but also residential premises are places of personal belonging which can make it hard to motivate participation if it means disrupting their way of life, especially if bill savings are deemed small by the end-consumer and are hence not worth the effort [14]. Furthermore, in the past, domestic end-consumers have not been equipped with the ability to view dynamic electricity prices and have typically had flat rate meters installed on their premises [35]. This has limited consumer awareness to the fact that electricity price changes with time, and hence has prevented them from being able to make informed energy decisions, however, this is changing with the roll-out of smart meters [35].

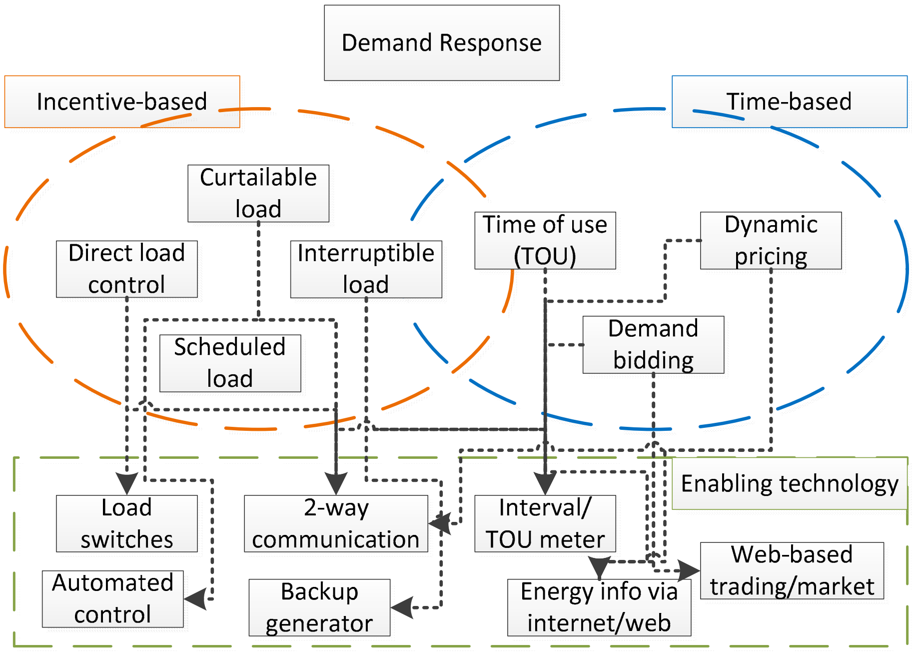

Figure 1. Demand response categories and the enabling technologies.

In the case of energy storage, EVs and V2G technology, the aggregators aim to form a bi-lateral contract with the EV/battery owner, where the aggregator seeks to remotely control the vehicle in return for providing the vehicle owner with some kind of incentive [36]. Additionally, aggregators often agree to replace and maintain the battery as an extra incentive to engage owners and to mitigate social concerns of battery wear and tear [7]. Most research concludes that V2G/battery aggregators are well suited to provide ancillary services to system operators with the particular emphasis on the reserves market to provide frequency regulation, and hence this will be the primary market focus for this type of aggregator [37,38]. Although bulk generating plants can supply cheaper sources of electricity compared to DR aggregators with the focus on V2Gs/batteries, the pricing mechanism of the reserves markets requires payments for 'standby' capacity and payments for the 'actual' energy dispatched, which enables V2G/battery aggregators to remain competitive [39]. Moreover, the research discusses the fact that these aggregators have lower capital costs for generation and storage equipment, faster ramping abilities, and can switch between ramp up/down modes with less equipment degradation compared to that of traditional centralized generators [39].

To improve the engagement performance of EV, V2G and energy storage within an aggregator, it is important to consider the comfort level of end-users along with other technical and economic criteria. For example, consumers should able to set some preferences on their loads and resources such as EVs and batteries [40]. Consumers should be able to set the priority of consumption, the availability during a day or a congestion, and the ability to withdraw the DR request from the aggregator in some situations. To this aim, aggregators are required to establish and update the status of participant appliances for each customer to make sure to make a right decision for addressing their obligations while maintaining the comfort levels of customers. An optimization algorithm should be employed to determine an optimum use of DR resources while satisfying the priorities of end-users [40]. Moreover, the implementation of DR aggregators can help deferring costly investment on pole and wire in distribution networks [21], which provides huge saving to utilities and aggregators. Taking into account this saving will improve rate of return of the projects and enhance customer contributions into DR programs.

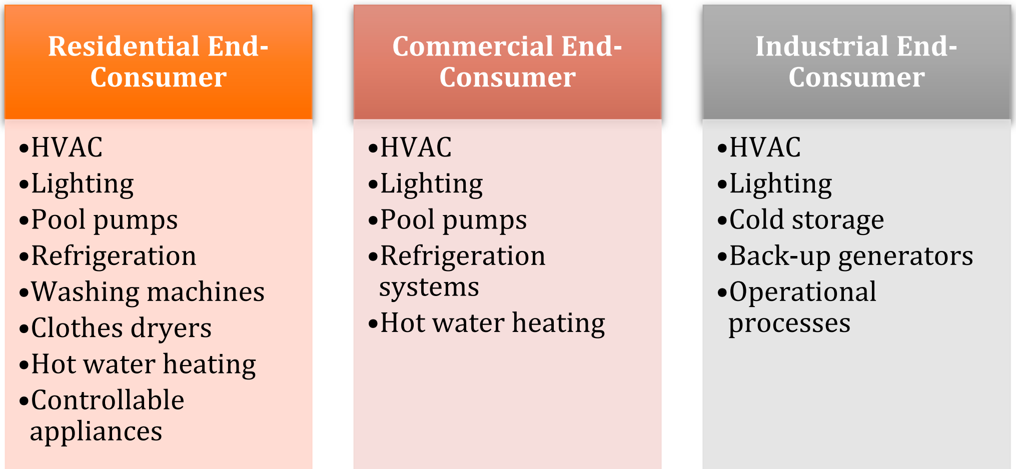

Figure 2. Potential participants in a demand response (DR) program.

Smart meters are devices that allow information such as energy consumption measurements of appliances, load profiles, time-of-use tariffs, interruption events, voltage levels, phase loss, and asymmetry to be communicated to end-consumers of electricity [41]. With this newfound knowledge, consumers can now respond to power signals and make smarter energy consumption decisions, thus becoming active participants in the power market [15]. Considering that traditional power systems are not generally equipped for monitoring low voltage networks, smart meters provide a monitoring device that makes them traceable and visible which is essential for successful DER integration [42]. Although the roll-out of this technology is a key enabling factor for residential participation in DR, the fact remains that these consumers are hard to motivate due the reasons mentioned earlier. Hence, activating the full potential of residents requires a third party to develop customized products that allow the consumers to contribute to the decision making process without the load curtailment instruction being too be difficult to implement [14]. System operators may not be able to take on the extra workload of developing such customized profiles for residents, as it would require determining their individual consumption patterns and preferences in order to effectively facilitate their participation [23]. However, DR aggregators are able to facilitate this level of end-consumer integration by developing customized products that allow loads to be remotely controlled while taking into consideration consumer preferences [1].

3. Demand Response Aggregator

DR aggregators in electricity market act as third-party intermediates between power market participants and industrial, commercial and residential end-consumers of electricity [23]. These aggregators realize end-consumers have the ability to provide system capacity by managing loads/generations during critical times such as peak times or shifting certain operations to periods of the day where electricity is cheaper [35]. The aggregator capitalizes on this ability by engaging with enough end-consumers so that their total accumulative capacity is large enough to fulfil the requirements for entering into wholesale energy markets [43]. The capacity provided by DR aggregators is bought by system operators and other market participants as ancillary services, capacity reserves or balancing provisions [1]. Thus, DR aggregators provide the power system with a means to captivate available energy capacities that as singular parts may not have been realized or deemed valuable enough to enter into the market [15]. This is exceptionally useful for operators who need to secure extra system capacity due to rising levels of renewable energy penetration on the grid. Figure 3 shows an example of electricity market in the presence of DR aggregator [15,17,33,44,45]. Aggregators of DR programs are also referred to as "curtailment service providers (CSP)" in the U.S. and are relatively well established within the market place compared to that of Europe's where they are called "independent aggregators" [17,45]. However, by increasing the flexibility of consumers and integration of renewables, DR aggregators can contribute by increasing and decreasing of loads as required. Aggregators of DR are forecasted to be major players in the transitioning of the power system from the centralized approach to a more distributed architecture as they allow the active participation of smaller energy consumers, which traditionally have not been effectively realized [4,15]. The following sections highlight the technical, economic, social and political considerations of DR aggregators.

The concept of virtual power plant (VPP) is introduced to integrate the benefits of utilizing DR programs and DERs in a set of customers with a potential participation in electricity market as well. VPP can be categorized as commercial VPP (CVPP) and technical VPP (TVPP). Constraints of electricity grids in TVPPs' energy management strategy is considered but not in CVPP [46]. These VPPs use a bidding strategy considering their resources and market situation in, for example, day-ahead electricity market [46]. In addition, energy storage integrated VPPs can contribute to the adequacy and reliability of generation systems in distribution networks [47,48], for which an optimization algorithm should determine the charging/discharging of energy storage. As uncertainties associated with load profile, renewable energy and electricity price makes forecast of DR very difficult, ref. [49] proposes a dynamic load profile in a form of VPP to be selected based on a ranking system of individual load profile. It is important to mention that usually VPPs discuss a management strategy for the available resources within the existing system and infrastructure, while an aggregator searches for new opportunities of joint investment on infrastructure, communication, and management systems including hardware and software. An aggregator can also include multiple VPP with diver functions such as TVPP, CVPP, storage-based VPP, etc. to establish a framework for addressing different aspects of terms of technical, economic, social, and political, as discussed later in this paper.

To reduce electricity consumption from electricity grids for households, one of the approaches is the installation of devices to generate electricity and heat from the so-called combined heat and power systems (CHP) and micro-CHP, which is a smaller scale of CHP usually with a capacity less than 15 kW [50]. The use of CHP can change the requirement of DR. For example, the whole of part of the excess energy generated from renewable resources can be used to generate heat instead of exporting and participating within an aggregator. Generation of heat will help to mitigate renewable generation fluctuation and provide more efficiency for heat and power efficiency within prosumers [51]. In addition, A wide range of CHP implementation can contribute towards moderating electricity price spikes as well [51], resulting in a more effective DR aggregator in controlling electricity prices.

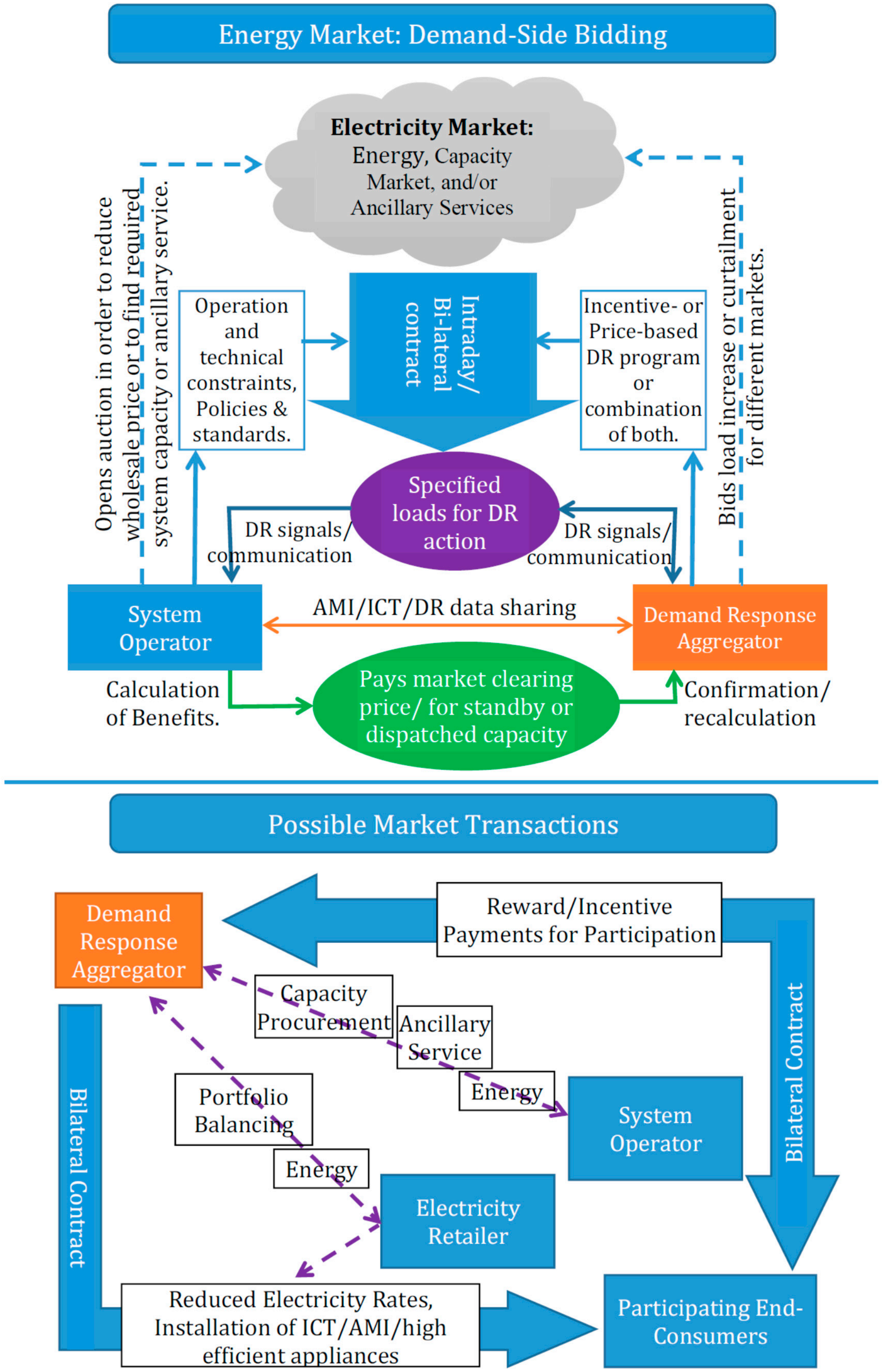

Figure 3. Market Action for Demand Response Aggregator structure.

4. Technical Considerations

Aggregators of DR must have some means in which they can communicate with end-consumers effectively. More specifically, aggregators should be able to remotely access appliances or pre-determined loads, specified by the end-consumer, and be able to conduct load controls to extract a specified DR capacity [14,15]. In addition to this, reasonable graphical user interfaces (GUI) must be made available to end-consumers by aggregators in order to (1) communicate DR signals and (2) allow for some level of end-consumer customization [14]. Advances in ICT/AMI have allowed the development of home energy management systems (HEMS) and building energy management systems (BEMS), which support interactive environments that allow effective control of consumer loads and enable effective communication abilities [33]. AMI is defined as an infrastructure that measure, monitor, collect, and analyze data of energy parameters and the associated quality figures [52]. This system can communicate with meters based on a coordinated schedule and with central/distributed controllers. In some literature, these is an expectation for an AMI to activate two-way communication among several players in smart grids such as consumers, aggregators, retailers, and utilities to enable advanced intelligent functions within AMI [53]. In addition, accuracy improvement in monitoring and the associated feature of state estimation for AMI is desirable in near future [54] to improve grid operational exercise and power quality for end-user as well as to provide a better cyber security. HEMS/BEMS units are capable of providing signals of DR for load control purposes and also provide the measured energy consumption rates of different appliances/loads, while also communicating relevant environmental conditions [35]. These units communicate all of the relevant data back to the DR aggregator through the use of home area networks (HAN), access points/gateways, wide area networks (WAN), power line carrier (PLC) communications and backhaul networks [33,35]. Aggregators then communicate the appropriate accumulated data back to the utility provider or system operator through these same networks.

HEMS/BEMS are inclusive of many different types of technology components including smart meters, central controller, local controllers, sensors, load switches, and GUIs [55]. Smart meters and interval meters act as the gateway/access point for utility providers and aggregators [56]. These components not only allow for the measurement of energy deviation due to a demand response signals, which defines an essential requirement for successful billing and successful incentive/reward development, but they also can act as the GUI for end-consumers [57]. GUIs can be such devices as smart meters, smart phones, laptops, desktops, home energy displays or web dashboards/portals [33]. GUIs are critical devices for determining customer load profiles/preferences as they allow the end-consumer to interact with their appliances remotely and thus decide whether or not they wish to "opt-in" or "opt-out" individual appliances [14]. Hence, GUIs provide an interface avenue that enables the customization of end-use load preferences, which is an essential criterion for larger market participation. GUIs also allow the end-consumers to see potential DR signals in advance and communicate relevant power system information [55].

HEMS/BEMS controllers are located in the end-consumers premise, and is used as a main point of contact for the energy aggregator where the unit dispatches control signals according to appropriate algorithms and methods [14,55]. This controller is in communication with the various sensors and local load controllers that determine the states, parameters and operating conditions of the dispatchable loads and appliances [57,58]. In order to transform the current energy systems into intelligent cyber-enabled systems, the concept of internet of things (IoT) is developed [52]. IoT help realize the potential capabilities of situational awareness, smart control, cyber security, and online monitoring. These functions, if designed properly, would improve efficiency, sustainability, and security of energy systems. Improving the productivity and observability of energy systems, efficient DER control, and effective customer engagement are amongst the benefits of IoT. For example, one important sensor that has recently come into play is the wireless smart thermostat [56]. This sensor is important to note as it allows aggregators to remotely change temperature settings, and hence represents a technology that greatly advances the potential for DR penetration [12]. Sensors (wired/wireless) and local controllers are used in HEMS/BEMS units to translate relevant environmental information of the end-consumer and then perform the appropriate load control signals sent by the HEMS/BEMS unit [15,56].

Communication modules are also needed to facilitate the successful transfer of data between the HEMS/BEMS unit, appliances/load controllers, sensors, GUI and appropriate participants. Traditional demand response programs use wired communication modules and protocols such as power line carriers, fiber optics, and Ethernet protocols to transfer and receive signals [55]. However, compared to that of their wireless counterparts, these forms of communication have higher installation/maintenance costs associated with their physical hardware requirements [56]. Recent advances in wireless communication modules and standards such as Zigbee, 6LoWPAN, WiFi, Bluetooth, and Z-Wave have provided a more economically efficient and flexible form of communication that suits the distributed topology of the changing power system. These communication modules adopt standard protocols developed by the IEEE for advanced metering infrastructure, which provide essential bi-directional communication [55]. The scalable energy management infrastructure for aggregation of households (SEMIAH) project described in [59] outlines the technologies associated with an energy management system for DR purposes. The project develops the appropriate system, which enables aggregators to control a large scale of residential load appliances effectively. In addition, the types of data systems needed for aggregators to effectively participate in markets are described. The proposed system is first simulated using a residential grid model that consists of 200,000 households; then field tested in Norway and Switzerland, where 200 households were successfully used for the demonstration of their system [59]. EnerNOC is an existing aggregator of DR that has a strong international presence and an established market base in the U.S. [60]. This aggregator can directly control the load appliances of industrial and commercial sized end-consumers using their in-house developed Network Operating Center. EnerNOC can directly control HVAC systems, lighting, pumps and other operational equipment of participants to respond to system reliability events and peak demand signals [61]. Albertsons grocery stores is a franchise across America that has enrolled itself in EnerNOC's demand response program. Three hundred of the stores were installed with EnerNOC's technology to control lighting and HVAC, which cost U.S. $11,000 per store or approximately U.S. $450 per kW. Since their enrolment with EnerNOC, the grocery stores have been able to save 25 kW per store.

Table 1 highlights the main components of an energy management system [14,15,23,33,35,44,55–61]. This table presents various components related to technical consideration of DR aggregators. As seen, the associated technologies with each technology along with the available communication systems are also provided. Moreover, the compatible communication protocols and standards for each device are depicted. The portfolio of a DR aggregator must be able to meet the technical parameters of the specific market if they wish to participate [62]. For example, to participate within the capacity resource market, aggregators bid their available manageable load increase or decrease into the market and if successful are usually required to dispatch the contracted load within 30 min to 2 h. Whereas aggregators who wish to participate in the ancillary service market must be able to dispatch loads in less than 30 min. Therefore, these aggregators would need to ensure that their DR equipment can handle the corresponding data transfer rates [62]. Furthermore, different markets require different capacity entries, for example for DR aggregator to enter into the New York independent system operator (NYISO) emergency market, they must be able to reduce a minimum load size of 100 kW per zone [63,64]. It is worth mentioning that the application of open-source hardware and software under general public license such as Arduino is increasing [65] due to the lower cost and ease of use of such systems. The utilization of Arduino platform in research activities becomes very attractive, for example, developing a system in weather station prototype for renewable generation [65] or a system for air quality control based on the do-it-yourself (DIY) kits of Arduino [66].

Table 1. Component associated with Energy Management System for Technical Considerations of DR Aggregators.

HEMS/BEMS Components	Technology	Available Communication Device	Compatible Communication Protocol/Standard
Access Point/Gateway	Smart Meter and Interval Meter	RF Mesh network (Common in Residential)	ZigBee, 6LowPan, Bluetooth, IEEE 802.15x, WiFi
		PLC (Common in Commercial Buildings)	HomePlug, Narrowband, X10
		Wireless Star Network (Common in Rural Areas)	GMS/EDGE, LTE
Communication Module	Wireless	WiFi	IEEE 802.11x
		Bluetooth	IEEE 802.15.1
		ZigBee	ZigBee, ZigBee Pro, IEEE 802.15.4
		Cellular	GSM/GPRS/EDGE
		RFID	IEEE 1451, IEEE 802.11, XBee
		WirelessHART	IEE 802.15.4
		6LoWPAN	IEE 802.15.4
		Z-Wave	Z-Wave, 802.11
		Xbee	ZigBee, IEEE 802.15.4, WiFi
	Wired	Power Line Carriers (PLC)	HomePlug, Narrowband, X10
		Ethernet	IEEE 802.3x, BACnet
		Serial	RS-232/422/423 /485, UART, I2C, SPI, Modbus, DLMS/COSEM
		BACnet	IEEE 802.3, RS-232, RS-485
Sensors	Light Sensors	ZigBee, WiFi, Z-Wave, 6LoWPAN, Serial, Xbee, BACnet, WirelessHART	See Above
	Temperature Sensors		
	Humidity Sensors		
	Voltage and Current Sensors		
	Motion Sensors		
Local Controller	Arduino	WiFi, Bluetooth, Xbee, ZigBee, Serial, X10, Cellular	See Above
	Banana Pi	ZigBee, Bluetooth, WiFi, Serial, Cellular	
	BeagleBone Black	Serial, PLC, Ethernet, Bluetooth, Cellular	
	Rasberry Pi	Cellular, Z-Wave, Ethernet, Serial, WiFi, ZigBee	
	FPGA	Serial, Bluetooth	
	Intelligent Thermostat	ZigBee, Bluetooth, WiFi, Z-Wave, Cellular	
	Electronic Relay Circuits	Serial	
GUI	Home Energy Display	Smart meter, Tablet, Stand-alone devices	N/A
	Web Dashboard/Portal	Laptop, Desktop, Smartphone	
	Smartphone Application	iPhones, Android phones, and others	

5. Economic Considerations

The economic characteristics of DR aggregators in terms of their ability to generate revenue, capital expenditure, type of market transactions, and installation, maintenance and operation costs depend on a number of parameters, which are mainly categorized as follows [15,30,62]:

1. the market type, conditions and environment,
2. entry barriers to markets,
3. what type of supporting technology and infrastructure exists in the area, as discussed in Section 4,
4. the geographical area in terms of population,
5. whether or not social adoption is apparent, as described in Section 4,
6. what type of government policies and standards are in place, as addressed in Section 4.

Much research illustrates that aggregators can earn greater profits in the capacity and ancillary services market, if enabled, as these markets are better designed for the use of the aggregators flexible capacity. For example, in the White Oak Campus Microgrid project, the U.S. Food and Drug

Administration campus is enrolled to participate in DR programs that are being entered into both the ancillary service market and the capacity market. The campus's load, which consists of curtailable loads, storage technology, and renewable generation technology, had been retrofitted with control infrastructure developed by Honeywell. The results from the project demonstrated that as of 2013, the White Oak Campus has been able to generate U.S. $3 million from participation in DR programs in capacity and ancillary service markets [67].

The initial costs of making a potential end-consumer DR ready, is usually carried out by the aggregator and depending on whether or not there is existing infrastructure. The cost for enabling a large mass of end-consumers can represent a substantial market barrier for aggregators [15]. Residential end-consumers usually have higher incremental costs associated with DR enabling technology due to the lack of awareness, and the cost of implementing advanced metering if it does not already exist [31]. However, aggregators may find that the additional cost for enabling commercial and industrial end-consumers to participate in a DR program is significantly less due to their previous exposure to DR programs and their tendency to already have some pre-existing infrastructure [15].

Research conducted in [1] suggests that the investment costs associated with enabling a single residential household with intelligent ICT/AMI infrastructure capable of facilitating automated DR, is approximately 500 € for smart meters and wireless sensors. Another 500 € is necessary to cover the cost of the appropriate microcontroller/processor in addition to 50 € for the annual operating and maintenance (O&M) costs. However, the costs and benefits associated with implementation of ICT/AMI infrastructure depends on various parameters as mentioned in the beginning of this Section. Some of the known operational costs and benefits experienced by aggregators in regards to smart meters and their appropriate ICT/AMI is depicted in Figure 4 [1,15,30,62,67]. As shown in Figure 4, average cost per meter installation and the associated systems is different in different cases, which is from 0.8 to 2.2 units per meter (unit = $200), depending on the geographical area and availability of existing infrastructure. This Figure shows that O&M cost savings are not the only advantages of AMI. Also, the benefits from DR and energy conservation are significant in many cases. Consequently, depending on the type of policies and price reforms committed by regulators and utilities, the total benefit per cost is different. This economic analysis should be undertaken for every DR aggregator.

Aggregators must also analyze the cost/benefit of customers as well and make sure that the customers' contributions are affordable for those consumers. Therefore, DR aggregators should take into consideration whether or not the economic benefit they provide to the end-consumer is incentive-based (reward for participation), price-based (bill-savings/reduced rates) or a combination of both [15]. Furthermore, remuneration to end-consumers depends on the aggregator being able to determine their baseline profile (BLP), which is the normal demand profile of customers without DR. BLP is critical for determining the amount of energy deviation due to DR signals/actions [31]. If the BLP is not easily explained to the end-consumer, this can cause uncertainty [23] to aggregators and customers. The research in [68] identifies that the most successful approach used by aggregators to motivate end-consumers into reducing their loads during critical peak times is to offer them monetary incentives. However, the study shows that this mechanism is most effective if the end-consumers are given advanced warning of the peak event, so that they may prepare to shift certain loads to predetermined off-peak times [68].

As mentioned in this section, there are many parameters that make an investment decision cost-friendly. In general, rate of return, payback period and lifetime of investment are among important criteria for an end-user to make a decision on an investment [69]. For example, if the payback period of an investment of an end-user considering all benefits and costs is less than the lifetime of that investment, which would be a beneficial investment for this end-user. However, it depends on other factors such as total investment cost and the uncertainties around the future parameters which the payback calculation is carried out based on. If the uncertainties or the investment cost if very high, the decision can be based on probabilistic cost of investment, resulting in a calculation of average and standard deviation of payback period. In such cases, nodal price of contribution can help to provide a better understanding of the value of investment in a long-term planning horizon [70].

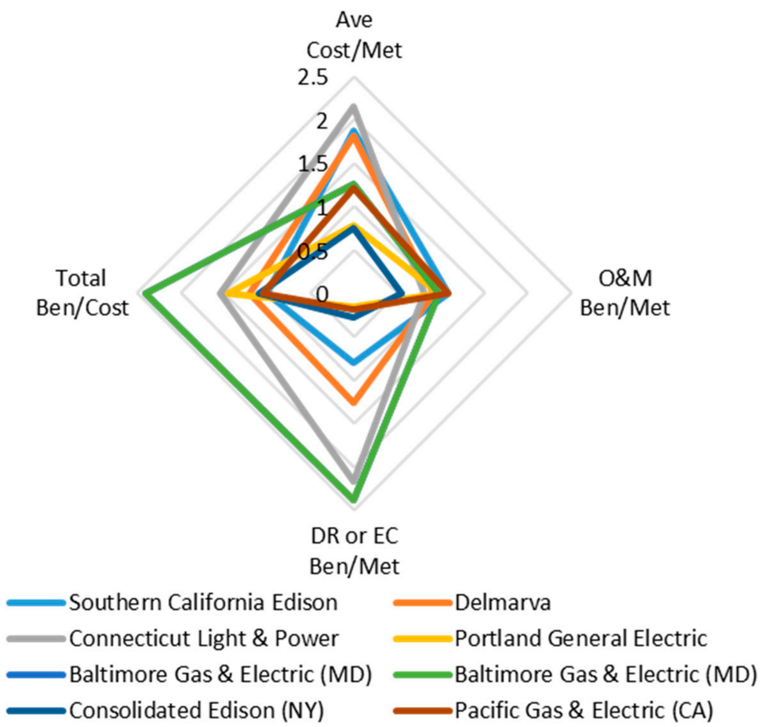

Figure 4. Economic consideration regarding implementation of ICT/AMI for DR aggregator. Ave: Average, Met: Meter, Ben: Benefit, EC: Energy conservation. All parameters except "Total Ben/Cost" are divided by $200 and represented here for better appearance.

Aggregators can also provide system operators with better grid cost savings as they defer grid expansion [11] by incorporating DR aggregators to shape the load profile in order to satisfy thermal limits of grid equipment during peak demand periods. For example, utility through DR aggregator can incentivize customers to participate in a DR program during high renewable generation [71] by increasing their loads and/or during peak demands by decreasing their loads [72]. In addition, DR aggregators can contribute on voltage quality of grid by investing on some compensators such distribution static VAr compensators (dSTATCOM) in unbalanced three-phase distribution grids [18] and establishing an appropriate coordinated control with existing equipment such as on load tap changers (OLTCs). Moreover, a DR aggregator can reduce potential equipment damage along the grid by offering a better power quality, provide operators with better mechanisms for load forecasting by better understanding of load profile through an effective communication [16,17]. Mitigation of congestions and reliability improvement through the investment on energy storage and other low-cost technical solutions such as dynamic voltage restorer would be other benefits of DR aggregators [48,73]. This area is another benefit for DR aggregators can provide to utilities and communities, which needs an appropriate agreement between aggregators and utilities and the corresponding analysis.

6. Social and Political Considerations

Social implications of DR aggregators are intertwined with political implications in many aspects. Thereby, in this section, both social and political are presented along with their relationships.

Research in [31] discusses the social implications of motivating residential end-consumers to engage in DR programs. The study highlights how government rollouts for DR enabling technology such as smart meters, encourages market participation by helping to facilitate the active participation of end-consumers through economies of scale. Some consumers may find the idea of having their appliance energy consumption rates monitored and changed by various electricity market participants, to be an invasion of privacy. Therefore, it is up to the aggregator to ensure that the correct security measures are undertaken, in order help mitigate this social concern [14]. Cyber-security and intrusion/theft/fraud detection in AMI is one of challenging topics in IoT and privacy protection. To this aim, some protocols and authentications are defined to improve the security of communications and transactions. However, there is always a tradeoff between the level of security and the investment on a scalable and comprehensive intrusion detection, involving which technology and which locations are the optimal configuration [74]. With increasing number of customers connecting to a form of electricity market through their smart devices, it is essential to validate their contribution to that market and consequently determine their payments, so detecting any fraud in AMI is becoming very important [75].

Based on the report of the US Department of Energy (DOE) to US Congress, residential consumer behavior and preferences can also have a great impact on available capacity for aggregators, especially those who are just starting up [30]. This is because their available energy pool is not only restricted by the number of participants but also the consumer's appliance preferences. Hence, it is important for a DR aggregator to assess whether or not an end-consumer's potential profit is greater than their installation/operation cost of enabling DR. Also, collecting participant cost information needs additional reporting requirements on DR aggregators. In the US, it is recommended to arrange multiyear commitments from regional entities for their contribution to a DR program to make it easier for DR aggregators to provide timely responses [30].

Consumers are also becoming increasingly aware of the cost of electricity, which provides DR aggregators with an opportunity for effective marketing by providing an easy solution that requires minimal effort for consumers to reduce their bill [14]. Through these considerations, DR aggregators in Europe [14] can provide network operators with a large flexible portfolio of defined and dispatchable energy, by tapping into residential end-consumers. This flexibility can be used to effectively smooth the stochastic and intermittent nature of renewable energy technology, which fluctuates on a yearly, seasonal, daily, and hourly basis [29,76]. It should also be noted that grid regions that have higher penetration levels of wind and solar resources need higher levels of reserve capacity/generation. DR aggregators also have the benefit of having a diverse, flexible portfolio, which by its very nature allows them to spread potential risk [30]. A study done in [59] discusses the instability effects DR aggregators can have on the power system, which can be caused by a rebound effect. This rebound effect can occur when an aggregator schedules a large-scale curtailment of residential loads whose households happen to be located relatively close together on the grid. However, the research determines that aggregators can mitigate this adverse effect by staggering the scheduling of their load curtailments and by also maximizing their geographic portfolio span. The research in [59] also demonstrates that DR aggregators, who serve the purpose of "pooling" available residential loads together to enter into markets, provide the grid with more stability compared to aggregators of DR, who purely seek to communicate prices to end-consumers as it can create market volatility.

In addition to the economic benefits of DR aggregators, as explained in Section 5, these aggregators also improve the power system security and help mitigate congestion [16,17]. Consequently, the comfort level of customers and feeling of having a reliable electricity network will be improved. In the study for US DOE, aggregators of retail customers (ARC) are proposed to harness the demand response opportunities through DR programs and the associated tariffs, approved by local governing entities or state regulatory agencies [16]. The grid operator must comply with the security and reliability standards, set by the North American Electric Reliability Corporation (NERC). Therefore, for participation of DR aggregators in electricity markets, the same procedure for approval in US should be considered to make sure their contribution is aligned with the rules and standards [16]. In Europe, the Energy Efficiency Directive provides an important step towards the implementation of aggregators [17]. Article 15.8 of this directive specifies that member states shall include the participation of aggregators for facilitating the access of participant in DR program to electricity market.

Services to retailers include the opportunity to hedge their risks against market volatility, by allowing the aggregator to stabilize their consumer's peak demand [23]. DR aggregators also provide a method of peak load reduction, that can rival that of peaking stations and generators as they have usually far less marginal costs than traditional methods of generation and are not emitting as much carbon dioxide [15,16]. Analysis of existing DER participation in the energy market through aggregators for long-term customer satisfaction and also provide services to different actors in Europe is provided in [15]. Some business cases for implementation of aggregators in Europe are discussed such as business case for aggregators with the aim of energy storage integration, peak reduction, or cost reduction [15]. Another advantage is that DR aggregators can usually respond faster, as conventional generating plants often have operational limitations that affect their ability to change their power output quickly [77].

The research depicted in [31] discusses the market barriers presented to DR aggregators due to political uncertainty. The study highlights that how policies and a lack of standardization can create unfair advantages and represents a large risk that can deter aggregators of demand response from entering into markets. Currently there are no standard rules for DR aggregators to follow including remuneration, which can create unfair advantages for different market participants [78]. For example, some electricity markets allow aggregators to directly participate in forward auctions, whereas other markets specify aggregators must create bi-lateral contracts with utility providers, which inherently minimizes the potential for DR participation in wholesale market bids. Hence, lack of standard market policies creates opportunistic value for some participants, which can be deemed an unfair advantage [76]. In this environment, the economic benefits, realized through DR aggregators, depends mainly on the commitment of utilities and regulators to pricing reform and their willingness to establish new policies/standard. Furthermore, some regulatory conflictions and contradictions exist, that make clear identification for revenue potential and market participation difficult [30]. For example, the Federal Energy Regulatory Commission's (FERC) Order 747 requires DR aggregators be paid/reimbursed for the capacity they provide at rates equivalent to the proportional generation they have displaced [76]. However, due to regulating jurisdiction concerns, the US Court of Appeals has recently determined that DR is a type of retail product and must be controlled within each state. This essentially minimizes potential profit for DR aggregators, as they cannot benefit from wholesale capacity markets, where revenue generation tends to be higher. In addition, many governments are supporting the large-scale rollout of smart meters to encourage the active participation of end-consumers, as a result of climate change initiatives [56]. Although this represents an opportunity for aggregators to activate their demand response potential, there is also no current standard for smart meter communication [30]. This means that smart meter communication protocol could change region to region, requiring aggregators to adapt their technology accordingly, which minimizes their ability to capitalize on economies of scale and scope [23].

In China, some efforts for realizing the benefit of DR aggregators have been done. A large-scale DR aggregator was initiated to integrate customers' DR for reducing peak demand by 800 MW in Beijing, conducted by the Beijing Energy Conservation and Environmental Protection Center (BEEC) and Natural Resources Defense Council (NRDC) [19]. A policy framework for a DR incentive program was developed based on the US experiences on DR aggregator implementation. From the social point of view, to improve the knowledge on the peak reduction and its benefits, BEEC and NRDC carried out several workshops and seminars different target groups, for example, utilities, aggregators and electricity users, including residential, commercial, and industrial sectors. A business Model for buildings, participating in DR programs via aggregators, is proposed in [20] for Chinese aggregators. The regulatory activities such as access to electricity market, incentives, payment procedure, data management from consumers and market, etc. are also discussed. This study shows that consumers are very cooperative during DR events in the Foshan DR pilot program, which was designed for 450 MW peak load reduction with the incentive of 130 yuan per kW. In this DR pilot program, the main portion of participants were industrial companies, so the uncertainties of their load profile are much less than other types of consumers. As such, they can plan and participate effectively in DR programs [20].

7. SWOT Analysis

To clearly identify the advantages and disadvantages of a demand response aggregator a SWOT analysis framework is applied for a typical DR aggregator in this section. The SWOT analysis framework is a business model used to illustrate the internal 'strengths' and 'weaknesses' of a business operation, but also the external 'threats' and 'opportunities' [28]. This SWOT analysis is a typical statement and should be updated based on the situation of individual DR aggregator.

(A) Strengths

The main strengths of a DR aggregator can be as follows:

- Incremental cost for enabling DR for industrial and commercial consumers is low. Also, the incremental costs for enabling battery-only vehicles with bidirectional power flow is relatively low.
- Advances in ICT has reduced the cost of technology and have expanded the range of loads and appliances that can be used for DR. Also, the manufacturing costs of battery technology is decreasing, which provides V2G aggregators with more opportunity to capitalize on the available technology.
- Activating a large amount of residential DR diversifies the portfolio and helps to mitigate risk.
- DR aggregators have lower O&M costs than traditional power station for peak demand, and can therefore offer competitive pricing.
- DR aggregators can improve the capital productivity of by providing access to market.
- DR aggregators provide a capacity resource that offers minimal carbon footprint.
- EVs have fast response times and high power capacities that provide V2G/battery aggregators with a competitive advantage over slower responding generators and peaking plants.

(B) Weaknesses

Some possible weaknesses of a DR aggregator are listed below.

- Incremental costs for enabling individual residential end-consumer is high. In addition, hybrid and fuel cell electric vehicles have significantly higher capital costs associated with making them beneficial to V2G aggregators.
- Highly skilled technical staff are necessary but represent a high business cost. Further, existing infrastructure for V2G capability (i.e., charging stations in workplaces, public parking and residential areas) is very limited.
- End-consumers can experience discomfort from having to change their consumption patterns. Moreover, the social acceptance for V2G/battery aggregators is extremely low, hence high investment costs are needed for effective marketing strategies.
- End-consumer preference behavior greatly effects available profits.
- Market membership and start-up fees represent high initial and on-going costs.
- Residential consumer awareness of dynamic electricity price is relatively low, thus effective marketing engagement is needed.

(C) Opportunities

There are many opportunities for a DR aggregator as it can:

- Capitalize on economies of scale with government technology roll-outs.

- Provide a flexible capacity that is able to help integrate the intermittent nature of renewable energy resources.
- Provide retailers with risk hedging mechanism via portfolio optimization.
- Provide a system capacity that can displace traditional generation and costly peaking plants.
- Contribute to lowering the cost of energy delivery in a long-term period.
- Offer peak load services to system operators to maintain grid reliability and to apply better congestion management.
- Provide better forecasting mechanisms for system operators by integrating end-consumer technology and load behavior.
- Capitalize on consumer concern of increasing electricity prices and propose cheaper solutions.
- Provide a cost-effective method for system operators to avoid costly grid expansion/upgrade.

These opportunities would be valid for V2G/battery aggregators as well.

(D) Threats

Some threats that a DR aggregator can face are as follows:

- Lack of smart meter communication standards can minimize potential for economies of scale and scope but also create data ownership risks.
- Lack of standard market participation rules creates unfair advantages and can restrict potential profit.
- Lack of standardized methods for end-consumer remuneration can create social uncertainty.
- Lack of standard government policies and the existence of contradicting policies creates uncertain business environments.
- End-consumers may be concerned over the viewing and exchange of their electrical consumption data to external market participants.

These opportunities would be valid for V2G/battery aggregators as well. In addition, V2G infrastructure on a large scale requires high capital expenditure and investment, for which a long-term plan should be prepared.

8. Conclusions

This paper provides an assessment on DR aggregators from different perspectives, including the political, economic, social and technological. Therefore, a SWOT analysis is conducted to present strengths, weaknesses, opportunities, and threats for a typical DR aggregator. This study shows that the DR aggregator has the potential to play a key role in creating value that benefits the entire power networks and customers. The position of DR aggregators in the power market is discussed in this paper including what benefits these aggregators actually provide. Also, the concept surrounding who receives these benefits, what potential issues may be caused by this concept are investigated. In addition, this paper shows that for each case, a feasibility study should be conducted to answer whether the DR aggregator in fact creates a more efficient power system or they are simply transferring rent and adding another step in the process.

Future works include development of an aggregator for smart grid to arrange the contribution of consumers in a peer-to-peer market, and to quantify the contribution of participants from different perspectives such as contribution to electricity price reduction, reliability, or grid investment. Moreover, a value chain analysis would be useful in future work to determine the value that each aggregator is able to add to the overall energy system.

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market, in addition to the funding acquisition. A.S. and G.L. were involved with the supervision of this study, the proofreading of the paper, and commented on the approaches.

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