Honours Engineering Thesis
An Analysis of How Energy Aggregator Concepts Add Value to the Power System

by

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In the discipline of
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Author’s Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.
Abstract

The power system is in a state of transition due to the increased amount of distributed energy resources (renewable energy technology, electric vehicles and demand response programs) emerging on the demand-side of the grid. Integrating these new technology sources into existing infrastructure and energy markets poses extensive challenges for power systems worldwide as operators do not have the appropriate mechanisms for monitoring or controlling low voltage networks, which is typically where these sources are connected. Energy aggregators are emerging market participants that facilitate the integration of demand-side technology by capitalising on current advances in information communication technology to develop new products that engage end-consumer participation in electricity markets. The main goal of an energy aggregator is to contractually engage with sufficient distributed energy resources from various end-consumers that the accumulative whole is large enough to participate in wholesale electricity markets. These aggregators have the ability to bridge the information and technology gap that is currently being faced by power networks today. This honours research thesis outlines the structure of a Demand Response Aggregator, Distributed Generation Aggregator and Vehicle-to-Grid Aggregator and applies the following analyses: A strengths, weaknesses, opportunities and threats (SWOT) analysis for each aggregator is presented, and an investment matrix is qualitatively derived which is then used to evaluate the potential ‘value’ the aggregators can add to the overall power system. In addition, a Porter’s Value Chain analysis is used to distinguish what ‘support’ activities each aggregator can provide to enhance and add value to the power systems ‘primary activities’ (supply chain activities).
Acknowledgements

It is with great pride that I present my honours engineering thesis and I would like to take the time to express my deepest gratitude to all those who have not only supported me throughout this process but also my entire degree, because if it was not for them I would not be here.

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<th>Description</th>
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<tbody>
<tr>
<td>BEMS</td>
<td>Building Energy Management System</td>
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<td>BLP</td>
<td>Baseline Profile</td>
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<td>BMS</td>
<td>Battery Management System</td>
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<td>CAISO</td>
<td>California Independent System Operator (California ISO)</td>
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<td>CRP</td>
<td>Conditional Reprofiling</td>
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<td>DER</td>
<td>Distributed Energy Resource</td>
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<td>DG</td>
<td>Distributed Generation</td>
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<td>DR</td>
<td>Demand Response</td>
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<td>DSO</td>
<td>Distribution System Operator</td>
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<tr>
<td>ISO/IEC</td>
<td>International Organization for Standardization/ International Electrotechnical Commission</td>
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<td>EST</td>
<td>Energy Storage Technology</td>
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<td>EV</td>
<td>Electric Vehicle</td>
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<td>EVSE</td>
<td>Electric Vehicle Supply Equipment</td>
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<td>GUI</td>
<td>Graphical User Interfaces</td>
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<td>HAN</td>
<td>Home Area Network</td>
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<tr>
<td>HEMS</td>
<td>Home Energy Management System</td>
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<tr>
<td>HVAC</td>
<td>Heating Ventilation and Air-Conditioning</td>
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<td>ICT</td>
<td>Information Communication Technology</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
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<tr>
<td>NYISO</td>
<td>New York Independent System Operator</td>
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<tr>
<td>PEST</td>
<td>Political, Economic, Social and Technological</td>
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<tr>
<td>PLC</td>
<td>Power Line Carriers</td>
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<tr>
<td>SEMIAH</td>
<td>Scalable Energy Management Infrastructure for Aggregation of Households</td>
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<td>SRP</td>
<td>Scheduled Reprofiling</td>
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<tr>
<td>SWOT</td>
<td>Strengths, Weaknesses, Opportunities and Threats</td>
</tr>
<tr>
<td>TSO</td>
<td>Transmission System Operator</td>
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<tr>
<td>V2G</td>
<td>Vehicle-to-Grid</td>
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<tr>
<td>WAN</td>
<td>Wide Area Network</td>
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<td>WSN</td>
<td>Wireless Sensor Network</td>
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Chapter 1   Introduction

1.1 Project Motivation

The world is progressing towards a more advanced society where end-consumers have access to advanced forms of information and technology [1]. Hence it is in a current state of transition from the traditional approach to power generation and distribution, where end-consumers of electricity have typically been inactive in their involvement with energy markets; towards a new approach that integrates the active participation of end-consumers [1]. This new approach includes the use of distributed energy resources (DERs) which are being rapidly adopted by end-consumers [2]. DERs include renewable technology such as wind farms, electric vehicles and solar photovoltaic systems, but also encompass other resource capacities such as demand response programs, batteries, microgrids and small generators [2]. These DERs present a new source of energy capacity for all power market participants; however, there is much debate as to how these sources should be effectively integrated into the power systems. The energy aggregator is a concept that is being implemented worldwide to try and effectively integrate DER technology into the power market through the use of information communication technology (ICTs) and industry knowledge. In this current state where the role of end-consumers is changing, the energy aggregator has the potential to play a key role in creating value that benefits the entire power system, however, there is still much uncertainty surrounding this concept and how to effectively integrate it. Current debate surrounding energy aggregators and their position in the power market stipulates questions as to what benefits energy aggregators actually provide, who receives these benefits, what potential issues may be caused by this concept and whether the energy aggregators in fact create a more efficient power system or simply transfer rent and add another step in the process.
1.2 Aims and Objectives

Since the energy aggregator concept is relatively in its early stages of development worldwide, there is much research that still needs to be achieved to fully understand this concept and hence be able to integrate aggregators effectively into markets. As the power system is in a state of transition between liberalised market competition and a regulated monopoly, a clear idea of the operating structure and market transactions concerning aggregators often gets lost in translation as researchers attempt to illustrate the market rules and relationships of the area. Furthermore, current research is yet to evaluate the value different aggregators can add to the power system overall.

Thus, the aims of this honours thesis project are to:

1. Undertake a literature review to clearly identify the main energy aggregator concepts being adopted internationally;
2. Undertake a literature review to clearly outline the basic structure of each of these energy aggregators;
3. Undertake a literature review to identify the advantages and disadvantages of each energy aggregator; and
4. Apply SWOT analysis, investment matrix and Porter’s Value Chain methods to qualitatively discuss the potential value that energy aggregators can add to the power system overall.
Chapter 2  Background Information

2.1  Global Changes

Advances in technology are increasing at an exponential rate, and with the coming of the internet, communication capabilities have also dramatically increased, allowing the use of open platforms and free information exchange [3]. In past years, traditional power system architecture has employed the use of a centralised approach to electricity generation and distribution, where end-consumers typically have had limited interaction with the wholesale market prices of electricity; however, this is changing [4]. Increased penetrations of distributed energy resources (DERs) and advances in Information Communication Technology (ICT) have been main driving factors for a change in the traditional power system, although it is, in essence, a combination of various factors. The U.S. Department of Energy describes five key trends that have driven the push for new power system architecture:

1) the fact that there are increasing amounts of different *types* of electricity generation sources being connected to the grid, hence changing the characteristics of the generation mix;

2) Consumer energy consumption is becoming harder to predict and more diverse due to an increased environmental awareness and cost consciousness. Hence the need for more energy-efficient solutions has increased which consequently changes the typical load demand profile of an end-consumer;

3) Advanced communication systems and renewable energy technology are becoming more readily available and more economically viable, and hence is helping to both drive and facilitate the integration of smart grid technologies;

4) End-consumers have a growing need and expectation for power supplies to be more reliable and secure;

5) Growing electricity demand requires new infrastructure; however, this new infrastructure should also take into consideration the growing application of DERs on the grid [3].
These five key factors are creating a driving force that steers away from the traditional centralised approach to energy generation which typically consists of a few main large generating plants, to a more distributed architecture that facilitates the active participation of end-consumers by integrating their available information and technology [5].

As has been previously mentioned, DERs are inclusive of renewable energy technologies such as photovoltaic panels, hydro, biomass and wind turbines, but also include other sources of energy such as battery technology and electric vehicles [6]. DERs can be owned by residential, commercial, institutional or industrial end-consumers of electricity and are typically found connected to the distribution grid close to the point of energy consumption where voltages range from medium to low levels [2]. Internationally, DER acceptance and uptake is relatively in its early stages although countries such as Germany, Spain and Denmark have had high levels of DER penetration [7]. These countries have conducted research projects which suggest that as DER levels increase without coordination or control, grid integrity and security becomes jeopardised, operation and investments costs increase and deployment rates decrease [8]. In truth, successful integration of DERs on national grid infrastructures has not yet been properly achieved on a technical or commercial level [9]. However, advanced information communication systems may be able to help mitigate this [9]. There are still many concerns regarding DER integration as they have the potential to introduce voltage fluctuations, jeopardise grid stability due to reverse power flow effects and potentially create a public safety risk [10]. The challenges created by various DER technologies and emerging relevant ICTs that are helping to drive the change in the power system will be discussed in further detail in the next section.
2.2 Global Challenges and Opportunities

2.2.1 Advances in Information Communication Technology

Information communication technology (ICT) allows power network signals and important/relevant information to be communicated across large distances in short periods of time, to the appropriate utility or participant [11]. These signals create the backbone for maintaining power systems economically, technically and politically, and as the power system increases in complexity more advanced forms of information communication systems will be needed [9].

Power systems use a wide range of technologies to communicate and collect data. These technologies can include real-time embedded processors which include Supervisory Control and Data Acquisition Systems (SCADA), telecommunications, dedicated links, radio systems, monitoring and control systems, internet networks, power line carriers, fibre optics, network nodes and network sensors [12]. Advances in technology have led to the development of ICTs that have the potential to facilitate distributed power topologies and hence integrate DER technology into the power system [13]. Emerging technologies that are driving this change include smart meters, wireless sensor networks and increased communication abilities [14].

Smart meters are devices that allow information such as energy consumption measurements of appliances, load profiles, time-of-use tariffs, interruption events, phase loss and asymmetry, and voltage levels to be communicated to end-consumers of electricity [15]. In previous years this information has typically remained unknown to electricity users and network operators; hence with this new found knowledge consumers can respond to power signals and make informed energy decisions, thus becoming active participants in the power market [16]. Considering that traditional power systems are not generally equipped for monitoring low voltage networks, smart meters provide a monitoring device that makes low voltage networks traceable and visible which is essential for successful DER integration [17].
Nodes are used as central data points to gather relevant electrical information, which make them critical components of power networks [18]. Nodes consist of sensors that are used to monitor various environmental parameters, a microcontroller that can communicate with the sensor and can be used to activate controls, a transceiver that allows for signal communication and a power pack (i.e.: power to the device and a module for managing its energy consumption) [18].

The wireless sensor network (WSN) area has recently had a breakthrough in technology, allowing provisions of low-cost, low-power and multi-functional sensors to be installed throughout the power system [19]. Power system applications for WSN include real-time data monitoring and control, residential and building monitoring and control, asset management, environmental monitoring, power usage, generation efficiency, phase angle measurements, voltage measurements and frequency measurements [20]. Wireless sensors are easily transferable, adaptable and can be deployed at any time, and in most environments [21]. WSN provide the power system with flexibility and reduced maintenance costs due to minimalistic wiring requirements; this flexibility is essential for successfully integrating distributed energy resources [21]. Some new wireless sensors and protocols that are facilitating the integration of DERs include smart thermostats which allow for the remote control of temperature setting, and also Zigbee (IEEE 802.15.4) protocol devices which provide low cost, low power consumption, long distant, reliable and high levels of communication [22].
2.2.2 Distributed Energy Resources

2.2.2.1 Renewable Energy Technology

The topic of climate change has been gaining momentum globally over the last few years and has encouraged government bodies to reduce their carbon footprint by adopting cleaner energy sources and increasing their energy efficiency [23]. Thus to meet desired carbon dioxide (CO2) reduction targets governments have been implementing various CO2 emission caps on business processes and have also been providing various incentives that encourage end-consumers of electricity to adopt cleaner sources of energy such as renewable energy technologies [24]. Renewable energy technologies harvest natural sources of energy such as solar, wind, biomass or hydro and turn it into electricity which can then be used accordingly [24].

Solar and wind energy sources are often referred to as ‘variable energy sources’ due to their intermittent and often unpredictable behaviour [25]. Solar energy is converted through the use of a photovoltaic system or a solar PV system [25]. The system can be installed on top of a commercial or residential rooftop, or it can be established as a solar power station sometimes referred to as a ‘solar farm’, which tend to be popular in rural areas and often are even stand alone units [26]. Solar PV systems can be grid-connected or off-grid, although grid-connected solar PV systems tend to be more popular as they are designed for typical end-consumers and are cheaper than off-grid systems which require expensive battery sets [27]. Wind energy is converted through the use of individual wind turbines which combine to make ‘wind farms’ and can be installed onshore or offshore [23]. Onshore wind farm installations tend to have lower operating costs, however, are often seen to be more ‘visually’ offensive; whereas offshore wind farms are less visually offensive, have stronger and more consistent wind generation levels, but have higher initial investment costs, and their operation and maintenance costs are significantly higher [28].
The global solar PV capacity for the end of 2015 was estimated at 227 GW, with China, Germany, and Japan respectively having the largest amounts of solar PV capacity/generation [28]. Wind power had an estimated capacity of about 443 GW worldwide, with China, United States, and Germany taking the lead for the most capacity/generation in that field [28]. These figures represent significant changes in the global electricity generation mix compared to that of just ten years ago which had a capacity estimate of about 6 GW and 59 GW for solar and wind respectively [29]. Forecasts predict that this volume of penetration will only increase as technology prices and installation costs fall, and as was mentioned earlier increased penetration levels lead to increased potential issues [28].

Power system architecture was originally designed in a centralised hierarchical approach that assumed power would flow in one direction, with higher voltages typically at the supply end and lower voltages typically at the consumption end [30]. Voltage regulation is used to keep the grid voltage at a relatively stable and constant level to maintain grid integrity (usually allowing voltage variations of up to ± 10%) [31]. However, these schemes were designed under the premise of traditional power flow and did not take into consideration the possibility of reverse power flow effects [32]. Hence when grid-connected wind and solar farms have low demand loads resulting in a surplus of energy being generated from the systems, voltage levels at the connection point to the grid can increase, causing current to flow in the reverse direction allowing the system to inject power into the grid [33]. If there are high penetration levels of solar and wind systems in a particular area on the grid, it may cause accumulative voltage fluctuations to surpass acceptable limits resulting in jeopardised grid reliability and stability [32]. What is worse is that due to traditional design, system operators do not have the appropriate monitoring equipment for distribution feeders that would normally allow these variations to be detected and dealt with accordingly [25]. This lack of information causes uncertainty among system operators in regards to whether or not net-load variations on the grid are in fact caused by changes in end-consumer demand or changes in solar and wind generation systems, hence making energy forecasts increasingly difficult [25].
Both solar and wind are intermittent in nature, although wind generation tends to be more stable and is easier to predict than solar generation which changes second to second [25]. However, because of this nature, these sources of energy are often not considered able to be dispatched by grid operators in the sense that they are able to be turned ‘on’ or ‘off’ at any given notice as the utility may require [34]. Furthermore, this intermittency can cause rapid variations in grid voltage, which are sometimes seen by end-consumers as ‘flickers’ in lighting or other means [35]. These are typically associated with turn on/off events, not variability in the RE source. Variations in voltage affect grid stability, hence in regions where there are high levels of wind and solar penetration it is necessary to have larger amounts of reserved dispatchable generation/capacity from more traditional energy sources to mitigate the imbalance that solar and wind fluctuations cause [33]. However, this not only increases operating and investments costs, but also the balancing sources must bear the equipment damage caused by constant cyclic readjustments [33]. It was found in a study that spanned across the United States, Canada, and Mexico that cyclic readjustments such as the ones just discussed had the potential to incur costs of up to US$35 - US$157 million per year [36].

Other concerns surrounding solar and wind generation systems include potential safety risks due to unintentional islanding caused by solar and wind systems not responding appropriately to grid failures or blackouts [25]. Islanding refers to the concept where the grid experiences a failure that causes power to be disconnected; however, some portion of the grid remains energised due to a source maintaining its power [34]. Although there are cases where this effect is desirable, more often than not it raises safety concerns for electricity maintenance workers who may not know that a portion of the grid remains energised, hence their risk of being electrocuted increases [34].
In response, the IEEE 1547 *Standard for Interconnecting Distributed Resources with Electric Power Systems*, attempts to address these safety concerns by implementing anti-islanding standards that require DERs such as wind and solar to disconnect within two seconds in the event of a local fault or a voltage variation that exceeds design parameters [37]. To simplify potential system issues the standard also requires that all grid-connected DERs operate at the relevant power system grid parameters (frequency values are typically 50Hz in Europe and 60Hz in the U.S., and 230V, 120V for home use respectively) [38]. Effectively managing the power output of renewable energy technology on the demand-side of the grid, represents a significant challenge for system operators who in the past have adopted a ‘fit-and-forget’ mentality.

### 2.2.2.2 Energy Storage Technology and Electric Vehicles

Battery technology or commonly referred to as energy storage technology (EST) has also been gaining much attention and momentum lately as the manufacturing price has been dropping and the quality has been increasing [39]. EST plays a key development role in the current and future power systems by allowing electricity to be stored by some means and then retrieved again for later use [39]. EST provides the power system with a wide range of applications, but the main benefit that EST systems provide is electrical ‘flexibility’ to power participants, which is an essential aspect of the successful integration of DER technology [40]. Although many power systems operate without energy storage, stability in a complex system is commonly recognised as requiring a diverse range of energy storage technology connected to the grid, as no single storage system can fulfil all of the complex needs that are required to maintain stability [41].

Common applications for EST in today’s power networks include: maintaining grid stability through frequency and voltage regulation; providing supply reserves in order to maintain system balance; integrating renewable energy sources by smoothing unexpected transients; peak shaving and load levelling in order to reduce electricity costs and to smooth load profiles; effective energy management and maintaining power quality [42]. The ability to provide a particular service to the grid depends on the storage systems energy capacity, power density and response time, [40].
It has been a common topic among many research studies lately that electric vehicles (EVs) may now provide a new type of energy storage capacity for power participants [43]. Electric vehicles are vehicles whose primary source of power is electric-based; hence EVs have rechargeable batteries that are able to be connected/disconnected from the grid [44]. Due to the physical and technical requirements of electric vehicles (i.e.: accelerating, decelerating continuously), electric vehicle batteries must have fast response times, high energy capacities, high power abilities and must be cost efficient while being limited to space and size [45].

EVs employ the use of advanced lead-acid, lithium ion (Li-ion) or nickel metal hydride batteries, although other storage technologies such as super capacitors and fuel cells have also been used [42]. Electric vehicle technology is expected to significantly increase and advance over the coming years, with potential for more electric vehicles to actively participate in the power market by acting as ‘sinks’ or ‘sources’ of energy [46]. It is therefore hypothesised that as EV penetration increases and battery technology advances, the opportunity will open for electric vehicles to actively participate in grid applications such as ancillary services and optimisation [45].
2.2.2.3 Demand Response Programs

Although end-consumers in residential areas have not generally had access to dynamic price signals of electricity and therefore have been limited in their participation in energy markets, commercial and industrial end-consumers have had an easier time gaining a foothold in markets through the use of demand response (DR) programs [6]. Demand response programs are used by grid operators to maintain stability in times of peak demand or peak price and are often referred to as ancillary services if they are dispatchable [7]. These programs help to increase the energy efficiency of the power system, by capitalising on the ability of some end-consumers to curtail or shift certain loads of their operations during peak energy times in exchange for rewards or incentives [8]. The curtailment of these loads provides power utilities with an economically efficient measure for maintaining the balance of supply and demand without necessarily having to invest in the expansion of grid infrastructure for rising maximum demand levels [9].

There are various types of demand response programs which can be characterised by their load profiles, grid application and event triggers [10]. A conventional method of categorising demand response programs is to separate them in terms of ‘Incentive-Based’ programs or ‘Time-Based’ programs (often referred to as load-response or price-response respectively) [11].

Incentive-based programs typically have contracted terms and conditions and involve participants receiving monetary rewards or rate discounts for their curtailment commitments [11]. These programs can come in the form of direct load control, curtailable loads, interruptible loads and scheduled loads [11] [12]. Direct load control programs are those in which the system operator or utility providers remotely disconnect participating consumers’ pre-defined electrical equipment within short notice [12]. Curtailable loads are those which can reduce their electricity consumption while still maintaining some level of operation [4]. For example, reducing the power output on an air-conditioning unit by changing the temperature settings [13].
Although the terms ‘curtailable’ and ‘interruptible’ loads are used interchangeably throughout much literature, the Rocky Mountain Institute in Colorado separates the two by defining interruptible loads as those in which only the largest industrial and commercial companies can participate (>1000kW) [11]. These programs involve shutting off specific pre-defined operations in tightly bound contracts which incur penalties if there is a failure to comply with the contract conditions [11]. Scheduled load programs are those in which the specific time and amount of curtailment is pre-defined and pre-arranged between the end-consumer and the utility provider [11]. Time-based programs reflect the dynamic prices of the wholesale electricity market to end-consumers, who can then choose whether or not they wish to respond to those economic signals [8]. These programs can come in such forms as Time-of-Use (TOU) pricing, Dynamic pricing (critical peak pricing and real-time pricing) and demand bidding [1]. Figure 2.1 below illustrates the various demand response programs and their technology requirements.

**Figure 2.1: Demand Response Programs and Enabling Technology**

Adapted from the following sources: [15] [14] [11]
As has been previously mentioned commercial and industrial consumers have had greater access to demand response programs. This is primarily due to their ability to curtail larger loads which give them greater bargaining power and the fact that these consumers tend to employ the use of interval meters which allows energy consumption to be dynamically monitored and measured [9]. Smart meters allow dynamic price signals to be communicated to endconsumers, furthermore, these devices also allow utilities to measure the individual consumption rates of various appliances [5]. Historically residential consumers have typically had flat rate meters installed on their premises, which can be seen as a technical constraint that prevents them from being able to enter into demand response programs as they cannot view or respond to dynamic market signals directly from a utility meter [16]. However, with the large-scale roll-out of smart meters across multiple international electricity markets, this barrier is becoming redundant [4].

It should be mentioned that some forms of demand response programs have been available to residents such as direct load control as they tend to be pre-defined controls that do not need dynamic metering ability; however, access to other programs has been limited [17] [18].

There are many types of loads that are able to be curtailed for demand response purposes. Industrial consumers are not only able to reduce loads such as lighting and Heating, Ventilation and Air-Conditioning (HVAC), but their potential for load curtailment is also characterised by their specific industrial processes [4]. Commercial consumers have curtailed loads such as lighting, HVAC, refrigeration systems, water heaters, pool pumps and laundry areas [19]. Residential consumers who have been a part of direct load control programs curtail loads such as HVAC, water heaters and pool pumps [18]. Overall, the benefits from curtailing these loads through the use of demand response programs include: bill savings and rewards for endconsumers; stabilising market volatility; providing system operators with an alternative avenue to costly grid expansion; reducing the market power of generators and peaking stations; improving grid reliability and stability while reducing marginal cost during peak events; and providing flexibility within the power system that is essential for smoothing the variations caused by renewable energy sources [14] [7].
The rapid advancement in information communication technology, such as wireless sensors and smart meters, means that not only is there more potential for commercial and industrial players to expand their profile of curtailable loads, but this principle can also now be applied to residential areas and hence increase their potential for demand response [8].

As residential areas are places of personal belonging, the idea of direct external control over home appliances without being able to contribute to the decision process can raise social security concerns and hence deter residents from wanting to participate [20]. Hence some method of communication between the utility and consumer that allows consumers to exercise some level of control over the decision process must be developed to allay the concerns of residents, particularly as their numbers increase [21].

This would suggest that a level of consumer customisation must be made available for DR, however; market participants such as system operators may not have the ability to take on the extra workload of developing such customised profiles for individual residents which would facilitate their participation [21]. Adding to this difficulty is that residents may not be motivated enough to participate in DR programs if bill savings are small and therefore deemed less valuable than the discomfort of having to monitor personal energy use and respond accordingly to demand response signals [20].

Thus to activate the full potential of private end-consumers, there must be some form of automated remote control by a third-party that allows for some level of end-consumer control [4]. Tapping into the residential DR market suggests that economies of scale and scope would need to be achieved to maximise potential profits [22]. Energy aggregators can facilitate this level of end-consumer integration.
Chapter 3  Literature Review

3.1  The Energy Aggregator

Research has demonstrated that the energy aggregator concept refers to a third party entity that acts as an intermediary between end-consumers of electricity and market participants [57]. The aggregator realises that some end-consumers have the ability to provide energy capacity through the use of DERs that are inclusive of renewable energy technology, electric vehicles, and DR programs [58]. The aggregator capitalises on this ability and defines a bi-lateral contract with the DER owner that allows them to enter the DER owner’s available capacity into the electricity market as a part of a larger total capacity, which can then be used by other market participants in the form of services [59]. Thus aggregators provide the power system with a means to captivate available energy capacities that as singular parts may not have been realised or deemed valuable enough to enter into the market [4].

In [47], the European ADDRESS (Active Demand for the Smart Grids of the Future) Project highlighted the role and responsibilities of the energy aggregator. The project defines that the primary functions of an aggregator are to:

1) Engage with end-consumers and tap into their available flexibility by offering products and services that actively and effectively engage end-consumer participation. Then offer that defined flexible capacity to market participants through the use of bi-lateral contracts or market action;

2) Manage the risk and uncertainty associated with electricity markets and the aggregator’s available consumer profile;

3) Optimise the value of the end-consumer’s assets in order to maximise potential benefits while communicating to participants about the appropriate price and volume signals; and

4) Forecast the consumption and load preference behaviour of the end-consumer [47].
The research in [48] emphasises the aggregator role as a provider of power flexibility and should: Provide information management in regards to insight and forecasts of end-consumer flexibility; Bundle services together to optimise the flexibility of end-consumer asset; Match market demands with services; Guarantee the transactions committed to market participants.

To fulfil these roles, the research in [49] determines that aggregators must capitalise on advanced information communication technology and ensure that they have effective communication abilities which enable real-time data measurement and remote control. The ADDRESS project in [47] was able to fulfil these roles by developing their own technology referred to as an ‘Energybox’. The Energybox communicates appropriate signals to end-consumers, controls home appliances, enables end-consumer preference control, records and stores measured data, and acts as the gateway between the aggregator and end-consumer [47].

Research in [50] discusses the services that aggregators may be able to provide to various market participants. The study suggests that aggregators can offer peak-load shaving services to system operators through Scheduled Reprofiling (SRP), where the aggregator forms a bi-lateral contract with operators and agrees to curtail a specified load during a predetermined time. Alternatively, they could offer this service through Conditional Reprofiling (CRP), where the system operator pays the aggregator a fixed fee for having a defined amount of flexible power on standby and is then paid an additional variable fee for when that flexibility is called into use [50]. CRP contracts are used to correct variations in supply and demand in the intra-day markets and are thus often activated within short notice, and incur penalties for those who fail to meet their obligations [50]. The research in [50] also suggests that the flexibility of these services offered by the Aggregator also provides system operators with an economically efficient mechanism that can be used to smooth the variations caused by intermittent renewable technology.

Voltalis is an example of an aggregator located in France who has a bi-lateral contract with the Transmission System Operator (TSO) and therefore does not participate in the day-ahead or intraday energy markets [48]. This aggregator has a Scheduled Reprofiling (SRP) contract with
the TSO, and installs their in-house technology known as a Bluepod in residential premises for free. This allows them to control heating appliances remotely [48]. The Bluepod allows end-consumers to override the control of their appliances at any time if they choose; otherwise, the Bluepod automatically curtails the device load by manipulating the temperature settings [48]. Voltalis dispatches load curtailment signals when the TSO communicates an event signal that jeopardises the grid stability [48]. In this business model, the Aggregator receives a defined contractual fee from the TSO for providing a ‘dispatchable’ load shedding service, where the end-consumer’s benefit is purely defined by the amount reduced on their electricity bill [48].

There are various services that aggregators can provide to market participants with the literature suggesting that aggregators can offer portfolio balancing services to retailers [51]. In this scenario, the aggregator can become an independent service provider for an electricity retailer, where the aggregator seeks to optimise the retailer’s portfolio through efficient forecasting models and end-consumer load control [51]. In this case, the aggregator does not participate in the electricity market but instead forms a service contract with the retailer where the payment for the service is discussed and agreed upon between the two parties [51]. The retailer can use an aggregator in this scenario as a source of risk hedging against unexpected market events. The aggregator service ensures that the contractual obligations of the retailer’s supply and demand portfolio is optimised and always guaranteed [51]. Thus the retailer can avoid costly penalties for failing to meet contracted supply/demand agreements, where typically they would need to purchase insurance to eliminate this potential penalty risk. The research in [51] demonstrated a potential scenario in Australia where an aggregator program such as this had the potential to earn $2 billion annually.

A field test done in the energy markets of Italy, Spain and France by the ADDRESS project has been described [47]; the test’s purpose was validating their ‘Energybox’ technology and aggregator market mechanisms. This demonstration proved that an aggregator can provide energy supply services, peaking shaving services, relief from network congestion and overload, balancing services which help to mitigate the grid variations experienced from renewable
energy technology and finally, ancillary services which include frequency regulation, voltage support and tertiary reserves [47]. The results from the field test also demonstrated that grid operators were still able to maintain normal operating conditions while managing the technical validation of bids coming from distributed generation aggregators. The research in [47], also demonstrated that energy aggregators were able to effectively decrease the market price, hence providing end-consumers with more economically efficient energy rates [47].

Barriers to aggregators were thoroughly discussed in [52] where it was identified that there is a lack of markets that effectively allow the participation of aggregators due to the technical constraints for market participation and regulatory barriers [52]. Regulatory frameworks of aggregators throughout Europe were reviewed in [53] where the emphasis was made on the modified standards and participation rules by policy makers to support aggregator integration. Such modifications include the reduction of the pre-qualification size for participation in the reserves market in Austria, which was reduced from 10MW to 5MW in 2014 to enable the participation of smaller sized aggregators [53]. The research concludes that political frameworks and market models need to be re-designed appropriately to facilitate the active involvement of end-consumers and hence allow aggregators to participate in electricity markets.

The main advantages that energy aggregation seems to bring is that DERs and ICTs are integrated by aggregators in such a manner that economic benefits are created for end-consumers who traditionally have had minimal bargaining power in the electricity market. Furthermore, it provides both retailers and system operators with generation services, reserve capacities, ancillary services and balancing services that all work towards maintaining grid integrity, while providing a competitive market for electricity prices [54]. Potential issues that the energy aggregation may bring include: the possibility of decreased power quality when adding large quantities of distributed generation or demand response to the grid; a decrease in grid reliability and unbalanced power flow due to ill-managed dispatchment of distributed energy sources; and potential risks to the public and to worker safety due to anti-islanding [55].
The research in [49] [52], both discuss the types of energy aggregators that exist in markets today [52]. The studies determine that the main types of aggregators that are present throughout international energy markets are those that aggregate demand response programs and distributed generation sources. However, the research also suggests that aggregators of electric vehicles are forecasted to have a large impact on energy markets to come. Hence the project will seek to outline the relevant research found on these types of Aggregators and their role in the changing power system.

3.2 Aggregator of Demand Response

Aggregators of demand response programs are referred to as ‘curtailment service providers’ (CSP) in the U.S and are relatively well established within the marketplace compared to that of Europe’s where they are called ‘independent aggregators’ [6] [27] [28]. Aggregators of demand response have been the focus of much literary research to date. This is because they are forecasted to be major players in the transitioning of the power system from the centralised approach to a more distributed architecture as they allow the active participation of smaller energy consumers, who traditionally have not been effectively activated [5] [4]. Demand Response Aggregators play a fundamental role in tapping into the residential market by creating customised, automated controls for residential loads and appliances that enable remote access and while taking into consideration consumer preferences [5] [4].

Demand response aggregators can participate in energy markets, capacity markets, emergency markets, and ancillary services markets, where prices for curtailment are based on wholesale or retail electricity prices depending on the market type [56]. Market transactions for aggregators are between independent system operators, distributed system operators, retailers, balancing responsible parties and utility providers, where the monetary interactions between these market participants are filtered down through to the participating end-consumers [57]. The general operating scenario of a DR aggregator includes a response to a signal sent out by the system.
operator, where this signal may simply convey cheaper electricity rates or convey a critical peak event [57]. Research depicted in [58] explains that Demand Response Aggregators can reduce the specified loads of end-consumers in response to both economic and grid reliability signals communicated by the system operator. However, to do so, the aggregator must be equipped with the appropriate technology and communication abilities [58].

Aggregators of demand response 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 demand response capacity [52] [59].

In addition to this, a graphical user interface (GUI) must be made available to end-consumers by aggregators in order to 1) communicate demand response signals and 2) allow for some level of end-consumer customisation [59]. Advances in ICTs 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 [60]. HEMS/BEMS units are capable of providing signals of demand response for load control purposes and also provide the measured energy consumption rates of different appliances/loads, while also communicating relevant environmental conditions [61]. These units communicate all of the relevant data back to the demand response aggregator through the use of home area networks (HANs), access points/gateways, wide area networks (WANs), power line carrier (PLC) communications and backhaul networks [60] [61]. Aggregators then communicate the appropriate accumulated data back to the utility provider or system operator through these same networks [60].

HEMS/BEMS are inclusive of many different types of technology components including smart meters, central controller, local controllers, sensors, load switches, central controllers and GUIs [62]. Smart meters and interval meters act as the gateway/access point for utility providers and aggregators [9]. 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 [9]. GUIs can be such devices as smart meters, smart phones, laptops, desktops, home energy displays or web dashboards/portals [60]. 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 [59]. Hence GUIs provide an interface avenue that enables the customisation of end-use load preferences which is an essential criterion for larger market participation [62] [59]. GUIs also allow the end-consumers to see potential demand response signals in advance and communicate relevant power system information [62].

Central controllers are located in the end-consumer’s premises and are usually depicted as the HEMS/BEMS unit itself [62]. This central controller is used as a main point of contact for the energy aggregator where the unit dispatches control signals according to appropriate algorithms and methods [59]. 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 [63] [64]. One important sensor that has recently begun to be used is the wireless smart thermostat [9]. 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 demand response penetration [65]. 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 [52] [9].
Communication modules are needed to facilitate the successful transfer of data between the HEMS/BEMS unit, appliances/load controllers, sensors, GUI and appropriate participants [62]. Traditional demand response programs use wired communication modules and protocols such as power line carriers, fibre optics, and Ethernet protocols to transfer and receive signals [62]. However, compared to that of their wireless counterparts, these forms of communication have higher installation/maintenance costs associated with their physical hardware requirements [9]. 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 [62]. These communication modules adopt standard protocols developed by the IEEE for advanced metering infrastructure, which provide essential bi-directional communication [62].

The SEMIAH (Scalable Energy Management Infrastructure for Aggregation of Households) project described in [66], outlines the technology requirements and necessary components needed to create an energy management system for demand response purposes. The project develops the appropriate system which enables aggregators to control a large scale of residential load appliances effectively and also describes the types of data systems needed for aggregators to effectively participate in markets [66]. 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 [66].

EnerNOC is an existing aggregator of DR that has a strong international presence and an established market base in the U.S [67]. 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 [68]. Albertsons grocery stores is a franchise across America that has enrolled
itself in EnerNOC’s DR program. 300 of the stores were installed with EnerNOC’s technology to control lighting and HVAC, which cost US$11,000 per store or approximately US$450 per kW. Since their enrolment with EnerNOC, the grocery stores have been able to reduce peak demand by 25kW per store.

The economic characteristics of DR aggregators – in terms of their ability to generate revenue, capital expenditure, installation/maintenance/operation costs, and the type of market transactions – depend on a number of factors including: the market conditions and environment; entry barriers to markets; what type of supporting technology and infrastructure exists in the area; the geographical area in terms of population; whether or not social adoption is apparent; and most importantly what type of government policies and standards are in place [52]. Much research illustrates that aggregators can increase profits if enabled to run in the capacity and ancillary services market which is suited to the use of the aggregators’ flexible capacity [69] [52] [70].

In [58] the White Oak Campus Microgrid project is discussed, where the U.S Food and Drug Administration campus was enrolled to participate in DR programs that were 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 [58]. The results from the project demonstrated that as of 2013 the White Oak Campus had been able to generate US$3 million from participation in demand response programs that were being entered into capacity and ancillary service markets [58].

The portfolio of a demand response aggregator must be able to meet the technical parameters of the specific market if they wish to participate [69]. For example, to participate within the capacity resource market, aggregators bid their available curtailment loads into the market and if successful are usually required to dispatch the contracted load within 30 minutes to 2 hours.
Whereas aggregators who wish to participate in the ancillary service market must be able to dispatch loads in less than 30 minutes, hence these aggregators would need to ensure that their demand response equipment can handle the corresponding data transfer rates [69]. Furthermore different markets require different capacity entries, for example for DR aggregator to enter into the NYISO emergency market; they must be able to reduce a minimum load size of 100kW per zone [71].

The initial costs of making a potential end-consumer demand response 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 (aka smart meters) [70]. Residential end-consumers usually have higher incremental costs associated with demand response enabling technology due to the lack of awareness, and the cost of implementing advanced metering if it does not already exist [72]. However, aggregators may find that the additional cost for enabling commercial and industrial end-consumers to participate in a demand response program is significantly less due to their previous exposure to demand response programs and their tendency to already have some pre-existing infrastructure [52].

Research conducted in [73] suggests that the investment costs associated with enabling a single residential household with intelligent infrastructure capable of facilitating automated demand response, was approximately 500 EUROs for the appropriate information communication technology which was inclusive of smart meters and wireless sensors; another 500 EUROs for the cost of the appropriate microcontroller; and annual operating and maintenance costs which was estimated at a total of 50 EUROS. The research in [33] identifies some of the known operational costs and benefits experienced by aggregators in the U.S markets in regards to smart meters and their appropriate communication infrastructure, see Table 6-3 in Appendix A.1.1.
Aggregators must also 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 [52]. Furthermore remuneration to end-consumers depends on the aggregator being able to determine their Baseline Profile (BLP), which is critical for determining the amount of energy deviation due to demand response signals [72]. If the BLP is not easily explained to the end-consumer, this can cause uncertainty [57]. The research in [74] 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 [74]. Research in [75] also discusses the social implications of motivating residential end-consumers to engage in demand response programs. The study highlights how government roll-outs for demand response enabling technology such as smart meters, encourages market participation by helping to facilitate the active participation of end-consumers through economies of scale [75].

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 [59]. Therefore it is up to the aggregator to ensure that the correct security measures are undertaken, in order help mitigate this social concern [59]. Residential-consumer behaviour and preferences can also have a great impact on available capacity for aggregators, especially those who are just starting up [70]. This is because their available energy pool is not only restricted by the number of participants but also the consumer’s appliance preferences [59]. Hence, it is important for an aggregator to assess whether or not an end-consumers potential profit is greater than their installation/operation cost of enabling demand response [59]. Consumers are also becoming increasingly aware of the cost of electricity, which provides demand response aggregators with an opportunity for effective marketing by providing an easy solution that requires minimal effort for consumers to reduce their bill [59].
Through the systems just mentioned, demand response aggregators can provide network operators with a large flexible portfolio of defined and dispatchable energy, by tapping into residential end-consumers [52]. 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 [56] [3]. 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 [70]. DR aggregators also have the benefit of having a diverse, flexible portfolio, which by its very nature allows them to spread potential risk [70]. A study done in [66] discusses the instability effects Demand Response 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 [66]. However, the research determines that aggregators can mitigate this adverse effect by staggering the scheduling of their load curtailments and by also maximising their geographic portfolio span [66]. The research in [66] also demonstrates that Demand response 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.

Aggregators also provide system operators with better grid cost savings as they deter grid expansion, reduce potential equipment damage along the grid, provide operators with better mechanisms for load forecasting and help mitigate congestion [76] [77]. Services to retailers include the opportunity to hedge their risks against market volatility, by allowing the aggregator to stabilise their consumers’ peak demand [57]. Demand response aggregators also provide a method of peak load reduction, that can rival that of peaking stations and generators as they have far less marginal costs than traditional methods of generation and are not emitting as much carbon dioxide [77] [52]. Another advantage they have over peaking stations is that DR aggregators can respond faster, as conventional generating plants often have operational limitations that affect their ability to change their power output quickly [78].
The research depicted in [75] discusses the market barriers presented to demand response aggregators due to political uncertainty. The study highlights the how policies and lack of standardisation can create unfair advantages and represents a large risk that can deter aggregators of demand response from entering into markets [75]. Currently there are no standard rules for demand response aggregators to follow including remuneration, which can create unfair advantages for different market participants [70]. 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 minimises the potential for demand response participation in wholesale market bids [56]. Hence, lack of standard market policies creates opportunistic value for some participants which can be deemed an unfair advantage [56].

Furthermore, some regulatory conflictsions and contradictions exist, that make it difficult to clearly identify revenue potential and market participation [70]. For example, in the United States of America, the Federal Energy Regulatory Commission (FERC) order 747 requires demand response aggregators be paid/reimbursed for the capacity they provide at rates which are equivalent to the proportional generation they have displaced [56]. However, the U.S Court of Appeals due to regulating jurisdiction concerns has recently determined that demand response is a type of retail product and must be controlled within each state [56]. This essentially minimises potential profit for demand response aggregators as they cannot benefit from wholesale capacity markets, where revenue generation tends to be higher [56]. Many governments are supporting the large-scale roll-out of smart meters to encourage the active participation of end-consumers, as a result of climate change initiatives [9]. Although this represents an opportunity for aggregators to activate their demand response potential, there is also no current standard for smart meter communication [70]. This means that smart meter communication protocols could change from region to region, hence requiring aggregators to adapt their technology accordingly which minimises their ability to capitalise on economies of scale and scope [57].
3.3 Aggregator of Distributed Generation

With more and more Aggregators of Distributed Generation (DG) technology emerging on the grid, they have also received much attention, as focus shifts away from the ‘fit-and-forget’ mentality, to a more integrated approach [79]. Aggregators of DG, are described as third party entities that engage with end-consumers who already own, or who are interested in owning renewable energy generation systems, and are very prominent throughout the European markets [49].

Individual owners of renewable energy systems do not typically have the ability to enter their surplus generation into energy markets directly as their scale of production is usually limited to kWh, whereas utility providers are looking to purchase energy quantities in the range of MWh as it is more economically viable [80]. Hence, incentives for end-consumers to adopt renewable energy sources such as wind, solar and biogas usually come in the form of ‘feed-in’ tariffs which provide owners with compensation for the surplus energy they inject into the grid [80] [75].

Due to accumulative generation providing a more economically viable option for utilities, aggregators can negotiate better rates and incentives with market participants and hence are then able to provide participating end-consumers with cheaper electricity than what they might have been able to obtain if they were simply engaging in a standard feed-in tariff [81]. Aggregators who wish to engage ‘prosumers’ (end-consumers who can generate electricity through the use of renewable energy sources) often guarantee the lowest available electricity rates [81]. Typically participating end-consumers will agree to a power purchase agreement (PPA) where their electricity needs are met directly from the aggregator instead of the electricity provider, who then makes a commitment to those prosumers to secure the best possible electricity price [79] [52] [49]. In that way, an Aggregator of Distributed Generation can be a retailer of electricity.
Aggregators also seek to sell the surplus energy generated by consumers back to the grid utilities, to generate profit [52] [82]. Much of the literature illustrates that these types of aggregators can generate additional economic benefits for themselves and their participating end-consumers, by charging storage systems using end-consumers renewable energy, then discharging the storage systems during critical times [79] [52] [49]. Most of the market action for these types of aggregators occurs in the energy market. Although there is potential to enter into the ancillary services market through the use of wind and solar PV systems research, market designs which seek to facilitate ancillary services via renewable generation sources are yet to be achieved and hence will not be a focal point in this thesis project [83] [75].

Research in [54] outlines the control infrastructure for Distributed Generation Aggregators which is inclusive of: 1) the source controller which takes advantage of the distributed generation sources embedded graphical interface to control the system and its outputs; and 2) the central controller which sends commands to the appropriate source controllers according to the aggregators method of dispatch, which seeks to optimise the assets power consumption and power output in order to generate the best economic returns [54]. These types of control systems are relatively cheap to implement as they take advantage of the pre-existing technology and interfaces already integrated into the energy source itself [54]. Hence these systems can range from $US100 to US$1000 [80]. The combinations of these components are often referred to as the energy management system for a Distribution Generation Aggregator [80].

For aggregators of DG, their investment costs are primarily focused on the control infrastructure and not the actual production or storage of the energy (Gordijn & Akkermans, 2007). However, there are Distributed Generation Aggregators who also invest in renewable energy technology and storage technology if the end-consumer profile is not satisfactory [49]. Other aggregators of DG allow end-consumers to lease renewable energy technology so that their investment risk is lessened [80]. The National Renewable Energy Laboratory provides a current list of the estimated costs associated with renewable energy technology which can be viewed in Appendix A.1.2 in Table 6-4 [85].
Generally speaking, the technology requirements of a Distributed Generation Aggregator include the appropriate grid infrastructure, generation sources, communication abilities, battery energy storage systems (which include the battery management system) and data management systems [79].

Many existing business models for aggregators of DG involve various types of transactions and seek to engage different categories of consumers. Research discussed in [86] identifies the different concepts and models that can be used for a Distribute Generation Aggregator made up of stand-alone solar PV systems. The research highlights the benefits of ‘Solar Gardens’ where customers can purchase energy from a local solar garden, which guarantees lower electricity prices than the conventional generation sources [86].

An example of this can be seen in the U.S. based company ‘Clean Energy Collective’ (CEC), where the corporation allows end-consumers in that area to purchase solar panels that are a part of the ‘community’ solar garden [87]. The energy generated is fed into the grid and purchased by other consumers in the area [87]. CEC pays the owner of the panel in the form of ‘electricity credits’ which is determined by the amount of energy generated from each panel owned by the consumer [87]. The company can capitalise on economies of scale, by purchasing solar PV systems on a large scale, thus leveraging their bargaining power against manufacturers [87].
The research in [82], demonstrates how a distributed generation aggregator can engage residents in a commercial building. The research study illustrates an electricity pricing scheme that guarantees the lowest price of energy delivery and is provided by the aggregator to its participating consumers in an apartment building, who also receive incentives for participation [82]. The research clearly outlines the technical considerations the aggregator must undertake, as well as the incentive and billing mechanisms developed to generate profit [82]. The proposed system integrates rooftop solar PVs, with a battery energy storage system (BESS) and seeks to charge the battery storage during times of cheap grid import or high surplus energy generation [82]. The aggregator discharges the battery during times of peak demand or peak-price to secure its contractual obligation of lowest price guarantee while making a profit from the higher energy price [82]. The research also demonstrates that end-consumers can obtain better benefits from their solar PV systems, with the assistance of an aggregator [82].

In the research depicted in [84] an aggregator in Spain has adopted a business model that seeks to group together end-consumers who are not only able to respond to load shift signals but who are also able to produce their energy. The aggregator uses the end-consumers distributed generation sources (micro hydro, Solar PV systems and micro turbines) to supply power to the portfolio of end-consumers when the cost of operating the generation source is cheaper than the market electricity price [84]. In this case, the aggregator can be seen bundling energy efficient services together with electricity supply to maximise their potential profit while reducing the electricity bill of participating end-consumers [84]. Bundling services together like this resulted in higher economic benefits for Aggregators, rather than separating the services [84].

[84] Also demonstrates types of Distributed Generation Aggregators that are being adopted in Norway, where the aggregator seeks to engage with end-consumers who can supply part or all of their own energy demands, while also generating surplus energy to be sold back into the power market. The aggregator takes care of any additional costs needed in order to effectively engage these end-consumers [84]. Hence, to use the distribution grid infrastructure and metering services, the aggregator pays the Distribution System Operator (DSO) a network tariff [84]. If
the aggregator’s generation portfolio exceeds a certain level of generation, they are required to submit a generation forecast to the TSO who is in charge of managing the balance of supply and demand [84]. In this model the Distributed Generation Aggregator typically sells the accumulative surplus energy to a local electricity retailer [84]. In this scenario, all market participants including the system operator, electricity retailer, and end-consumer experience profits [84].

Distributed Generation Aggregators in The Netherlands, who wish to provide balancing services for the variations between the day-ahead market contracts and the real-time requirements of demand and supply, are also demonstrated in [84]. In this scenario, aggregators hold an economic advantage over traditional balancing reserves and can offer competitive prices, as the aggregator’s investment costs are primarily focused on the control infrastructure and not the actual production or storage of the energy [84]. The aggregator engages with end-consumers who can offer sources of generation and controllable consumption (heating and cooling), particularly end-consumers who own large cooling storages and greenhouses [84]. The aggregator develops a flexible load profile that is entered into the balancing market where it can be used by system operators to maintain grid stability or electricity retailers to maintain the contractual obligations of their forecasted demand and supply portfolio.

Distributed Generation Aggregators such as ‘Good Energy’ located in the U.K, ‘Next Kraftwerke’ located in Germany, France, and Belgium, and Oekostrom located in Austria were analysed throughout the study and demonstrated much of their business operations and how they went about engaging with end-consumers [49]. The economic mechanism in which aggregators can generate revenue is often entirely dependent on the feed-in tariffs and available financial mechanisms emplaced on the market by government bodies [49]. Research in [88] describes some of the pricing models available to sources of distributed generation; see Table 6-5 in Appendix A1.2.
The Bornholm power system demonstrates that the cost of electricity is dramatically reduced when there is high penetration of wind generation [89]. Consumers may be able to shift loads to periods when wind generation is high, and hence electricity price is low [89]. This will result in the consumer having a reduced electricity bill, but also the grid equipment experiences less demand on its components [89]. Incentivising consumer to actively participate in load shifts for times when renewable generation supply is high will result in less dependency on traditional generators for typical peak times, as loads are being curtailed [89]. Thus decreasing the demand for energy during typically high peak periods and reducing the need for expensive peaking stations [89].

One of the main benefits that Distributed Generation Aggregators provided to the system is more of control and predictability over variable energy resources, which is essential for forecasting purposes [49] [88]. Aggregators of this type are also able to provide system operators with grid support services by offering a mechanism to maintain the balance of electrical supply and demand [88]. The presence of these types of Aggregators in electricity markets also encourages end-consumers to adopt more renewable energy technology, which works towards the goal of decreasing carbon emissions but can also reduce the need for grid expansion [49] [88]. However, much of the research determines that the benefits that can be experienced by DG Aggregators depend on the geographical location of the sources in regards to environmental conditions; the sources proximity to congestion points along the grid; the time in which the source is able to generate power; the aggregators’ level of control over the generation sources; the accumulative size of the portfolio; and the supporting policies and standards in the market [88]. Some of the possible negative effects that a Distributed Generation Aggregator can have on the power system include: the fact that higher penetrations of aggregators could displace a large portion of traditional ‘dispatchable’ supply due to their lower marginal costs; and forecast errors in aggregator systems can cause volatile markets where it is difficult to predict the outcome [84].
3.4 Aggregator of Electric Vehicles (V2G)

Electric vehicles (EV) are designed to have continuously fluctuating loads due to the nature of their operation which inherently means that they can ‘ramp-up’ and ‘ramp-down’ at high rates and quick response times [45]. Furthermore, EVs by design can connect and disconnect from the grid for charging purposes [45]. Aggregators who wish to engage with owners of electric vehicles for the purpose of capitalising of their available power and storage abilities are known as Vehicle-to-Grid (V2G) Aggregators [90]. 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 [90].

These aggregators hope to form a bi-lateral contract with the EV owner, where the aggregator seeks to remotely control the vehicle in return for providing the vehicle owner with some kind of incentive [91]. Additionally, aggregators often agree to replace and maintain the battery of the vehicle as an extra incentive to engage owners and to mitigate social concerns of battery wear and tear [92]. Most research concludes that V2G 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 [90] [93] [94] [39].

The research in [91] discusses the fact that the ancillary service market requires entries to be in the scale MW; hence V2G aggregators seek to control fleets of electric vehicles to this scale to meet market requirements. The article also determines that the aggregator’s main goal is to generate maximum profit while providing a reliable regulation service [91]. Although bulk generating plants can supply cheaper sources of electricity compared to V2G Aggregators, the pricing mechanism of the reserves markets requires payments for ‘standby’ capacity and payments for the ‘actual’ energy dispatched, which enables V2G aggregators to remain competitive [94]. Furthermore, the research discusses the fact that V2G 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 centralised generators [94]. The general operating scenario for a V2G Aggregator would include some kind of bilateral contract between the grid operator that allows the aggregator to participate in the reserves market for frequency regulation in the day-ahead and intraday market [94].

Research in [94] highlights the fact that aggregators of V2G must provide EV owners with the functions that allow them to participate in the reserves market effectively. These functions include: 1) A mechanism that enables bidirectional power to flow; 2) the appropriate control system which will enable the vehicle to be remotely controlled and communicated to in real-time; and 3) on-board precise metering abilities for billing purposes [94]. The study conducted in [95], demonstrates the development of a successful system for electric vehicles that enables V2G capability via an aggregator. The system includes the use of an onboard GPS tracking system which allows the aggregator to know the location of the vehicle which is necessary for dispatch coordination purposes [95]. A power system developed by AC Propulsions Inc. is used which costs approximately US$400 and allows excessive control of the vehicles battery and also enables bi-directional power flow [94]. This allows the vehicle to inject and draw power from the grid thereby allowing the vehicle to participate in both regulation up and down services [94]. A power chip from Analog Devices is used for the purpose of on-board metering which accurately measures the power flow of the EV due to signals communicated by the aggregator [94]. This device had the estimated purchase and installation cost of US$50. For effective communication abilities that allow the aggregator to control the power flow of the vehicle remotely, the research article discussed the use of a wireless communication system which had an incremental cost of US$100. The combination of these technical components is often referred to as the vehicle’s Battery Management System (BMS) which represents a critical technical component and expense for V2G aggregators [90].

Research depicted in [96] discusses various political and social concerns surrounding the concept of V2G. The study details the concept of ‘range anxiety’, which refers to vehicle
owners’ fears that their car battery may run out before they can reach their destination [96]. This fear is said to represent quite a large social concern and hence accounts for a large market barrier [96]. The research demonstrated in [97] however, was able to mitigate this risk through the use of graphical user interface which forces owners to enter travel details upon the entering and start-up of their vehicle. The information entered into the GUI, is communicated to the vehicle’s Battery Management System (BMS) and ensures that the battery is always able to complete the owners travel journey [97]. Hence V2G Aggregators should view this technical component as a critical installation. The aggregator does not directly communicate to the electric vehicle, instead, the electric vehicle supply equipment (EVSE) or charging station, acts as the interface and gateway between the BMS and the aggregator [90].

The study in [98] pays particular attention to the standardisation of protocols and communication interfaces, as they represent the largest market barrier. The authors place special emphasis on the International Organization for Standardization/ International Electrotechnical Commission (ISO/IEC) 15118 standard and its evolution (See Appendix A.1.3, Table 6-9 for other relevant standards) [98]. This standard details the communication requirements between the electrical vehicle supply equipment (EVSE) and the vehicle itself [98]. The standard describes the use of power line carriers (PLC) to communicate signals between the charging station and the vehicles battery management system [98]. The research depicted in [97] goes into high levels of detail of how to accomplish this type of communication, and also suggests that wireless technology such as Zigbee devices can be used to communicate data between the EVSE and the vehicle.

The results from a V2G pilot project conducted in [96] used a fleet of 100 Th!nk City electric vehicles in the U.S California ISO (CAISO) regulation market over a period of 3 years. The results demonstrated that an aggregated V2G fleet had the potential to generate an annual net profit value of US$150,000 to US$ 2.1 million in the ancillary services market by providing both regulation up and down services [96]. This article also discussed some of the technical constraints experienced by the project which included the cars rated power capacity, the
vehicles’ actual grid connection location in regards to the maximum power rating of the grid cables and charging station, as well as the batteries’ state of charge [96].

The V2G simulation in [99] demonstrates how aggregators of V2G can participate in the reserves market and can help to effectively mitigate the variations in supply and demand caused by renewable energy technology. The research lays emphasis on the Aggregators need to be able to co-orderate the vehicles effectively across large areas and at times stagger their dispatch signals to prevent large grid variations [99]. The research simulates a typical U.S reserve market, where it was found that V2G aggregators were able to provide competitive pricing for reserve generation against traditional reserve generators, however, this was determined to be entirely dependent on the market environment and the associated operating costs of participants [99].

Research conducted by the University of Delaware in [100] focused on simulating and testing the capabilities of a V2G aggregator. The study used a variety of different electric vehicles and tested their potential for earnings on the CAISO ancillary market for regulation services [100]. The results of the study can be seen in Appendix A.1.3 in Table 6-6 and Table 6-7.

[100]. The research also discussed that the significant barriers hindering the integration of V2G capability into electricity markets included: the lack of standards in regards to communication interfaces and protocols; the lack of appropriate charging infrastructure; the cost of current technology; the lack of effective remuneration schemes for V2G participation (Table 6-8 in Appendix A.1.3 highlights some existing government incentive schemes for purchasing EVs); and the task of having to educate and engage owners of electric vehicles [100].
Chapter 4  Methodology

This section seeks to outline the methods and analytical tools used to complete the project objectives. As this is a research-based honours thesis project, finding multiple international energy aggregator case studies plays a key factor in the ‘methodology’ of this thesis project, hence it should also be noted as its limiting factor. The background information and literature review in this report represents the qualitative pool of information that was reviewed, analysed and used to complete the project objectives. Please note that case examples used and relevant information regarding aggregators can be found in Appendix A.

To clearly outline the structure of each aggregator, a Political, Economic, Social and Technical (PEST) analysis framework was used to highlight those aspects of a business operation [101]. Each aggregator will have the political and economic considerations outlined which will demonstrate the general market environment and seek to highlight the economic transactions of each aggregator type. The types of end-consumers the aggregator aims to engage with will be illustrated in the social considerations, followed by the technical components required for engaging an end-consumer. Each structural consideration of the aggregator will be outlined using simple tables and diagrams which seek to illustrate the findings from the background and literature review in a clear and precise manner.

To clearly identify the advantages and disadvantages of each aggregator a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis framework was used, which seeks to highlight the internal ‘strengths’ and ‘weaknesses’ of a business, but also the external ‘threats’ and ‘opportunities’ [102]. For ease of reading, the results will be presented in a typical SWOT analysis framework fashion.
A comparison matrix was also used to compare the potential investment requirements that might be needed for the integration of each aggregator. The comparison is a qualitative representation that takes into account the level of supporting technology, standards and legislation, existing infrastructure and the level of social acceptance associated with each aggregator type. This matrix seeks to illustrate the overall investment advantage and disadvantages associated with each aggregator by comparing them relatively against each other (please see Appendix B.1 for a more detailed explanation).

Finally, to determine the value each aggregator was able to add to the power system overall, Porter’s Value Chain analysis was used see Figure 4.1 below. Porter’s Value Chain analysis is a business framework used to outline an operations supply chain that is made up of ‘primary activities’ [103]. These primary activities include: the operation (power generation in bulk); inbound/outbound logistics (transmission and distribution); marketing and sales (electricity retailers); and the service provided (electricity supplied to end-consumers) [4] [103]. The ‘support activities’ of the framework include the ‘procurement’ of resources for the business, ‘human resource management’, the ‘technological development’ and the businesses ‘infrastructure’ [103]. This framework seeks to outline the ‘primary’ activities of a business operation to see where the ‘supporting’ activities can be used to enhance a particular primary activity [103].
In this project, ‘procurement’ relates to an aggregator’s ability to add value to the system by providing sources of generation or capacity that are able to compete against traditional generating plants. ‘Human resource management’ relates to the aggregator’s ability to add value to the system by providing valuable information regarding the energy consumption and behaviour of end-consumers which can be used for load forecasting. ‘Technology development’ refers to an aggregator’s ability to provide new products that actively engage end-consumers and facilitate their integration. Finally, infrastructure relates to an aggregator’s ability to provide useful services that enhance the quality and reliability of the grid. This framework will be used to assess the energy aggregator’s ability to add value to the overall power system, by evaluating the qualitative value of support activities an aggregator can provide. A detailed explanation of this analysis can be viewed in Appendix B.2

**Figure 4.1: Porter’s Value Chain Analysis Framework**

![Porter’s Value Chain Analysis Framework](image)

[103].
Chapter 5   Results

5.1   Energy Aggregator Structures- PEST Analysis

5.1.1   Demand Response Aggregator

5.1.1.1   Political and Economic

As previously discussed demand response aggregators are able to participate in both ancillary and capacity markets. Figure 5.1 below illustrates the typical interactions experienced by energy market participants. In these markets the system operator opens up an auction in the day-ahead market (forward market), with the purpose of securing the future energy needs of a particular region. Traditional power generating plants and aggregators of demand response bid their available capacities into the market, where the most economically viable bid is selected by the system operator. As mentioned before aggregators of demand response provide a cost effective method for providing system capacity and are often able to outbid their competitors. Once the winning bid has been decided a bilateral contract is formed between the system operator and the relevant capacity provider. This bilateral contract involves the system operator offering an agreed payment to the winning bid for providing ‘standby’ energy capacity whether it is used or not and then an additional payment for the capacity actually used. If the winning bid fails to comply with the specified capacity when called upon by the system operator, major penalties occur.

Demand response aggregators also have the ability to participate in real-time energy markets through the use of demand-side bidding. Figure 5.2 illustrates the interactions experienced in these types of markets, where the system operator opens up a spot market auction in order to fulfil the immediate energy needs of a given region. Energy participants bid their immediate available capacity into the auction, and the winning bid is paid the markets clearing price and is required to provide capacity within a short amount of time. Figure 2.1 also illustrates the general overall transactions between a demand response aggregator, system operator, end-consumer and retailer.
Figure 5.1: Market Action for a Demand Response Aggregator with an Incentive-Based Remuneration Scheme for End-Consumers

- **System Operator**: Opens auction in order to find required system capacity.
- **Demand Response Aggregator**: Bids load curtailment capacity.
- **Auction for System Capacity**: If DR Aggregator is successful.
- **Bilateral Contract**: Specified Load Curtailment
  - System Operator pays for available ‘standby’ capacity.
  - Demand Response Aggregator pays for ‘actual’ dispatched capacity.
**Figure 5.2: Market Action for Demand Response Aggregator with Time-Based Remuneration for End-Consumers**

- **Energy Market**
  - Demand-Side Bidding
    - **Market Auction**
      - If DR Aggregator is successful
      - **Intraday Day-Ahead**
        - **Specified Load Curtailment**
          - System Operator
          - Demand Response Aggregator
            - Pays market clearing price

- **Possible Market Transactions**
  - **Demand Response Aggregator**
    - Capacity Procurement
    - System Reliability
    - Portfolio Balancing
  - **Electricity Retailer**
  - **System Operator**
  - **Participating End-Consumers**

- **Bilateral Contract**
- **Reward for Participation**

**Overview**
- **Energy Market**:
  - **Demand-Side Bidding**
  - **Market Auction**
    - **Intraday Day-Ahead**
    - **Specified Load Curtailment**
      - System Operator
      - Demand Response Aggregator
        - Pays market clearing price

**Details**
- **System Operator**
- **Demand Response Aggregator**
- **Possible Market Transactions**
- **Bilateral Contract**
- **Reward for Participation**
5.1.1.2 Social

Figure 5.3 below simply illustrates the various types of end-consumers that aggregators of demand response seek to engage with, as well as the types of loads and appliances that are available for demand response purposes.

Figure 5.3: Potential Participants for a Demand Response Aggregator

- HVAC
- Lighting
- Cold Storage
- Back-up generators
- Operational processes

- HVAC
- Lighting
- Pool pumps
- Refrigeration Systems
- Hot water heating

- HVAC
- Lighting
- Pool pumps
- Refrigeration
- Washing Machines
- Clothes Dryers
- Hot water heating systems
- Controllable appliances
5.1.1.3 Technical

Table 5-1 below highlights all of the possible technical components, devices, and standards/protocols needed for a demand response aggregator to engage successfully with its desired end-consumers.

<table>
<thead>
<tr>
<th>Components</th>
<th>Technology</th>
<th>Available Communication Device</th>
<th>Compatible Communication Protocol/ Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access Point/ Gateway</td>
<td>Smart Meter &amp; Interval Meter</td>
<td>RF Mesh network (Common in Residential)</td>
<td>ZigBee, 6LowPan, Bluetooth, IEEE 802.15x, WiFi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PLC (Common in Commercial Buildings)</td>
<td>HomePlug, Narrowband, X10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wireless Star Network (Common in Rural Areas)</td>
<td>GMS/EDGE,LTE</td>
</tr>
<tr>
<td>Communication Module</td>
<td>Wireless</td>
<td>WiFi</td>
<td>IEEE 802.11x</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bluetooth</td>
<td>IEEE 802.15.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZigBee</td>
<td>ZigBee, ZigBee Pro, IEEE 802.15.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cellular</td>
<td>GSM/GPRS/EDGE</td>
</tr>
<tr>
<td></td>
<td>Wired</td>
<td>RFID</td>
<td>IEEE 1451, IEEE 802.11, XBee</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WirelessHART</td>
<td>IEE 802.15.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6LoWPAN</td>
<td>IEE 802.15.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z-Wave</td>
<td>Z-Wave, 802.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Xbee</td>
<td>ZigBee, IEEE 802.15.4, WiFi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power Line Carriers (PLC)</td>
<td>HomePlug, Narrowband, X10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ethernet</td>
<td>IEEE 802.3x, BACnet</td>
</tr>
<tr>
<td>Component</td>
<td>Technology</td>
<td>Available Communication Device</td>
<td>Compatible Communication Protocol/ Standard</td>
</tr>
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<td>---------------------------------------------</td>
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<tr>
<td><strong>Sensors</strong></td>
<td></td>
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<tr>
<td>Light Sensors</td>
<td></td>
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<td></td>
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<tr>
<td>Temperature Sensors</td>
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<td></td>
<td></td>
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<tr>
<td>Humidity Sensors</td>
<td></td>
<td></td>
<td>See Above</td>
</tr>
<tr>
<td>Voltage and Current Sensors</td>
<td></td>
<td>ZincBee, WiFi, Z-Wave, 6LoWPAN, Serial, Xbee, BACnet, WirelessHART</td>
<td></td>
</tr>
<tr>
<td>Motion Sensors</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Local Controller</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arduino</td>
<td>WiFi, Bluetooth, Xbee, ZigBee, Serial, X10, Cellular</td>
<td>See Above</td>
<td></td>
</tr>
<tr>
<td>Banana Pi</td>
<td>ZigBee, Bluetooth, WiFi, Serial, Cellular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BeagleBone Black</td>
<td>Serial, PLC, Ethernet, Bluetooth, Cellular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rasberry Pi</td>
<td>Cellular, Z-Wave, Ethernet, Serial, WiFi, ZigBee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPGA</td>
<td>Serial, Bluetooth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intelligent Thermostat</td>
<td>ZigBee, Bluetooth, WiFi, Z-Wave, Cellular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic Relay Circuits</td>
<td></td>
<td>Serial</td>
<td></td>
</tr>
<tr>
<td><strong>Graphical User Interface (GUI)</strong></td>
<td></td>
<td>Home Energy Display Smart meter, Tablet, Stand-alone devices</td>
<td>N/A</td>
</tr>
<tr>
<td>Web</td>
<td>Laptop, Desktop, Smartphone</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.1.2 Distributed Generation Aggregator

5.1.2.1 Political and Economic

Distributed generation aggregators are also able to participate in real-time energy markets through the use of demand side bidding. Figure 5.4 below illustrates the market action typically experienced in these circumstances, where a system operator will open a spot market auction in order to reduce high electricity prices or to fulfil the immediate needs of a particular region. Sometimes the auction can be held for the day-ahead market as well, however energy participants would have to guarantee their availability. In this case an aggregator of distributed energy would bid the surplus energy generated by its end-consumers as a whole, into the market and if successful would provide the system operator with a specified surplus generation (which may be discharged from an energy storage system controlled by the aggregator) in return for being paid the markets clearing price.

Figure 5.5 below highlights other possible market transactions that may occur, where the aggregator can also negotiate better feed-in tariffs with a utility provider in exchange for guaranteed/specified energy generation. Furthermore, the figure illustrates a general overview of all the possible market transactions between participants which have been previously discussed in the literature review.
Figure 5.4: Market Action for a Distributed Generation Aggregator

Energy Market

Demand-Side Bidding

Opens auction in order reduce wholesale price of electricity or for system supply

Spot Market Auction

Bids Surplus Energy into market

Intraday

Day-Ahead

Specified Generation Supply

System Operator

Pays market clearing price

Distributed Generation Aggregator

Pays market clearing price
Figure 5.5: Types of Market Transactions for Distributed Generation Aggregator

Possible Market Transactions

Negotiate Feed-In Tariff

Utility Provider

Bilateral Contract

Distributed Generation Aggregator

Specified Generation & Forecasts

Provides better Feed-in Tariff

Distributed Generation Aggregator

Power Purchase Agreement

Bilateral Contract

System Operator

Retailer

Generation Procurement

Capacity Procurement

Response to Economic Signals

Bilateral Contract

Participating End-Consumers

Lowest Price Guarantee
5.1.2.2 Social

Figure 5.6 below highlights the types of end-consumers and the renewable energy technology, that an aggregator of distributed energy would seek to engage with.

**Figure 5.6: Potential End-Consumers for Distributed Generation Aggregators**

- Industrial End-Consumer
  - Solar PV Systems
  - Micro Turbines
  - Wind Turbines
  - Back-up generators
  - Biomass
  - Hydro

- Commercial End-Consumer
  - Solar PV Systems
  - Micro Turbines
  - Wind Turbines
  - Back-up generators
  - Biomass

- Residential End-Consumer
  - Solar PV Systems
  - Micro Turbines
  - Wind Turbines
  - Biomass
5.1.2.3 Technical

Table 5-2 below highlights all of the possible technical components, devices, and standards/protocols needed for a distributed generation aggregator to engage successfully with its desired end-consumers.

Table 5-2: Technical Components of a Distributed Generation Aggregator

<table>
<thead>
<tr>
<th>Component</th>
<th>Device</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Management System</td>
<td>Source Controller</td>
<td>Smart Inverter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Banana Pi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BeagleBone Black</td>
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<td></td>
<td>Rasberry Pi</td>
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<td></td>
<td></td>
<td>FPGA</td>
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<td></td>
<td>Arduino</td>
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<tr>
<td></td>
<td></td>
<td>Electronic Relay Circuits</td>
</tr>
<tr>
<td></td>
<td>Central Controller</td>
<td>iControl</td>
</tr>
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<td></td>
<td></td>
<td>General Electric Brillion Technology</td>
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<td></td>
<td></td>
<td>Honewell Control Systems</td>
</tr>
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<td></td>
<td></td>
<td>Control4Home</td>
</tr>
<tr>
<td>Generation Sources</td>
<td>Solar PV Systems</td>
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<tr>
<td></td>
<td>Wind Turbines</td>
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<tr>
<td></td>
<td>Micro Turbines</td>
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<td></td>
<td>Biomass</td>
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<tr>
<td></td>
<td>Hydro</td>
<td></td>
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<tr>
<td>Storage Systems</td>
<td>Battery Systems</td>
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<tr>
<td></td>
<td>HVAC, Cold Storage</td>
<td></td>
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<tr>
<td></td>
<td>Electric Vehicles</td>
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<tr>
<td></td>
<td>Battery Management Systems</td>
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<tr>
<td>Data Management Systems</td>
<td>Sensors</td>
<td>Radiation Sensors</td>
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<td>Temperature Sensors</td>
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<td></td>
<td></td>
<td>Voltage Sensors</td>
</tr>
</tbody>
</table>
5.1.3 Vehicle-to-Grid Aggregator

5.1.3.1 Political and Economic

Aggregators of vehicle-to-grid are able to participate in ancillary services and capacity markets, where the system operator opens a forward market auction in order to secure the reliability of the grid for future needs. The operator specifies a needed capacity (reserves) and energy participants bid their availability. If a vehicle-to-grid aggregator is successful in winning the bid, a bilateral contract is formed between the system operator and aggregator, where the operator pays the aggregator for its standby capacity. The operator must then also pay the aggregator additionally for its regulation up or down service when its actually needed. See Figure 5.7 below.

Figure 5.8 below also illustrates the general overview of various market transactions between all of the relevant parties in a vehicle-to-grid setting which has been previously discussed in the literature review.
System Operator

Opens auction in order to find required system capacity

Day-Ahead Market (Forward Market)

Auction for System Capacity

Bids load curtailment capacity

If DR Aggregator is successful

Bilateral Contract

Frequency Regulation (Up/Down)

System Operator

Pays for available ‘standby’ capacity

V2G Aggregator

Pays for ‘actual’ dispatched capacity

Figure 5.7: Market Action for a Vehicle-to-Grid Aggregator
Figure 5.8: Types of Market Transactions for Vehicle-to-Grid Aggregator

Possible Market Transactions

Vehicle-to-Grid Aggregator

Response to Economic Signals

Capacity Reserves

Frequency Regulation

System Operator

Provides Rewards and Incentives

Replaces Battery

Participating End-Consumers

Bilateral Contract

Possible Market Transactions

Bilateral Contract
5.1.3.2 Social

Figure 5.9 below illustrates the various types of electric vehicle fleets that an aggregator may seek to control for the purpose of providing services to system operators.

Figure 5.9: Electric Vehicle Fleets that V2G Aggregators Seek to Control

5.1.3.3 Technical

Table 5-1 below highlights all of the possible technical components, devices, and standards/protocols needed for a distributed generation aggregator to engage successfully with its desired end-consumers.

Table 5-3: Technical Components of a Vehicle-to-Grid Aggregator

<table>
<thead>
<tr>
<th>Component</th>
<th>Device</th>
<th>Purpose</th>
<th>Protocols/ Standard (if Applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>On-Board Communication Modules</strong></td>
<td>Cellular/Radio Devices, controllers and wireless modems (Telematics)</td>
<td>Method for communicating various control signals to EV owner</td>
<td>GPRS, SMS, GPS</td>
</tr>
<tr>
<td>Electric Vehicle Supply Equipment (EVSE)</td>
<td>AC Charging</td>
<td>AC Level 1</td>
<td>SAE J2836</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>-------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AC Level 2</td>
<td>ISO/IEC 15118</td>
</tr>
<tr>
<td></td>
<td>DC Charging</td>
<td>DC Level 1</td>
<td>IEC 62196-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DC Level 2</td>
<td>IEC 61851</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DC Level 3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On-Board Metering</th>
<th>Analog Devices Inc. Smart Meters</th>
<th>Metering of electrical flow for billing purposes</th>
<th>IEC 61851</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>IEC 15118</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bi-Directional Power Flow</th>
<th>AC Propulsions Bi-directional DC-DC converters</th>
<th>Enables the EV to act as both 'sink' and 'source' of energy</th>
<th>SAE J2293</th>
</tr>
</thead>
</table>

5.2 Advantages and Disadvantages of Energy Aggregators – SWOT Analysis

The following section highlights the internal strengths, weaknesses and external opportunities and threats of each of the aggregators, derived from the literature review.
## 5.2.1 Demand Response Aggregator

### STRENGTHS

| S1 | Incremental cost for enabling industrial and commercial consumers is low |
| S2 | Advances in ICT has reduced the cost of technology and has expanded the range of loads and appliances that can be used for DR |
| S3 | Activating large amount of residential DR diversifies the portfolio and helps to mitigate risk |
| S4 | DR Aggregators have lower operating & maintenance costs than traditional peaking stations, & can therefore offer competitive pricing |
| S5 | DR Aggregators provide a capacity resource that offers minimal carbon footprint |

### WEAKNESSES

| W1 | Incremental costs for enabling residential end-consumer is high |
| W2 | Highly skilled technical staff are necessary but represent a high business cost |
| W3 | End-consumers can experience discomfort from having to change their consumption patterns |
| W4 | End-consumer preference behaviour greatly effects available profits |
| W5 | Market membership and start-up fees represent high initial & on-going costs |
| W6 | Residential consumer awareness of dynamic electricity price is relatively low, thus effective marketing engagement is needed |

### OPPORTUNITIES

| O1 | Aggregators can capitalise on economies of scale with government technology roll-outs |
| O2 | Provide flexible capacity that is able to help integrate the intermittent nature of renewable energy technology |
| O3 | Provide retailers with risk hedging mechanism via portfolio optimisation |
| O4 | Provide system capacity that can displace traditional generation & costly peaking plants |
| O5 | Lower the cost of energy delivery |
| O6 | Offer peak load services to system operators to maintain grid reliability |
| O7 | Provides better forecasting mechanisms for system operators by integrating end-consumer technology and load behaviour |
| O8 | Capitalise on consumer concern of increasing electricity prices |
| O9 | Provide cost-effective method for system operators to avoid costly grid expansion |

### THREATS

| T1 | Lack of smart meter communication standards can minimise potential for economies of scale & scope but also create data ownership risks |
| T2 | Lack of standard market participation rules creates unfair advantages & can restrict potential profit |
| T3 | Lack of standardised methods for end-consumer remuneration can create social uncertainty |
| T4 | Lack of standard government policies and the existence of contradicting policies creates uncertain business environments which could result |
| T5 | End-consumers may be concerned over the viewing and exchange of their electrical consumption data to external market participants. |
## 5.2.2 Distributed Generation Aggregator

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1- DG Aggregators tend to have low incremental costs for engaging end-consumers</td>
<td>W1- DG Aggregators are relatively new, thus must establish a reliable reputation in order to effectively engage with the market, which can incur high marketing costs</td>
</tr>
<tr>
<td>S2- Renewable generation technology has low operation and maintenance which reduces marginal costs</td>
<td>W2- Highly skilled technical staff are necessary but represent a high business cost</td>
</tr>
<tr>
<td>S3- Government policies on carbon footprint and incentives, encourage end-consumers to adopt renewable energy technology, which provides DG Aggregators with more potential profit</td>
<td>W3- Current forecasting models are likely to incur errors which effect contractual obligations</td>
</tr>
<tr>
<td>S4- Guarantee lowest electricity rates to participating end-consumers</td>
<td>W4- The geographical location of the DG sources greatly effects their power output (i.e. weather conditions) and hence their potential profit</td>
</tr>
<tr>
<td>S5- Social acceptance for renewable generation technology is relatively high</td>
<td>W5- Market membership and start-up fees represent high initial &amp; on-going costs</td>
</tr>
<tr>
<td>S7- DG Aggregators can offer more cost effective pricing schemes for generation supply compared to traditional generation plants due to their lower marginal and operational costs.</td>
<td>W6- Potential profit earnings is severely limited by the Feed-In tariff of the market.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPPORTUNITIES</th>
<th>THREATS</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1- DG Aggregators can capitalise on economies of scale with government technology roll-outs</td>
<td>T1- Only a few markets support ‘demand side bidding’ for DG Aggregators, hence there is a lack of available markets but also the markets are inadequately designed</td>
</tr>
<tr>
<td>O2- DG Aggregators can offer generation procurement services to system operators and electricity retailers</td>
<td>T2- Lack of standard market participation rules creates unfair advantages &amp; can restrict potential profit but also incur hidden tariff fees in some cases</td>
</tr>
<tr>
<td>O3- DG Aggregators’ control over variable generation sources provides system operators with better forecasting mechanisms</td>
<td>T3- Government standards and policies have been developed off of the traditional power system, and hence do not effectively integrate distributed generation sources into the system</td>
</tr>
<tr>
<td>O4- Provide system capacity that can displace traditional generation &amp; costly peaking plants</td>
<td>T5- Large penetrations of DG Aggregators may displace large amounts of dispatchable generation sources from energy markets</td>
</tr>
<tr>
<td>O5- Lower the cost of electricity prices</td>
<td>T6- Large scales of DG Aggregators may result in large grid congestion during high generation times.</td>
</tr>
<tr>
<td>O6- Are able to negotiate better Feed-In tariffs for end-consumers</td>
<td></td>
</tr>
<tr>
<td>O7- Provides better forecasting mechanisms for system operators and integrates end-consumer technology</td>
<td></td>
</tr>
<tr>
<td>O8- Capitalise on the growing environmental awareness of consumers.</td>
<td></td>
</tr>
</tbody>
</table>
## 5.2.3 Vehicle-to-Grid Aggregator

### STRENGTHS

<table>
<thead>
<tr>
<th>S1</th>
<th>Incremental costs for enabling battery-only vehicles with bi-directional power flow is relatively low</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2</td>
<td>EVs have fast response times and high power capacities which provides V2G Aggregators with a competitive advantage over slower responding generators and peaking plants</td>
</tr>
<tr>
<td>S3</td>
<td>The manufacturing costs of ICT and battery technology is decreasing, which provides V2G aggregators with more opportunity to capitalise on the available technology.</td>
</tr>
</tbody>
</table>

### WEAKNESSES

<table>
<thead>
<tr>
<th>W1</th>
<th>Hybrid and fuel cell electric vehicle have significantly higher capital costs associated with making them V2G capable</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2</td>
<td>Social acceptance for V2G Aggregators is extremely low, hence high investment costs are needed for effective marketing strategies</td>
</tr>
<tr>
<td>W3</td>
<td>Existing infrastructure for V2G capability (i.e.: charging stations in workplaces, public parking and residential areas) is very limited</td>
</tr>
<tr>
<td>W4</td>
<td>Market membership and start-up fees represent high initial &amp; on-going costs</td>
</tr>
<tr>
<td>W5</td>
<td>The available power capacity that a V2G vehicle is able to supply is limited by the charging station it's connected to, the battery state of charge and the vehicle owners travel requirements.</td>
</tr>
</tbody>
</table>

### OPPORTUNITIES

<table>
<thead>
<tr>
<th>O1</th>
<th>V2G Aggregators can provide regulation services for system operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>O2</td>
<td>V2G aggregators can provide the power system with flexible storage provisions that are able to mitigate the hourly variations of intermittent technology due to their fast response times</td>
</tr>
<tr>
<td>O3</td>
<td>Provide system operators with effective methods for peak load shedding or capacity supply</td>
</tr>
<tr>
<td>O3</td>
<td>Governments are incentivising end-consumers to adopt electric vehicles, which provides V2G aggregators with an economic leverage</td>
</tr>
<tr>
<td>O4</td>
<td>Provide system capacity that can displace traditional generation, costly peaking plants and reduce the need for grid expansion</td>
</tr>
<tr>
<td>O5</td>
<td>Lower the cost of electricity prices</td>
</tr>
<tr>
<td>O7</td>
<td>V2G Aggregators provide forecasting and control mechanisms for an end-consumer technology that is set to rapidly increase over the next year and on a mass scale can cause grid variations if not coordinated.</td>
</tr>
</tbody>
</table>

### THREATS

<table>
<thead>
<tr>
<th>T1</th>
<th>There is a serious lack of standards for communication interfaces and protocols between charging stations, electric vehicles and market participants, which creates market uncertainty, prevents entrants and diminishes economies of scale &amp; scope.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>There is a lack of appropriate market remuneration designs for V2G, as the current tariff structure for many electricity markets does not appropriately reflect the benefits provided from V2G and is instead reflective of renewable distribution benefits (which is intermittent, whereas V2G is predictable and dispatchable).</td>
</tr>
<tr>
<td>T3</td>
<td>Current market designs, rules and policies do not effectively allow the participation and integration of V2G Aggregators as they are still in the pilot project stage. Hence there is much political and regulatory uncertainty which represents a very large market barrier.</td>
</tr>
<tr>
<td>T4</td>
<td>V2G infrastructure on a large scale requires high capital expenditure and investment.</td>
</tr>
</tbody>
</table>
5.3 Potential Investment Requirements for Energy Aggregator Types

The results demonstrated in Figure 5.10 below represent the potential investment requirements needed for each aggregator type. The results portray the potential investment needed for an aggregator by the ‘size’ of the circle (see Appendix B.1 for marking criteria). It should be noted that for this particular analysis the Demand Response Aggregator was split into two categories. This is because there is quite a significant difference between the investments needed to engage a residential consumer with demand response capability compared to that of an industrial/commercial end-consumer.

It can be seen from this comparative analysis that a Vehicle-to-Grid Aggregator has the highest investment requirements, and the Demand Response Aggregator who engages with industrial and commercial end-consumer has the smallest potential investment requirement.

Figure 5.10: Potential Investment Requirements for Energy Aggregators
5.4 Value Added to the Power System by Energy Aggregators

5.4.1 Power System Supply Chain with Aggregator Integration

The results demonstrated in Table 5.4 below, comparatively illustrate the qualitative ‘value’ that each aggregator can add to the overall power system by providing a support activity to the primary activity of the supply chain. Please see Appendix B.2 for a detailed explanation of how these results were determined.

The results illustrate the amount of ‘value’ added to the system by the ‘size’ of the circle, i.e. the larger the circle, the larger the added value. The results demonstrate that the DR Aggregator and the DG Aggregator offer the power system the greatest value for providing ‘procurement’ services in regards to adding more generation or capacity to the system. Although it can be seen that DG Aggregators are the only ones available to provide this service for bulk generation purposes. DR Aggregators can be seen to add the most value to the system in regards to ‘technology development’ that can effectively engage end-consumers and facilitate their integration. They are able to provide this value for the transmission, distribution and retail activities, although it can be seen that DG Aggregators are the only aggregators that can engage with end-consumers for large scale generation purposes.

Again it can be seen that DR Aggregators can provide the power system with the greatest ‘value’ in regards to services that support and enhance the reliability and quality of the grid infrastructure (i.e. firm infrastructure). DR Aggregators can be seen to also provide the most value to the system in regards to offering relevant and useful information about end-consumer consumption behaviour (i.e. human resource management), which can then be used for effective load forecasting and demand predictions by all market participants. V2G aggregators in this regard also add significant value to consumer load forecasting due to their dispatch coordination abilities for charging large fleets of EVs.
Table 5-4: Qualitative 'Value' Added by Aggregator Support Activities to the Overall Supply Chain of the Power System

<table>
<thead>
<tr>
<th></th>
<th>Generation</th>
<th>Transmission</th>
<th>Distribution</th>
<th>Retail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Procurement</strong></td>
<td><img src="image" alt="Procurement" /></td>
<td><img src="image" alt="Procurement" /></td>
<td><img src="image" alt="Procurement" /></td>
<td><img src="image" alt="Procurement" /></td>
</tr>
<tr>
<td>(providing sources of generation that is competitive against traditional sources)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Technology Development</strong></td>
<td><img src="image" alt="Technology Development" /></td>
<td><img src="image" alt="Technology Development" /></td>
<td><img src="image" alt="Technology Development" /></td>
<td><img src="image" alt="Technology Development" /></td>
</tr>
<tr>
<td>(new products that facilitate consumer integration)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Firm Infrastructure</strong></td>
<td><img src="image" alt="Firm Infrastructure" /></td>
<td><img src="image" alt="Firm Infrastructure" /></td>
<td><img src="image" alt="Firm Infrastructure" /></td>
<td><img src="image" alt="Firm Infrastructure" /></td>
</tr>
<tr>
<td>(Increase the reliability of the grid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Human Resource Management</strong></td>
<td><img src="image" alt="Human Resource Management" /></td>
<td><img src="image" alt="Human Resource Management" /></td>
<td><img src="image" alt="Human Resource Management" /></td>
<td><img src="image" alt="Human Resource Management" /></td>
</tr>
<tr>
<td>(provide end-consumer load forecasting)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Distributed Generation Aggregator
Demand Response Aggregator
V2G Aggregator
Chapter 6 Conclusion and Recommendations

This research identified that the main energy aggregators existing internationally are Demand Response Aggregators, Distributed Generation Aggregators, and Vehicle-to-Grid Aggregators. The structure of each energy aggregator was clearly identified and illustrated using a PEST analysis framework and the associated advantages and disadvantages were highlighted using a SWOT analysis framework. The background information and literature review demonstrated the qualitative pool of information used to achieve these thesis objectives; in addition, Appendix A illustrates much of the case studies and information used for this analysis.

The research in this honours thesis evaluated the value added to the power system by these energy aggregators. This research demonstrated that aggregators could provide generation and capacity services that compete with traditional generation plants and are hence able to lower the cost of energy delivery. They also provide valuable services that enhance the reliability of the grid, engage end-consumers and provide system operators with useful information regarding end-consumer consumption behaviour that can be used for load forecasting. Even though the results demonstrated that the Demand Response Aggregator is currently able to provide the most overall ‘value’, the combination of all three aggregators provides all market participants with enhanced services and adds value to the entire power system supply chain.

Essentially aggregators bridge the gap between end-consumers and market participants by integrating end-consumer technology into the power system through the use of advanced information communication technology. This provides system operators with a mechanism for monitoring and control on the low voltage side, which traditionally has not been available. As the power system transforms from a ‘passive’ centralised monopoly to an ‘active’ distributed architecture, bridging the information and technology gap between end-consumers and market participants is essential for maintaining the stability and reliability of the grid, while meeting the
rising energy demand. However, to integrate the full potential of energy aggregators into the power system, the following recommendations should be considered:

- Market rules and policies need to be standardised to facilitate the appropriate participation of energy aggregators in capacity and energy markets and also to mitigate unfair advantages and political risk.

- The communication interfaces and protocols for smart meters and electric vehicle supply equipment need to be reviewed and standardised to mitigate uncertainty and investment risk, while also providing better data security.

- Governments should motivate market participation through economies of scale and scope by providing appropriate technology roll-outs.

- Research should be conducted in regards to optimising the combination of energy aggregators so that a dynamic, flexible and cost-effective asset that provides overall system value can be explored.
Bibliography


[Accessed 5 10 2016].


Appendix A  Aggregator Case Studies and Relevant Information

A.1.1 Demand Response Aggregator

Table 6-1: Case Examples of Demand Response Aggregators for both Incentive-Based and Time-Based Programs

<table>
<thead>
<tr>
<th>Demand Response Program</th>
<th>Incentive-Based: Interruptible load</th>
<th>Time-Based: Time-Of-Use</th>
<th>Mixed: Direct Load Control (DLC) &amp; Peak Time Rebate (PTR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company:</td>
<td>Xcel Energy</td>
<td>Tempo</td>
<td>BG&amp;E</td>
</tr>
<tr>
<td>Load Type:</td>
<td>Event-Based, Discretionary</td>
<td>Event-Based, Discretionary</td>
<td>Event-Based, Discretionary</td>
</tr>
<tr>
<td>Customer Profile:</td>
<td>Large commercial/industrial: must have 300kW available for Load shed</td>
<td>Small Retail</td>
<td>Residential (300,000 participants in 2013)</td>
</tr>
<tr>
<td>Compensation:</td>
<td>US$4-9/kW of agreed curtailable load per month</td>
<td>Customers are offered different rates for electricity instead of a flat rate</td>
<td>PeakRewards Program: DLC of air conditioning Curtail 50% = US$50/year (+ US$50 initial bonus) Curtail 100% = US$ 100/year (+ US$100 initial bonus)</td>
</tr>
</tbody>
</table>

*Smart Energy Rewards Program:*
Customers receive a rebate of $1.25/kWh of reduced consumption
(Peak Time Rebate)

| Customer Communication | Email, Phone, SMS, Control unit | Display Unit, Ripple Control System | Email, Text |

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Table 6-2: Case Studies of Demand Response Aggregators and Dispatchable End-Consumer Loads

<table>
<thead>
<tr>
<th>End-Consumer</th>
<th>Category of Participant</th>
<th>Demand Response Aggregator</th>
<th>Size (MW)</th>
<th>Method</th>
<th>Service</th>
<th>Payment for Participation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WalMart Stores</strong></td>
<td>Commercial</td>
<td>Not public</td>
<td>0.1 - 0.3 per Store</td>
<td>Automatic energy management system responds to pre-programmed strategy.</td>
<td>Emergency-events, Capacity</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>General Services Administration Buildings</strong></td>
<td>Commercial Buildings</td>
<td>Not public</td>
<td>5.916</td>
<td>BEMS for lighting, HVAC, water heater</td>
<td>Time-sensitive pricing, Capacity</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Notes:**
- Higher incentives for customers providing more useful demand response.
- 40% lower electricity prices for participants.
- Customer default is set to “opt-in” to the Smart Energy Rewards program. Hence customers must actively “opt-out” if they do not wish to participate.

[104]
<table>
<thead>
<tr>
<th>Company</th>
<th>Type</th>
<th>Player</th>
<th>Contract Type</th>
<th>Capacity</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Severstal Sparrows Point</strong></td>
<td>Large Industrial</td>
<td>Not public</td>
<td>Curtail</td>
<td>230</td>
<td>Operations at plant, such as shutting down blast furnace, or use behind the meter generation.</td>
</tr>
<tr>
<td><strong>Bridesburg Foundry</strong></td>
<td>Heavy Industrial</td>
<td>EnerNOC</td>
<td>Curtail</td>
<td>0.9</td>
<td>Controls to shut down foundry and furnaces. Time shifting of processes and production.</td>
</tr>
<tr>
<td><strong>Four Seasons Produce</strong></td>
<td>Warehouse for Agricultural Produce</td>
<td>EnerNOC</td>
<td>Load</td>
<td>1.0</td>
<td>Load shifting refrigeration systems. Load Response/shift, Reserve Market, Capacity</td>
</tr>
<tr>
<td><strong>Defense Logistics Agency Energy</strong></td>
<td>Government Military Sites</td>
<td>Viridity</td>
<td>Curtail</td>
<td>160</td>
<td>BEMS, HVAC optimisation, generator dispatch and leveraging ice storage. Demand response / Load Curtailment, Capacity</td>
</tr>
<tr>
<td><strong>Sinai Hospital</strong></td>
<td>Institutional</td>
<td>Converge</td>
<td>Curtail</td>
<td>2.2</td>
<td>Curtailment and backup generation.</td>
</tr>
<tr>
<td><strong>U.S. Department of Agriculture</strong></td>
<td>Agriculture</td>
<td>Energy Connect</td>
<td>Curtail</td>
<td>1</td>
<td>Capacity</td>
</tr>
<tr>
<td><strong>Bryn Mawr College</strong></td>
<td>Institutional</td>
<td>Energy Connect</td>
<td>1</td>
<td>BEMS for HVAC, lighting, refrigeration</td>
<td>Capacity, Load Curtailment, Time-Sensitive Pricing</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------</td>
<td>----------------</td>
<td>---</td>
<td>--------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td><strong>Berkshire Health Systems</strong></td>
<td>Institutional</td>
<td>EnerNOC</td>
<td>1.3</td>
<td>BEMS for HVAC, lighting</td>
<td>Capacity, Load Curtailment, Time-Sensitive Pricing</td>
</tr>
<tr>
<td><strong>Cabot Creamery</strong></td>
<td>Agriculture/Industrial</td>
<td>EnerNOC</td>
<td>1</td>
<td>Curtailment. Cabot shuts down large refrigeration and ice-making machinery within its manufacturing facilities.</td>
<td>Load Curtailment, Time-Sensitive Pricing, Capacity</td>
</tr>
<tr>
<td><strong>Gunstock Mountain Resort</strong></td>
<td>Resort/Commercial</td>
<td>EnerNOC</td>
<td>3</td>
<td>Curtailment. Shuts down snowmaking operations</td>
<td>Load Curtailment, Time-Sensitive Pricing, Capacity</td>
</tr>
<tr>
<td><strong>Durgin and Crowell Lumber</strong></td>
<td>Light Industrial/Manufacturer</td>
<td>EnerNOC</td>
<td>3</td>
<td>Curtailment. Shuts down major equipment including the sawmill, planer, and kilns.</td>
<td>Load Curtailment, Time-Sensitive Pricing, Capacity</td>
</tr>
<tr>
<td><strong>Harpoon Brewery</strong></td>
<td>Brewery/Commercial</td>
<td>EnerNOC</td>
<td>350</td>
<td>Time shift bottling</td>
<td>Load Curtailment,</td>
</tr>
<tr>
<td>Utility/Aggregator</td>
<td>Year</td>
<td>Meters (millions)</td>
<td>Average Cost/Meter Installed ($US/Meter)</td>
<td>Operational Benefits/Meter Installed ($US/Meter)</td>
<td>Demand Response or Energy Conservation Benefits/Meter ($US/Meter)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------</td>
<td>-------------------</td>
<td>-----------------------------------------</td>
<td>--------------------------------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Delmarva</td>
<td>2010</td>
<td>0.22</td>
<td>$363</td>
<td>$183</td>
<td>$252</td>
</tr>
<tr>
<td>Connecticut Light &amp; Power</td>
<td>2010</td>
<td>1.2</td>
<td>$377 to $484</td>
<td>$94 to $232</td>
<td>$63 to $804</td>
</tr>
<tr>
<td>Portland General Electric</td>
<td>2007</td>
<td>0.843</td>
<td>$157</td>
<td>$197</td>
<td>$4 to $55</td>
</tr>
<tr>
<td>Southern California Edison</td>
<td>2007</td>
<td>5.3</td>
<td>$374</td>
<td>$217</td>
<td>$159</td>
</tr>
</tbody>
</table>

[105] Table 6-3: Smart Meter and Demand Response Cost Implications

[33]
### A.1.2 Distribution Generation Aggregator

**Table 6-4: Costs Associated with Renewable Generation Technology**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solar PV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10 kW</td>
<td>$3,897</td>
<td>$889</td>
<td>$21</td>
<td>$20</td>
<td>33.00</td>
<td></td>
</tr>
<tr>
<td>10 - 100 kW</td>
<td>$3,463</td>
<td>$947</td>
<td>$19</td>
<td>$18</td>
<td>33.00</td>
<td></td>
</tr>
<tr>
<td>100 - 1,000 kW</td>
<td>$2,493</td>
<td>$774</td>
<td>$19</td>
<td>$15</td>
<td>33.00</td>
<td></td>
</tr>
<tr>
<td>1 - 10 MW</td>
<td>$2,025</td>
<td>$694</td>
<td>$16</td>
<td>$9</td>
<td>33.00</td>
<td></td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10 kW</td>
<td>$7,645</td>
<td>$2,431</td>
<td>$40</td>
<td>$34</td>
<td>14.00</td>
<td></td>
</tr>
<tr>
<td>10 - 100 kW</td>
<td>$6,118</td>
<td>$2,101</td>
<td>$35</td>
<td>$12</td>
<td>19.00</td>
<td></td>
</tr>
<tr>
<td>100 - 1,000 kW</td>
<td>$3,751</td>
<td>$1,376</td>
<td>$31</td>
<td>$10</td>
<td>16.00</td>
<td></td>
</tr>
<tr>
<td>1 - 10 MW</td>
<td>$2,346</td>
<td>$770</td>
<td>$33</td>
<td>$16</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combustion</td>
<td>N/A</td>
<td>$5,792</td>
<td>$2,762</td>
<td>$98</td>
<td>$29</td>
<td>28</td>
</tr>
<tr>
<td>Combined Heat &amp; Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[85]
<table>
<thead>
<tr>
<th>Pricing Model</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Granular Rate</strong></td>
<td>Disaggregated retail rate: where the sources reliance on the distribution grids services is explicitly determined, and therefore can be precisely accounted for when paying the source for the power they inject instead of bundling the charge together</td>
<td>Net metering</td>
</tr>
<tr>
<td><strong>Buy/Sell Arrangement</strong></td>
<td>Two part transaction: The source “owner” pays a bundled fee for using the distribution network. The utility provider pays the source owner for the power they provide</td>
<td>Bill credit</td>
</tr>
<tr>
<td><strong>Procurement Model</strong></td>
<td>Market Auction: Utility holds an auction for the procurement of distributed generation (request for proposals), Distributed Generation Aggregators submit bids. Utility pays bid winner market clearing price</td>
<td>Demand-side</td>
</tr>
<tr>
<td><strong>DER-Specific Rates</strong></td>
<td>Aggregator is offered a tailor rate for the use of the distribution network from the utility provider</td>
<td>Partial</td>
</tr>
</tbody>
</table>
## A.1.3 Vehicle-to-Grid Aggregator

### Table 6-6: Cost Comparison of Different Electric Vehicles Providing Ancillary Services

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Electric Vehicle Battery Parameters</th>
<th>Cost of Providing Spinning Reserves &amp; Peak Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Battery Type</td>
<td>Total Cost to Owner (US$/kWh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost of Battery Degradation (US$/kWh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost of Recharge Electricity (US$/kWh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fixed costs (US$/year)</td>
</tr>
<tr>
<td>Lead-Acid Acid Prototype</td>
<td>Battery cycle life (cycles)</td>
<td>0.229</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>0.388</td>
</tr>
<tr>
<td></td>
<td>Battery life (years)</td>
<td>0.446</td>
</tr>
<tr>
<td></td>
<td>3 to 4</td>
<td>0.267</td>
</tr>
<tr>
<td></td>
<td>Battery Cost</td>
<td>0.322</td>
</tr>
<tr>
<td></td>
<td>OEM</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>(US$/kWh)</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>0.172</td>
</tr>
<tr>
<td></td>
<td>300 to 450</td>
<td>0.388</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>0.267</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>843 to 1123</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>578</td>
</tr>
<tr>
<td></td>
<td></td>
<td>578</td>
</tr>
<tr>
<td>Honda EV Plus</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 to 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>300</td>
<td></td>
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<td></td>
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<td>300</td>
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<td></td>
</tr>
<tr>
<td>Th!nk City</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6V</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ford Prodigy P200</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 to 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>300</td>
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<td>300</td>
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<td></td>
<td>300</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toyota Prius</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 to 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>843 to 1123</td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Notes
- **Battery Type:**
  - **Pb-acid, 66Ah, 30 modules 12V**
  - **NiMh, 95Ah, 24 modules 12V**
  - **NiCd, 100Ah 19 modules 6V**
  - **NiMh, 6.5Ah 38 modules, 6 cells, 1.2V**

- **Battery cycle life (cycles):**
  - 1000
  - 1000
  - 1500
  - N/A
  - 1000

- **Battery life (years):**
  - 3 to 4
  - 5 to 6
  - 5
  - N/A
  - 5 to 6

- **Battery Cost (US$/kWh):**
  - 125
  - 300 to 450
  - 300
  - NA
  - 843 to 1123

- **Total Cost to Owner (US$/kWh):**
  - 0.229
  - 0.446
  - 0.322
  - to 0.380
  - 1.34

- **Cost of Battery Degradation (US$/kWh):**
  - 0.172
  - 0.388
  - 0.267
  - N/A
  - 1.29

- **Cost of Recharge Electricity (US$/kWh):**
  - 0.045
  - 0.045
  - 0.045
  - N/A
  - N/A

- **Fixed costs (US$/year):**
  - 8.13
  - 8.13
  - 8.13
  - 578
  - 578
<table>
<thead>
<tr>
<th>Electric Vehicle Type</th>
<th>Car Model</th>
<th>Capacity</th>
<th>Ancillary Service</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Peak Power</td>
<td>Spinning Reserves</td>
</tr>
<tr>
<td>Lead-Acid Prototype</td>
<td>5.1</td>
<td>993</td>
<td>715</td>
</tr>
<tr>
<td>Honda EV Plus</td>
<td>4.9</td>
<td>300</td>
<td>255</td>
</tr>
<tr>
<td>Think City</td>
<td>2.3</td>
<td>211</td>
<td>147</td>
</tr>
<tr>
<td>Fuel Cell (up only)</td>
<td>Ford Prodigy P200</td>
<td>22</td>
<td>1,774 to 10,082</td>
</tr>
<tr>
<td>Hybrid (up only)</td>
<td>Enlarged Battery</td>
<td>2.3</td>
<td>0</td>
</tr>
</tbody>
</table>
### Table 6-8: Examples of International Sales Rebates for Electric Vehicles

<table>
<thead>
<tr>
<th>Country</th>
<th>Incentive</th>
<th>Potential Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Belgium</strong></td>
<td>Personal income tax deduction of 30% of the vehicle sticker price</td>
<td>up to US$ 12,000</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td>Automakers receive monetary incentives from the government for manufacturing plug-in electric vehicles and battery electric vehicles. The incentives are expected to be filtered through to the consumer.</td>
<td>US$ 7,320 for plug-in electric vehicles US$ 8,800 for battery electric vehicles</td>
</tr>
<tr>
<td><strong>Denmark</strong></td>
<td>Electric vehicles are exempt from paying new vehicle registration tax. The tax is equal to 105% of the vehicle price for cars costing up to US$ 11,900. For cars that cost more than that, the tax is increased to 180% of the vehicle price.</td>
<td>Up to ~US$ 12,500 for cheaper priced vehicles ~US$ 21,100+ for vehicles above the lower threshold</td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td>Acquisition tax of a vehicle in Japan is 5% of the car sticker price. Consumers who purchase electric vehicles receive a 50-75% reduction on this tax by receiving a direct subsidy.</td>
<td>Between US$ 550 – US$ 2,700</td>
</tr>
<tr>
<td><strong>U.K.</strong></td>
<td>Electric vehicles receive a rebate equal to a discount of 25% off of the vehicle sticker price</td>
<td>Up to US$ 8,220</td>
</tr>
<tr>
<td><strong>U.S.</strong></td>
<td>Federal tax rebates</td>
<td>Up to US$ 3,400 for hybrid electric vehicles Up to US$ 7,500 for plug-in hybrid electric vehicles and battery electric vehicles</td>
</tr>
</tbody>
</table>

[107]
<table>
<thead>
<tr>
<th>Standard/Tariff</th>
<th>Purpose/Requirement</th>
<th>Implication (if Applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule 21</td>
<td>Anti-islanding requirements and Automatic disconnection upon large grid voltage or frequency variations</td>
<td>V2G cannot be used to provide reserve capacity if the grid fails</td>
</tr>
<tr>
<td>National Electrical Code, Article 625-25</td>
<td>Means shall be provided such that upon loss of voltage from the utility or other electric system(s), energy cannot be back fed through the electric vehicle supply equipment to the premises wiring system. The electric vehicle shall not be permitted to serve as a standby power supply. <em>(Earley, Caloggero and Sheehan 1996)</em></td>
<td></td>
</tr>
<tr>
<td>Net-Metering</td>
<td>Tariff: power company buys power at the same retail rate as it sells it</td>
<td>Considered an 'Incentive-rate' as utilities bear the grid system costs of intermittent energy V2G would require that vehicles provide power precisely when needed, in exchange for premium rates well above the net metering rates for site renewable energy.</td>
</tr>
<tr>
<td>Demand Charge</td>
<td>Tariff: Commercial customers are also billed &quot;demand charge&quot; which compensates the distribution company for expenses incurred by having to upgrade lines and transformers to handle the maximum 'Demand'. It is common for the demand charge to be 50% of a commercial customer's bill.</td>
<td>V2G Could be of use to commercial customers to offset this charge</td>
</tr>
<tr>
<td>interruptible rates</td>
<td>Tariff: Large users get a year-round discount off their energy bills (e.g., 15%) in exchange for agreeing to sharply curtail their consumption when asked by the grid operator</td>
<td>Allow on-site V2G to substitute for the curtailed grid power. Such commercial customers could achieve the 15% savings while not curtailing production or other business functions.</td>
</tr>
<tr>
<td>SAE J2836</td>
<td>Standard for power transfer between grid and EV (including reverse power flow)</td>
<td>These standards help to ensure that manufacturers of EVSE have interfaces that are compliant with the grid</td>
</tr>
<tr>
<td>SAE J1850</td>
<td>Standard discussing the network to be used between the EVSE and the vehicle</td>
<td></td>
</tr>
<tr>
<td>SAE J2293</td>
<td>defines V2G bi-directional flow, and communication medium as either power line communication or wireless</td>
<td></td>
</tr>
</tbody>
</table>
**SAE J2931**  Defines the communication requirements between the energy management system associated with the vehicle and the utility grid

**IEEE 1547**  Provide further cases and definitions for information exchange, monitoring and control of DER

[92] [90] [107]

### Table 6-10: Different Possible Charging Scenario for V2G Capable Vehicle

<table>
<thead>
<tr>
<th>Charging Scenario</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opportunity charging</strong></td>
<td>Anytime Owner charges vehicle for travel purposes</td>
</tr>
<tr>
<td><strong>Price-signal charging</strong></td>
<td>Real-time, Day-ahead, Time-of-use EV owner may choose to capitalise on high electricity prices by injecting power into the grid</td>
</tr>
<tr>
<td><strong>Load-signal charging</strong></td>
<td>Direct Command Aggregator sends direct control for charging or discharging</td>
</tr>
<tr>
<td><strong>Renewable energy signal charging</strong></td>
<td>Charging EV battery using renewable energy generation Capitalise on cheap power</td>
</tr>
</tbody>
</table>

[92] [90] [107]
Appendix B  Detailed Methodology

B.1  The Investment Matrix

The investment matrix represents a qualitative pool of information that seeks to highlight the level of supporting technology, legislations and standards, infrastructure and the level of social acceptance for each energy aggregator. The matrix is designed to represent a qualitative idea based on the research found and analysed from the literature review. Each marking criteria is given a score out of LOW, MEDIUM or HIGH, which corresponds to the numbers 1, 2 or 3 respectively, as can be seen in Table 6-11 below. The total score is then calculated in Table 6-12 below, where this score gives an idea of how much potential investment is required for that particular aggregator type. The HIGHER the score is the LESS potential investment is required for that Aggregator. The scores range from a maximum of 12 (which represents a very SMALL investment requirement, and hence is illustrated by a very small ‘circle’) to a minimum score of 4 (which represents the potential need for a LARGE investment requirement, and hence is illustrated by a very large ‘circle’).

Table 6-11: Investment Matrix Score Card

<table>
<thead>
<tr>
<th>Aggregator Type</th>
<th>Supporting Technology</th>
<th>Supporting Standards &amp; Legislation</th>
<th>Supporting Infrastructure</th>
<th>Level of Social Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Response</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>HIGH</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
<td>LOW</td>
</tr>
<tr>
<td>Commercial &amp; Industrial</td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>Distributed Generation</td>
<td>HIGH</td>
<td>HIGH</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>V2G</td>
<td>MEDIUM</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
</tbody>
</table>
### Table 6-12: Investment Matrix Score Card Total

<table>
<thead>
<tr>
<th>Aggregator Type</th>
<th>Supporting Standards &amp; Legislation</th>
<th>Supporting Infrastructure</th>
<th>Level of Social Acceptance</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Response</td>
<td>Residential</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Commercial &amp; Industrial</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Distributed Generation</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>V2G</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

#### B.2 Value Chain Analysis

Porter’s Value Chain analysis is a business framework used to outline an operations supply chain that is made up of ‘primary activities’ and includes the operation (power generation), inbound/outbound logistics (transmission and distribution), marketing and sales (electricity retailers) and the service provided (electricity provided to end-consumers) [4] [103]. The ‘support activities’ of the framework include the ‘procurement’ of resources for the business, ‘human resource management’, the ‘technological development’ and the businesses ‘infrastructure’ [103]. These support activities are used to enhance and add value to the primary activities [103].

In this project, ‘procurement’ relates to an aggregator’s ability to add value to the system by providing sources of generation or capacity that are able to compete against traditional generating plants; Human resource management relates to an aggregator’s ability to add value to the system by providing valuable information regarding the energy consumption and behaviour of end-consumers; Technology development refers to an aggregator’s ability to provide new products that actively engage end-consumers and facilitate their integration; and infrastructure relates to an aggregator’s ability to provide useful services that enhance the quality and reliability of the grid.

In order to qualitatively evaluate the ‘value’ of these support services, they were scored much like the criteria in the ‘investment matrix’ and took into consideration the PEST and SWOT analysis conducted on each of the aggregators. Each support service provided by an aggregator was qualitatively given a mark of LOW, MEDIUM or HIGH, which corresponded to a score of 5, 10 or 15 respectively, see Table 6-13 below.
Once this was conducted, in order to take into account, the potential investment requirements of each aggregator type, the value determined in the ‘investment matrix score card’ was added to the support activity score for each aggregator. The HIGHER the accumulative total of the two scores the more ‘value’ that aggregator was able to add to the power system through that support activity. The lowest available score once considering the ‘investment matrix score card’ was 10 and the highest available score was 25, see Table B4. It should be noted that the average total score (12+8/2) of the ‘Demand Response Aggregators’ potential investment requirement was taken for simplicity.

Table 6-14: ‘Value’ Added to the Power System Supply Chain by Aggregator Support Activities