Title: **How is Value Created and Captured in Smart Grids? A Review of the Literature and an Analysis of Pilot Projects**

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**Abstract**: Profitable business models for value creation and value capture with smart grid services are pivotal to realize the transition to smart and sustainable electricity grids. In addition to knowledge regarding the technical characteristics of smart grids, we need to know what drives companies and consumers to sell and purchase services in a smart grid. This paper reviews 45 scientific articles on business models for smart grid services and analyses information on value in 434 European and US smart grid pilot projects. Our review observes that the articles and pilots most often discuss three types of smart grid services: vehicle-to-grid and grid-to-vehicle services, demand response services, and services to integrate renewable energy (RE). We offer a classification of business models, value creation and capture for each of these services and for the different actors in the electricity value chain. Although business models have been developed for grid-to-vehicle services and for services that connect RE, knowledge regarding demand response services is restricted to different types of value creation and capture. Our results highlight that business models can be profitable when a new actor in the electricity industry, that is, the aggregator, can collect sufficiently large amounts of load. In addition, our analysis indicates that demand response services or vehicle-to-grid and grid-to-vehicle services will be offered in conjunction with the supply of RE.

**Keywords:** smart grids; business models; value creation; electric vehicles; demand response; renewable energy

## 1. Introduction

Increasing decentralized electricity production with renewable energy, more energy-efficient behaviour by consumers, and the grid-connection of electric vehicles will severely affect electricity industries in the next decades [1 Welsch et al., 2013, p. 344]. Although these changes will have positive effects on the environment and reduce $CO_2$ emissions, they will also fundamentally alter the peaks and valleys of electricity on the network and thereby negatively affect the reliability, quality and security of supply [2 Cappers et al., 2013; 3 Gordijn and Akkermans, 2007]. To cope with these changes and to guarantee the effective functioning of the network, electricity industries are implementing smart electricity grids, i.e., grids that integrate information and communication technologies (ICT) into the existing network to allow for a two-way flow of information and electricity between producers and consumers [4 Gerpott and Paukert, 2013]. A variety of smart grid technologies, such as smart meters and advanced metering infrastructures, have been developed and are slowly being implemented, often stimulated by regulation. Although technologically feasible, the investments associated with the smart grid are high, and it is thus far unclear how the electricity industry will source those investments. That is, smart grid technologies are not yet accompanied by new business models on a large scale [5 Barley, 2011; 6 Johnson and Suskewicz, 2009]. Companies need to develop new services that use smart grid functionalities, and they need to create value for consumers and capture value for themselves with these services. The successful transition to a smart grid will be compromised if companies cannot make money out of the smart grid or if consumers do not value the new services [7 Curtius et al., 2012].

This paper offers a review of state-of-the-art business models, value creation and value capture with smart grid services. Business models describe what products and services a company offers to customers, which customer segments the company targets, and the company's distribution channels, core competences, cost structure, and revenue model [8 Osterwalder et al., 2005]. They are defined as the means by which companies create value for consumers and capture value for themselves [9 Jolink and Niesten, 2015; 10 Magretta, 2002; 11 Zott et al., 2011]. In this paper, value creation refers to the value created for consumers of a service and may include financial benefits, improved service quality but also environmental benefits. Value capture refers to value captured by the service provider and often includes financial benefits such as reduced costs, increased revenues and profits. The paper reviews 45 scientific articles on business models for smart grid services and analyses information on value in 434 European and US smart grid pilot projects. The paper combines a literature review with an analysis of pilot projects to obtain a richer set of data and, in particular, to include information on document analyses, interviews and simulation studies from the scientific literature and real-life experiments from smart grid pilots. Although services for smart grids have not been offered on a large scale, this review provides valuable insights into the direction of smart grid developments. Our review finds that the articles and pilots most often discuss three types of smart grid services. First, vehicle-to-grid and grid-to-vehicle services concern the transfer of electricity between electric vehicle (EV) batteries and the grid to charge and discharge the batteries but also concern profit from price differences on the electricity market and supplying power to the operator of the electricity system. Second, in demand response services, consumers increase or decrease their electricity consumption in response to signals from the energy companies or system operators. Third, energy companies provide services that increase the integration of renewable energy sources into the electricity system.

Our analysis of the literature and pilot projects results in a classification of business models, value creation and value capture for each of these services and for the different actors in the electricity value chain. Although earlier studies reviewed the literature on the state of technology of electric vehicles, the integration of renewable energy and smart grids [e.g., 12 Mwasilu et al., 2014], our paper is the first to review evidence on value creation and capture with smart grid services. The paper makes three important contributions to the literature on smart grids. First, it demonstrates that if companies are to capture value from offering smart grid services, they will need to operate on a large scale, meaning they will need to become aggregators. Companies need to aggregate a large number of EV batteries to offer V2G and G2V services, to aggregate a great deal of consumer load to offer demand response services and to have access to a large number of sites with renewable energy sources. Second, the paper shows that companies can capture value when they offer a combination of the three complementary services. Finally, the paper shows that the literature offers evidence of business models and value capture by companies, but the pilot projects primarily address value creation for system operators and consumers. We therefore propose that future pilot projects focus more on the ability of service providers to generate revenue with smart grid services to facilitate the transition to a smarter electricity grid.

The following section discusses characteristics of smart grids and defines business models. Section 3 describes the method that we used to select the literature and to collect data on the pilot projects. Sections 4 and 5 present the results. Section 6 offers future research suggestions based on our review of state-of-the-art value creation and capture in smart grids, and section 7 presents the conclusions.

## 2. Smart Grids and Business Models

Several scholars have argued that a common functional and technical definition of a smart grid has not yet emerged and that there is no consensus on what a smart grid is [13 Verbong et al., 2013; 1 Welsch et al., 2013]. For this review, we identified the characteristics of a smart grid shared by most definitions in the literature; that is, a smart electricity grid integrates information and communication technologies into the existing electricity network to allow for a two-way flow of information and electricity between generators and consumers [e.g., 14 Colak et al., 2014, 15 Erlinghagen and Markard, 2012, 16 Faucheux and Nicolai, 2011; 13 Verbong et al., 2013; 1 Welsch et al., 2013]. The related information and communication technologies include smart meters at the consumer site, communication networks between the consumer and a service provider, and data reception and management systems that make the information available to the service provider [17 Markovic et al., 2013, p. 574]. These technologies can be considered enabling technologies because they are a prerequisite for firms to offer smart grid services to consumers [18 Siano, 2014, p. 461; 19 Shen et al., 2014, p. 4; 20 Warren, 2014, p. 947]. In addition to these enabling technologies, companies need to develop new business models that allow them to create and capture value on a large scale by offering new smart grid services to consumers [15 Erlinghagen and Markard, 2012]. Johnson and Suskewicz [6] (2009) have argued that the combination of a new technology and a new business model is especially important to stimulate a systemic change (e.g., a change from a fossil-fuelled economy to a clean-tech economy with renewable energy, electric vehicles and smart grids). A variety of definitions of business models exists, but the majority refer to value creation and capture. For instance, Teece [21] (2010) describes a business model as articulating the logic, the data and other evidence that support a value proposition for the customer, and a viable structure of revenues and costs for the enterprise delivering that value. Magretta [10] (2002) poses the two questions, "What does the customer value? How do we make money in this business?" when describing what a business model is. Zott et al. [11] (2011) mention that business models seek to explain both value creation and value capture. In this paper, we therefore define business models as ways in which companies create value for consumers and capture value for themselves [9 Jolink and Niesten, 2015; 10 Magretta, 2002; 11 Zott et al., 2011]. Based on a literature review of business models, Osterwalder et al. [8] (2005) identified nine building blocks of a business model. Table 1 illustrates how these building blocks offer a more detailed description of how a company creates and captures value.

**Table 1. Nine building blocks of a business model [8 Osterwalder et al., 2005]**

| | |
|---|---|
| **1. Value proposition** | A company's bundle of products and services |
| **2. Target customer** | Segments of customers to which a company wants to offer value |
| **3. Distribution channel** | Means a company uses to contact its customers |
| **4. Relationship** | Links between a company and different customer segments |
| **5. Value configuration** | Arrangement of activities and resources of the company |
| **6. Core competency** | Competencies necessary to execute a business model |
| **7. Partner network** | Network of cooperative agreements with other companies necessary to offer value |
| **8. Cost structure** | Monetary consequences of means used in a business model |
| **9. Revenue model** | How a company generates revenue with a business model |

## 3. Methods

To select the scientific, peer-reviewed articles for our literature review on business models for smart grid services, we opted for a two-step approach. First, we selected 20 journals with the highest impact factors in the two subject categories 'Environmental Studies' and 'Energy & Fuels' from the journal citation reports of Web of Science. A search for "smart grid" and "business model" in these 20 journals yielded 64 articles. After carefully scanning these 64 articles, we included in our study the 39 articles that specifically addressed the topic of business models for smart grid services. Second, after reviewing the 39 articles, we added six additional articles not found on our first search but that were referred to by several of the initial 39 articles as relevant works on business models and smart grids. The selected 45 articles appeared between 2005 and 2014; a majority (78%) were published in the last three years.

In this study, we combine a review of the literature with an analysis of smart grid pilot projects. The inclusion of pilot projects enables us to analyse data on real-life experiments, whereas the scientific literature consists for the most part of document analyses, interviews and simulation studies. Our database on smart grid pilot projects contains data from two sources: first, the database constructed by the European Commission's Joint Research Centre on European smart grid projects (ses.jrc.ec.europa.eu/smart-grids-observatory), and second, the database on smart grid projects in the United States that is maintained by the US Department of Energy (www.sgiclearinghouse.org). The database includes 434 projects, of which 240 are European and 194 are US projects.

## 4. Review of the Literature on Business Models for Smart Grid Services

Our review identified three types of smart grid services that were researched and discussed most extensively in the literature. Forty-nine per cent of the articles discuss *vehicle-to-grid and grid-to-vehicle services*, 53 per cent *demand response services*, and 71 per cent *services to integrate renewable energy sources*. These percentages indicate that the different types of services are often used in conjunction.

### *4.1. Vehicle-to-grid and grid-to-vehicle services*

The articles on business models for the connection of electric vehicles (EVs) to the grid study vehicle-to-grid (V2G) services and grid-to-vehicle (G2V) services. In V2G services, energy actors sell the electricity that is stored in EV batteries on the electricity market or to the system operator, whereas in G2V services energy actors purchase electricity to charge EV batteries. The articles focus on the role of a new type of actor in the electricity industry that offers these services: the EV aggregator. EV aggregators create and capture value by aggregating supply and demand for electricity in EV batteries and by intermediating transactions between the different consumers of V2G and G2V services, such as EV owners, system operators and buyers and sellers in the electricity market [22 Giordano and Fulli, 2012, p. 253]. Giordano and Fulli [22] (2012) describe EV aggregators as developers of a multi-sided platform. A multi-sided platform is a business model in which goods and services are provided to two or more distinct groups of consumers who rely on the platform to intermediate transactions between them (Evans and Noel, 2008, cited in Giordano and Fulli [22], 2012, p. 253).

**<Insert figure 1 here>**

Figure 1 illustrates which actors are involved in the multi-sided platform for EV-services and refers to the articles that discuss intermediate transactions. The EV aggregator brings together supply and demand for electricity by offering V2G and G2V services to the actors, thereby creating and capturing value in two different ways. First, it creates and captures value by purchasing electricity on the electricity market at low prices to charge batteries of EV owners, EV fleets or battery switch stations, and it discharges batteries to sell electricity on the market at high prices [35 Armstrong et al., 2013; 24 Goebel, 2013; 29 Loisel et al., 2014]. Second, it creates and captures value by offering electricity and capacity in EV batteries to system operators in the form of ancillary services (e.g., regulation and reserve power) [33 Kempton and Tomić, 2005a; 30 Richardson, 2013; 26 Guille and Gross, 2009; 27 Hill et al., 2012; 28 Jargstorf and Wickert, 2013].

Armstrong et al. [35] (2013) study the first type of value creation and capture, in particular the case of purchasing and selling electricity on the day-ahead market to charge and discharge battery switch stations. The paper concludes that G2V strategies are more cost-effective than buying electricity directly from a utility and that it is possible to generate revenue with V2G services. However, the latter is true only when the arrivals of EVs are evenly spaced throughout the day [35 Armstrong et al., 2013, p. 569, 580]. This point highlights "the importance of having a good understanding of [the] arrival times of the EVs, and suggests that it might be worthwhile proposing advantageous tariffs for EV owners who exchange their batteries at certain times in the day" [35 Armstrong et al., 2013, p. 580]. As another example, Goebel [24] (2013) studies the business case of an EV aggregator who centrally controls the charging of an EV fleet and who purchases electricity on the day-ahead market to charge the vehicles (G2V). In this study, the yearly savings potential per EV is rather low. However, a few options exist that could increase the profitability of the business model: 1) The size of the EV fleet must be large. 2) EV owners must charge their cars between 9 AM and noon and between 1 PM and 5 PM, i.e., when most vehicles are parked at the workplace. 3) Finally, the integration of renewable energy could contribute to the financial attractiveness of controlled charging because it allows for short-term balancing of variable supply [24 Goebel, 2013, p. 8-9]. Loisel et al. [29] (2014) analyse the business case for EV fleets that sell electricity to the wholesale market (V2G). They argue that further incentives are necessary to make the business model attractive for car owners. Some solutions for increasing the net benefit include payments for the support of renewable energy, capacity payments, and offering ancillary services [29 Loisel et al., 2014, p. 439, 441].

Kempton and Tomić [33] (2005a) discuss the second type of value creation and capture and focus on the business case of V2G in which an aggregator offers ancillary services to a system operator using the batteries of an EV fleet. Parties that may serve as aggregators include fleet operators, energy retailers, automobile and battery manufacturers, cell phone network providers, and distributed generation managers. The authors' calculations show that V2G generates revenue for regulation and spinning reserves, but is especially profitable for regulation.[i] Richardson [30] (2013, p. 248) offers an overview of articles that study the economic viability of V2G strategies in which ancillary services are offered to system operators. Most studies indicate an annual profit in the $100-300 range per EV for the service provider. Richardson questions, however, whether this level of profit is sufficient to induce participation by either EV owners or EV aggregators. An aggregator would be able to attract EV owners by offering them a package deal that consists of preferential rates for the acquisition of the battery, maintenance of the battery, and discount rates for battery charging and parking [26 Guille and Gross, 2009, p. 4388]. In return, the EV owner would be obligated to plug the EV into the grid at times specified in the agreement between the EV owner and aggregator. The aggregator is able to offer preferential rates because it can undertake transactions with economies of scale and considerably lower transaction costs relative to those incurred by individual EV owners [26 Guille and Gross, 2009, p. 4382]. Based on several simulation studies, Guille and Gross (2009) [26] conclude that the ability of an aggregator to provide ancillary services improves as the size of the EV aggregation increases. Jargstorf and Wickert (2013) [28] study EV fleets that only offer downward reserves for frequency control, in which EV fleets charge vehicles for system stability and thus offer free battery space (G2V). They show that the revenues of this service are modest, with an average of 5 and a maximum of 16 euros per month per car. These calculations do not consider compensation for EV owners or costs of communication, installation and an energy management system. Hill et al. [27] (2012) consider the financial risks associated with accelerated battery degradation in an EV-fleet that performs V2G services, and show that battery cycle life is a critical parameter that determines whether V2G is a viable business case [27 Hill et al., 2012, p. 221].

Table 2 summarizes the value that V2G and G2V services can create for consumers and the value that service providers / aggregators can capture. It also offers examples of value that V2G and G2V services create for system operators. For example, these services offer system operators access to fast-response capabilities and allow them to cope better with intermittent wind power and to improve grid stability [35 Andersen et al., 2009; 26 Guille and Gross, 2009; 33 Kempton and Tomić, 2005a].

**Table 2. Value for actors in smart grid services based on a literature review**

| | ***Value for consumer*** | ***Value for system operator*** | ***Value for service provider / aggregator*** |
|---|---|---|---|
| ***V2G & G2V services*** | - Lower prices for energy, battery, parking (25, 26, 31, 32, 33)<br>- Additional, but low, revenues for offering energy and ancillary services (27, 28, 29, 30) | - Lower system costs (29, 30)<br>- Access to improved regulation services (26)<br>- Improved grid stability and management of intermittent supply (15, 28, 30, 31, 32)<br>- Improved levelling of load (26, 35) | - Revenues and profit with V2G (30, 33, 35)<br>- Lower costs for energy provision with G2V (23, 35), cost savings are low (24, 28) |
| ***Demand response services*** | - Lower energy consumption and lower electricity bills (3, 7, 13, 17, 18, 19, 20, 22, 24, 36, 37, 38, 39)<br>- Greater power quality (1, 18)<br>- Improved choice for managing electricity costs; control over energy bill, consumption and carbon footprint (18, 22, 40)<br>- Lower load shedding & prioritization of loads of public importance (e.g., hospitals) (1) | - Lower congestion costs, energy losses, operating reserves; lower investment in transmission lines or network improvements (13, 18, 19, 38, 40, 41, 42, 43, 44)<br>- Cheaper system services (2, 18, 22)<br>- Access to improved regulation services and statistical reliability of large amount of DR resources (2)<br>- Flatter load curve (36, 39)<br>- Greater network reliability and quality of supply (18, 19, 36, 38) | - Lower plant investments by lowering peak demand; lower spot price volatility (1, 3, 13, 17, 18, 19, 38, 41, 43, 44)<br>- Revenue from offering ancillary services (20, 41)<br>- Lower sourcing costs for electricity retailers (17, 19, 22, 24, 38) |
| ***Services to integrate renewable energy*** | *Connecting RE:*<br>- Receives financing for installing solar energy system; cheaper electricity and profitable sale of electricity (5, 44, 45) | | *Connecting RE:*<br>- Earns interest on loan for connecting solar systems, and benefits from increase in rate base or feed-in tariff (45) |
| | *Increasing integration of RE:*<br>- Dynamic pricing lowers electricity bills of distributed generators of RE (45)<br>- Distributed generators of RE receive fee for offering balancing services (3) | *Increasing integration of RE:*<br>- Dynamic pricing reduces peak load and lowers grid capacity requirements at peak times (24, 43, 45, 47)<br>- Voltage management service is profitable with high wholesale tariffs (3)<br>- Storage decreases peak demand and system costs, improves flexibility of power system and power quality, reduces negative effects of RE (1, 18, 29, 30, 32, 33, 34, 43, 47, 48, 49)<br>- DR enhances system reliability and supply quality, lowers capacity requirements (1, 2, 3, 18, 19, 44) | *Increasing integration of RE:*<br>- Dynamic pricing reduces peak load, lowers back up capacity requirements (24, 45)<br>- Balancing services are profitable (3)<br>- EV aggregators that charge batteries when there is a great deal of wind power benefit from low electricity prices (23, 30, 48)<br>- Combination of RE and smart charging of EVs improves financial attractiveness of RE and EVs (23, 24) |

An exemplar case of an EV aggregator discussed extensively in the literature is Better Place. Better Place owned and coordinated EV charging infrastructure, batteries, and intelligent charging devices and software in Israel, Denmark, Japan and the Netherlands. They collaborated with EV and battery manufacturers and with grid operators for connecting charging points to the grid. They also purchased renewable energy on the electricity market. By acting as an intermediary between these actors, they were able to offer an e-mobility service to EV owners. The EV owners contracted with Better Place to lease batteries and access charging points and battery switch stations. Table 3 summarizes the business model of Better Place using the nine building blocks of a business model by Osterwalder et al. [8] (2005). Despite the promising start of this company with its large amount of venture capital and companies participating in the multi-sided platform, Better Place filed for bankruptcy in May 2013. Two reasons offered for bankruptcy were the slow pace of market penetration, which had not lived up to expectations,[ii] and the continued need for large investments in capital-intensive assets such as the charging infrastructure.[iii]

The case of Better Place illustrates a business model in which the aggregator invested large amounts of capital in charging infrastructure in the early phase of EV adoption. The literature discusses several other business models for the ownership and coordination of EV charging infrastructure [25 Gomez San Roman et al., 2011; 43 Schiavo et al., 2013], in which less capital-intensive business models characterize the initial phase of diffusion of electric vehicles. For instance, EV owners charge their vehicles at home based on a contract with the energy retailer, or private organizations, such as shopping malls, install a few charging points on their premises as an extra service to customers. In a later phase of diffusion, with high EV sales uptake, more public-street charging infrastructure is recommended, with system operators in a favourable position to own and operate the charging points (25 Gomez San Roman et al., 2011, p. 6373; 43 Schiavo et al., 2013, p. 515).

**Table 3. Business model of Better Place (BP)**[1]

| | |
|---|---|
| **1. Value proposition** | BP owns and coordinates EV charging infrastructure, batteries, intelligent charging software and devices, and the charging of batteries with renewable energy. Using these assets, it offers an E-mobility service to consumers. |
| **2. Target customer** | BP creates value for the EV owner by offering a lower total cost of ownership per km. It offers energy savings, efficiency and sustainability to the EV owner. |
| **3. Distribution channel** | Charging points and battery switch stations constitute the distribution channel. |
| **4. Relationship** | BP and EV owners have a contract for leasing car batteries and for the supply of electricity to charging points. They exchange information to intelligently charge the battery and to register payments that the owner must make to BP. |
| **5. Value configuration** | BP is an aggregator that coordinates information and electricity flows between the EV-owners, charging infrastructure, the grid, and the electricity market. |
| **6. Core competency** | The aggregator of an e-mobility platform must attract a large amount of capital and a large number of customers to support the capital-intensive business model. |
| **7. Partner network** | BP cooperates with Renault, who sells EVs to consumers; the Electricity market, to buy electricity; DSO, for connecting charging stations to the grid; Battery manufacturers and suppliers of network hardware; and with DONG Energy, to create VPPs with BP under joint ownership to provide the system operator with grid optimization and stabilization services. |
| **8. Cost structure** | BP has a capital-intensive business model due to the charging infrastructure and large stock of batteries. BP takes a risk with the large capital investments, which requires a critical mass of customers to reach economic break-even. |
| **9. Revenue model** | BP charges consumers a one-time subscription fee that (partly) finances batteries and charging stations. It also charges a monthly fee for an annual mileage limit (packages ranging from 10.000 to > 40.000) and an additional fee for miles exceeding the package. BP earns revenue by buying electricity on the spot market when prices are low, e.g., when a great deal of wind power is available. |

[1] Information on the business model of Better Place is taken from five articles: [22, 23, 32, 34, 50].

## *4.2. Demand response services*

The second type of smart grid service that is prominent in the scientific literature is the demand response (DR) service. In demand response services, energy retailers or system operators send signals to consumers in which they ask consumers to adjust their load (i.e., their electricity consumption). Retailers and system operators value the willingness of a consumer to adjust consumption because they aim for a reduction in electricity peaks to guarantee the security of supply and reliability of the system [43 Schiavo et al., 2013]. The US Department of Energy defines demand response as “changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentivize payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” [19 Shen et al., 2014, p. 1; 18 Siano, 2014, p. 462]. This definition refers to two types of demand response: *price-based* and *incentive-based* responses. First, in price-based responses, consumers adjust their electricity consumption based on the level of electricity retail prices. This type of demand response can take a variety of forms, including time-of-use pricing (TOU), critical-peak pricing (CPP), and real-time pricing (RTP). Time-of-use pricing divides the hours of the day into two periods and charges consumers using on- and off-peak tariffs [24 Goebel, 2013]. Another option is critical-peak pricing, wherein the electricity price increases significantly when the grid is in danger of not coping with peak demand [38 Stoll et al., 2014, p. 491]. Real-time pricing implies consumer notification of tariffs a day ahead or even on the day of demand, allowing consumers to adapt their behaviour accordingly. The tariffs are often based on spot market prices [39 Wissner, 2011, p. 2512].

Second, in incentive-based response programs, consumers are offered monetary incentives that are separate from the electricity retail prices [19 Shen et al., 2014, p. 4]. Consumers receive payments for allowing an energy company to directly control the consumers’ load by remotely turning off and restarting electrical equipment, such as lighting, refrigerators and heating [18 Siano, 2014, p. 465]. These direct load control programs can be combined with an option for consumers to retain a certain degree of control and thus the ability to interfere with the company’s load control actions [13 Verbong et al., 2013].

The articles in our review argue that business models for demand response services in the residential sector will only work when companies aggregate the loads of a large number of consumers [e.g., 41 Dave et al., 2013, p. 175-176); 20 Warren, 2014, p. 945].[iv] Demand response services therefore introduce a new actor in the electricity industry: the demand response (DR) aggregator. Dave et al. [41 2013, p. 173] define a DR aggregator as “an entity that coordinates houses/electrical loads such that they can be used as a grid balancing mechanism with the view of reducing peak demand”. Aggregation is necessary for offering electricity to balancing authorities, capacity or electricity markets, or electricity retailers (see figure 2). Most balancing authorities require a minimum offer of 1 MW, but some are experimenting with reducing this resource requirement to 0.1 MW to stimulate electricity supply from new sources such as demand response [2 Cappers et al., 2013, p. 1032]. However, for both resource requirements, providers of demand response services need to aggregate a large amount of load in the residential sector. In some countries, capacity markets offer up-front and on-going capacity payments for committed load reduction [19 Shen et al., 2014, p. 6]. This is attractive to DR aggregators because they require a stable source of revenue to cover their costs and make their operations profitable. Aggregators may also offer their base of consumption flexibility to retailers, who participate to buy active demand services [22 Giordano and Fulli, 2012]. Aggregators thus receive revenue for offering demand response services from balancing authorities, capacity and electricity markets, and electricity retailers, and they pay consumers for participating in demand response programs and for adjusting electricity consumption.

**<Insert figure 2 here>**

The articles on demand response do not offer detailed descriptions of business models for demand response services. Instead, they describe different ways in which service providers create value for consumers and for system operators, and capture value for themselves (see table 2). A survey among close to 500 consumers in four European countries shows that there exists a great willingness among consumers to change their behaviour and to adjust their consumption based on demand response signals in a smart grid [7 Curtius et al., 2012]. When consumers adjust their behaviour in response to these signals, they can benefit from lower energy consumption and a lower electricity bill [e.g., 38 Stoll et al., 2014; 20 Warren, 2014; 39 Wissner, 2011]. A demand response experiment with a token-based reward system was carried out in 69 households in Japan in December 2011. The reduction in electricity consumption was as high as 30% [37 Ngar-yin Mah et al., 2013, p. 732]. Empirical studies of time-of-use programs conclude that average households can save between 10 and 15% of their electricity bill if they adjust consumption to the time-of-use tariffs [24 Goebel, 2013, p. 2]. System operators receive value from demand response in the form of lower costs for system services, increased network reliability, and avoided capital and congestion costs. These benefits to system operators largely result from a reduction in peak demand enabled by demand response services. Research conducted in the US found that a 5 per cent reduction in peak demand would have resulted in avoided costs of $2.7 billion for generation, transmission, and distribution capacity per year [19 Shen et al., 2014, p. 2]. The providers of demand response services (i.e., the aggregators) are able to capture value for themselves. For instance, they are able to generate revenue by offering demand response as an ancillary service to system operators. Warren [20] (2014, p. 945) states that the economic revenue from 3MW of demand-side participation in short-term operating reserves can be 66,000 pounds per year in the UK. Using agent-based models, Dave et al. [41] (2013, p. 178) estimate that the calculated revenue is 1,800 pounds over a 20-year period for each household that the service provider aggregates. The business case is feasible when communication infrastructure has been installed and the service provider need only invest in data management and control [41 Dave at al., 2013, p. 179]. When aggregators also produce electricity, they benefit from demand response by reducing the need for investing in new generation capacity and thus reduce generation costs [43 Schiavo et al., 2013; 38 Stoll et al., 2014; 1 Welsch et al., 2013]. When aggregators also operate as electricity retailers, they capture value from demand response because it lowers electricity prices and thus the retailers’ costs of purchasing electricity [19 Shen et al., 2014; 38 Stoll et al., 2014]. Goebel [24] (2013, p. 2) argues that electricity retailers will have a major business interest in reducing these costs because the resale of electricity is their core business. Stoll et al. [38] (2014) compared the effects of shifting 1 kWh from an on-peak hour to an off-peak hour with real-time pricing and time-of-use tariffs on the Ontario, Great Britain and Swedish electricity markets. They found large effects of real-time and time-of-use pricing on reductions in costs of purchasing electricity on the Ontario market.

### *4.3. Services to integrate renewable energy*

The third type of smart-grid service integrates renewable energy into the electricity network and consists of two service categories. The first category concerns the actual connection and access of renewable energy sources to the network. The second category concerns services that enable energy companies and system operators to manage better the effects of intermittent renewable energy and consequently to increase the amount of renewable energy that is integrated into the electricity system.

With respect to the first service category (i.e., the connection and access of renewable energy to the network), several descriptions of business models are offered in the literature.

Barley [5] (2011, p. 77) quotes a venture capitalist who claims that "the world doesn't need a two-hundredth solar-panel start-up, but it does need two-hundred service companies dedicated to getting those panels on rooftops." He refers to the UK-based company Solarcentury that is implementing new business models for installing solar panels. Solarcentury installs photovoltaic systems and leases them to clients that would otherwise be unable to afford them. It entered into a partnership with Triodos Bank, which will buy solar systems from Solarcentury and will profit from the feed-in tariff [5 Barley, 2011, p. 7]. Richter [45] (2012) also offers a description of a business model in which energy companies offer network connection and access services to small consumers who produce renewable energy. This business model is partly based on an example of a New Jersey utility company that offers a Solar Loan Program, providing financing for solar energy systems on homes, businesses and municipal buildings throughout its electric service area. The utility finances between 40% and 60% of the investment costs. Customers receive Solar Renewable Energy Certificates when they produce renewable energy with their solar system, and they can repay their loans to the utility using the tradable certificates. The benefit for the utility consists of the interest on loans and the fact that costs such as program administration and meter installation can be treated as regulatory assets included in the utility's rate base, allowing a return to be earned on these [45 Richter, 2012, p. 2487]. Table 4 offers a detailed description of the business models, providing information on customer segments, key resources, activities and partnerships, and the revenue model.

**Table 4. Business model for customer-side renewable energy generation**[1]

| | |
|---|---|
| **Value proposition** | Utility offers financing for solar system on homes. Consumer is able to finance investments and repay with tradable energy certificates. |
| **Customer segments** | Utility must distinguish active from passive consumers. A customer interface management (with two-way flow of information) is essential. |
| **Infrastructure** | Key resources: e.g., photovoltaic solar systems.<br>Key activities: utilities develop new approaches to asset management and operation.<br>Key partnerships with manufacturers of RE systems or installation companies. |
| **Revenue model** | Utility earns interest on loan, and regulated utility can add RE investment to rate base.<br>Banks that finance solar systems benefit from feed-in tariff. |

[1] Information on business models is taken from the following articles: [5, 45].

The second category of renewable energy services aims to increase the amount of renewable energy on the network by reducing the adverse effects of intermittent energy sources on the electricity system. The intermittent nature of solar and wind power increases the number of peaks and valleys of electricity on the network [3 Gordijn and Akkermans, 2007]. System operators and energy companies have an incentive to reduce these peaks and valleys to better balance the supply and demand of electricity and to improve the reliability and quality of supply. The literature identifies a variety of services that can reduce the adverse effects of intermittent energy sources and thereby increase the integration of renewable energy. Examples include the following: services that enable distributed generators (DG) to respond to dynamic prices; services that enable DG to offer balancing power; voltage management services by the distribution system operator; services that enable DG to offer stored renewable energy to the grid; and demand response services to balance supply and demand. The remainder of this section will discuss these five services. First, dynamic pricing enables consumers to reduce their electricity bill by increasing consumption at low prices and reducing consumption at high prices [45 Richter, 2012]. The different types of dynamic pricing (time-of-use pricing, critical-peak pricing, and real-time pricing) are discussed in section 4.2 on demand response services. At high prices, consumers may also decide to consume their own locally produced renewable energy. Responses to dynamic price signals reduce peak loads, leading to lower backup capacity requirements for energy companies and lower grid capacity requirements at peak times for system operators [45 Richter, 2012, p. 2488-9]. Second, Gordijn and Akkermans [3] (2007) discuss a balancing service that exploits the use of DG technologies and equipment to minimize imbalances (e.g., a combined-heat-and-power installation that can distribute heat in the local environment when needed). They show that the providers of this service earn a profit and create value for consumers by offering them a fee for making balancing equipment available [3 Gordijn and Akkermans, 2007, p. 1184]. Third, studies have shown that with active management of distribution networks, the amount of DG that can be connected to existing distribution networks can be increased by a factor of 3–5 without requiring network reinforcements. The providers of active management services are able to earn a profit when the wholesale price of DG electricity is high [3 Gordijn and Akkermans, 2007, 1185-6]. Fourth, a number of articles discuss the ability of EV batteries to store electricity and thereby increase the amount of renewable energy integrated into the network [e.g., 48 Eberle et al., 2013; 29 Loisel et al., 2014]. Richardson [30] (2013, p. 251) mentions that the installed renewable energy capacity can increase by 30-75% with V2G-capable EVs due to their ability to store intermittent energy and discharge it back to the grid when required. The use of EVs as storage facilities for intermittent renewable energy offers a variety of advantages to system operators, including improvements in flexibility of the power system [43 Schiavo et al., 2013], in power quality [18 Siano, 2014], and in stability and reliability of the grid [33 Kempton and Tomić, 2005a]. Providers of this service may benefit by charging EV batteries when a great deal of wind power is available and prices on the electricity market are low [e.g., 48 Eberle et al., 2013; 30 Richardson, 2013]. Goebel [24] (2013, p. 9) argues that the addition of renewable energy generators could contribute to the financial attractiveness of controlled EV charging because it would facilitate short-term balancing of variable supply. Palizban et al. [49] (in press), Schleicher-Tappeser [46] (2012) and Wissner [39] (2011) note the benefits of virtual power plants as aggregators of distributed generators of renewable energy, energy storage and dispatchable loads. Finally, demand response can be used to balance supply and demand, thereby facilitating the integration of greater amounts of renewable energy production [46 Schleicher-Tappeser, 2012; 19 Shen et al., 2014]. This service offers advantages to system operators because it can increase network reliability and quality of supply [18 Siano, 2014]. These examples of services that enable a greater integration of renewable energy show that smart grid services are highly interconnected because companies are able to integrate more renewable energy into the network by offering V2G and G2V services and demand response services.

## 5. Review of Pilot Projects

In general, pilot projects show a focus that differs somewhat from the focus of the scientific literature. Although demand response and demand management (39% of projects) and the integration of renewable energy sources (35% of projects) are prominent in the pilot projects, this holds less for V2G and G2V services (14% of projects). Very few projects (fewer than 2%) refer to business models, and when they do, it is only to mention that business models may be developed in the future. What is also striking about the projects, and in contrast to the literature, is that none focusses on value capture at all. The pilot projects do not offer any evidence or even a discussion of value that can be captured by the service providers. One method of value creation that does feature prominently in the pilot project descriptions concerns the value created by smart grid technologies for the system operators through improved planning and operation. This value is often created in conjunction with the three services described above. The pilots also refer to different types of value creation for consumers among which the financial and environmental benefits feature most prominently.

Below, we describe how these new ways of value creation are visible in the pilot projects (see table 5 for a summary of value creation for consumers and system operators, and how many times the projects refer to these types of value creation).

### *5.1. EVs: V2G and G2V services*

Of the 434 projects in our database, 60 (14%) project plans include (hybrid) electric vehicles. The majority of these projects are pilot projects in which electric vehicles are part of an integrated smart grid project. For example, several pilots on intelligent charging combine the connection of electric vehicles to the grid with demand response, and several pilots focus on charging electric vehicles with renewable energy. A large part of the pilot projects on V2G and G2V services are aimed at ensuring the stability and reliability of grid operation when increasing amounts of electric vehicles are connected to the grid. These projects also test the ability of batteries in electric vehicles to offer balancing power or other types of ancillary services to the grid. A few projects address the consumer side of V2G and G2V services, studying under what conditions consumers are willing to participate in intelligent charging, how the visualization process and software layouts for adequate handling of charging facilities can be improved, and what incentives can be offered to promote the diffusion of electric vehicles.

The focus of most of the V2G and G2V projects is on technical feasibility, with limited attention to the business case. However, the projects' descriptions mention several possible sources of value creation. First, value is created for the system through increased reliability and stability of the grid, improvements in operating the grid and balancing supply and demand, and reductions in peak demand. Second, value is created for the consumer through environmental benefits, financial benefits, and increased participation in the electricity system.

### *5.2. Demand response services*

Project descriptions numbering 168 (39%) mention demand response and demand side management services as a source of value creation. Of these 168 projects, 108 are demand response projects in which the energy provider or system operator directly or indirectly controls consumer demand. In the case of direct control, the system operator alters consumer demand by (temporarily) shutting down consumer equipment. In the case of indirect control, the energy provider or system operator sends signals to the consumer, often in the form of dynamic prices, to influence electricity consumption. Demand side management is a broader category of measures aimed at managing consumption when compared with demand response and includes a variety of energy efficiency measures. Some examples of demand side management from the pilot projects are energy consultancy services and education programs on energy saving; new ways of making consumption data available to consumers that enable them to achieve energy savings; and convincing consumers to reduce energy consumption by making visible the largest energy consumers.

Value created by this service for the system operator includes reduced peak demand, improved system reliability and stability, improved access to regulation power, optimized grid operation, reduced system losses and costs, and improved power quality and security of supply. Value created for the consumer includes reduced energy use, reduced energy bills, enhanced control over energy consumption, and customer comfort. Additionally, seven projects refer to environmental benefits for the consumer and the system operator.

### *5.3. Services to integrate renewable energy*

Finally, 151 (35%) projects focus on the integration of renewable energy sources into the energy system. Different types of renewable energy are included in the pilot projects. The projects most often refer to the integration of solar and wind power (both are mentioned nearly 40 times). A few projects also refer to the use of combined heat and power and biomass. Hydropower and compressed air technologies are used to store energy generated with other types of renewable energy sources such as wind and solar power.

The projects often combine integration of renewable energy into the smart grid with other services. The combination of V2G and G2V services with renewable energy occurs 35 times, and the combination of demand response services with renewable energy occurs 42 times. Several pilot projects test the implementation of a smart grid by integrating all three types of services. One of these projects describes the aim of the pilot as follows: "to gain knowledge of whether it is technically possible and financially/environmentally advantageous for the customer and the electricity system to offer owners of electrical vehicles an intelligent charging facility comprising the possible use of spot electricity agreements and the choice of charging most cheaply or most greenly, based on hourly prices and production mix." The smart grid projects that combine the three services are often focused on testing and upgrading the network to ensure grid operation and a high system reliability and security and to invest in grid monitoring and control approaches at acceptable costs.

The service of integrating renewable energy into the smart grid creates value for the system operator. This value creation is associated with the supply of more renewable energy to the grid, which facilitates a greater access to regulation power for the system operator and reductions in peak demand (e.g., when prosumers consume their own energy). In addition, value is created for the system operator when the integration of renewable energy is combined with investments in a smart grid, thus allowing postponing investments in network capacity and improvements in reliability of the network, network operation, and security and stability of the network. Several projects also mention value created for consumers, such as environmental benefits, lower energy consumption, financial benefits (e.g., lower electricity bills or payments for supplying renewable energy), and a degree of control over energy bills and consumption.

**Table 5. Value for actors in smart grid services based on pilot projects**[1]

| Services | Value for consumer | Value for system operator |
|---|---|---|
| *V2G & G2V services* | - Environmental benefits (3)<br>- Financial benefits (3)<br>- Increased participation in the electricity system (1) | - Increased reliability & stability of the grid (8)<br>- Improved grid operation & balancing of supply and demand (6)<br>- Reduced peak demand (4) |
| *Demand response services* | - Reduced energy use (33)<br>- Reduced energy bills (33)<br>- Enhanced control over energy consumption (12)<br>- Customer comfort (3)<br>- Environmental benefits (6) | - Reduced peak demand (21)<br>- Improved system reliability & stability (20)<br>- Improved access to regulation power (10)<br>- Optimized grid operation (6)<br>- Reduced system losses & costs (4)<br>- Improved power quality & security of supply (3)<br>- Environmental benefits (1) |
| *Services to integrate renewable energy* | - Reduced energy use (12)<br>- Financial benefits (10)<br>- Environmental benefits (7)<br>- Enhanced control over energy bill and energy use (3)<br>- Increased participation in the electricity system (1) | - Reduced peak demand (18)<br>- Improved access to regulation power (10)<br><u>RE & SG:</u><br>- Improved reliability of supply and network (24)<br>- Improved grid operation (11)<br>- Improved security & stability of network (11)<br>- Postponed network investments (5) |

|  |  |  |
|---|---|---|

[1] The numbers refer to how many times the projects mention the specified types of value creation.

## 6. Discussion and Future Research Suggestions

Our review of the literature and pilot projects enables us to offer several future research suggestions. First, with respect to demand response services and services to increase the integration of renewable energy, more research can be devoted to studying business models that allow for a profitable delivery of these services. Second, our analysis shows that the focus on value creation for consumers in the pilot projects mostly relates to environmental benefits, lower energy consumption and lower energy bills, but there is hardly any attention for privacy concerns, which is relevant in most smart grid services in which information on consumer behaviour is transmitted to energy companies and system operators. A survey on consumers' opinion about smart grids shows that 26% of the 497 respondents have great concerns regarding security and privacy [7 Curtius et al., 2012]. Gerpott and Paukert [4] (2013) show that the lack of consumers' trust in the protection of their smart meter data negatively affects their willingness to pay for smart meters. Future research could focus on solutions for coping with the security of data exchange, and on integrating these solutions into smart grid services and into smart homes [52]. Third, future research should also be devoted to studying the roles of different actors in the business models of smart grid services. Several scholars have defined business models in terms of inter-organizational relations. For instance, in the nine building blocks of a business model, Osterwalder et al. [8] (2005) focus on the relationship of a firm with other firms to create and capture value. Zott and Amit [51] (2010) define a business model as a system of interdependent activities that transcends the focal firm and spans its boundaries. In a smart grid setting, the providers of smart grid services (e.g., the aggregator) depend on other companies, such as the system operators, operators of the electricity market and energy producers, to develop a business model and offer profitable services to consumers. Several articles in our review note that a great degree of uncertainty remains over the sharing of costs and benefits among the different actors, particularly concerning uncertainty related to the roles and responsibilities of the actors that offer smart grid services [e.g., 18 Siano, 2014, p. 475; 47 Roemer et al., 2012]. Future research should therefore study how incentives can be aligned among the variety of actors that are involved in supplying smart grid services, allowing each actor to earn (at least) sufficient revenue to cover their costs. Roemer et al. [47] (2012) argue for the development of cooperative business models to address the inefficiency effects of positive externalities. Finally, our results show that the literature offers insights on business models and value capture for service providers, whereas the pilot projects have a large focus on technical feasibility and value creation for system operators. Previous research has illustrated that the adoption of new technologies must be accompanied by new business models [6 Johnson and Suskewicz, 2009]. We therefore propose that future pilot projects focus more on the ability of service providers to generate revenue with smart grid services and that policy makers grant funds for new pilot projects that consider value capture in which results from simulation studies can be combined with real-life implementation [53].

## 7. Conclusions

This paper has addressed the business side of smart grid developments by offering an overview of state-of-the-art business models, value creation and value capture for smart grid services based on a review of the literature and pilot projects. The paper has demonstrated that the literature and pilots most often discuss three types of smart grid services: V2G and G2V services, demand response services, and services to integrate renewable energy sources. The literature review demonstrates that innovative business models have been implemented for V2G and G2V services and for connecting renewable energy to the grid, but with respect to demand response services and services that increase the integration of renewable energy, insights from the literature remain restricted to value creation and capture for consumers, system operators and service providers. The pilots indicate that the value for consumers most often relates to lower energy consumption and lower energy bills, whereas the value for system operators is concerned with reduced peak demand and improved system reliability. The pilots do not offer any evidence or discussion on business models, and they do not discuss how service providers can capture value by offering the three types of smart grid services.

The literature highlights the importance of a new actor in the smart electricity grid that is going to offer a variety of smart grid services. This new actor is an aggregator of EV batteries to offer V2G and G2V services, of consumer loads to offer demand response services, and of solar panels to connect renewable energy to the grid. The articles demonstrate that aggregation is necessary to make the business case profitable and that the aggregator must create and capture value by integrating a variety of smart grid services. Both the literature and the pilots discuss value creation by combining demand response and V2G and G2V services with the integration of renewable energy sources.

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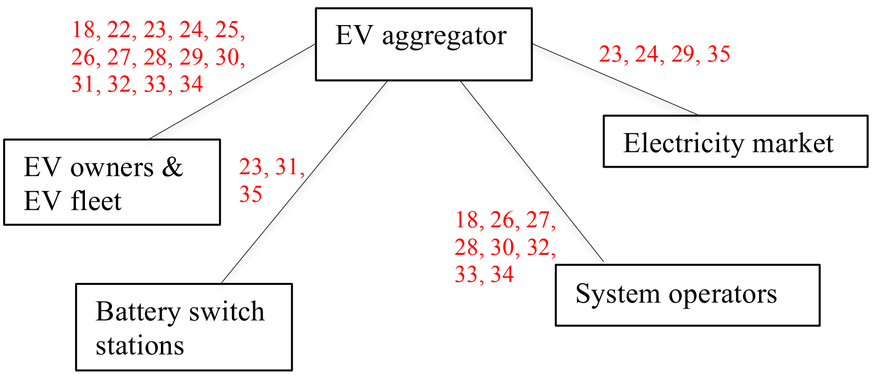
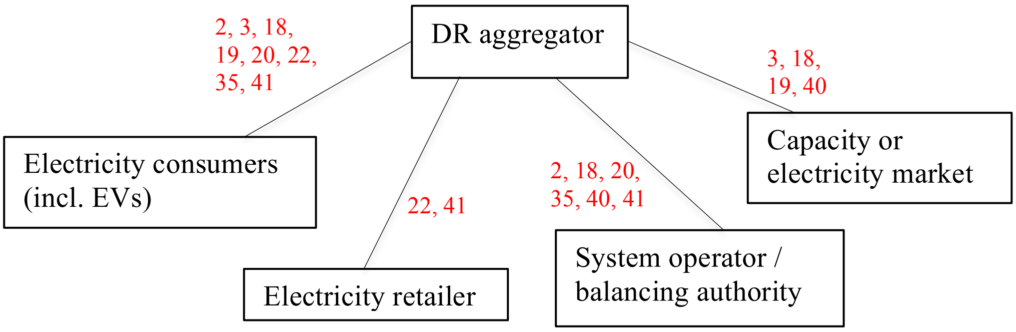
**Figure 1. Multi-sided platform for EV-services**[1]



1 Numbers refer to articles in the literature review

**Figure 2. Aggregator for DR-services**[1]



1 Numbers refer to articles in the literature review

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[i] Kempton and Tomić [54 2005b, p. 275-276] find that an EV battery that provides regulation services can deliver an annual profit of $2554, whereas a fuel cell vehicle offering spinning reserves will only create a profit of $262.

[ii] Isabel Kershner (2013-05-26). "Israeli Venture Meant to Serve Electric Cars Is Ending Its Run". *The New York Times*. Retrieved 2014-04-25.

[iii] "Another Clean Tech Startup Goes Down: Better Place Is Bankrupt". *The Atlantic*. Retrieved 2014-04-25.

[iv] In a simulation study, Dave et al. [41 2013, p. 275-276] find that "in order to provide a reliable demand response service, at least 27.5% of the population must participate." "For larger population sizes, there are generally fewer periods in which the saving is below the target level." Their data consist of 100 houses and 100 days of metering data for each house. Warren [20 2014] refers to 3MW of aggregated capacity as a requirement for participating in the UK balancing mechanism.