The electric vehicle and renewable energy: changes in boundary conditions that enhance business model innovations

Business model innovation consists of new ways of defining, creating, and capturing value including non-monetary value, and is an indicator of crossing traditional sector boundaries, thereby providing the necessary agency to achieve significant new market opportunities around technological innovation. Individual businesses may lack the scope or depth of competencies required, especially in the case of entrenched industrial structures, framings, regulatory provision, and consumer attitudes. Business models are thus potentially ossified within highly structured socio-technical systems. This article analyses innovation in business models arising from the confluence of two mature and stable industries under conditions of external pressure, deregulation, privatisation, and the emergence of a new, shared interest. We illustrate the paper with examples of vehicle manufacturers developing business concepts for vehicle-to-grid, domestic energy, second life, and industrial electricity provision from renewable energy. We find that in the period 2012 to 2020, 17 vehicle manufacturers used 38 electric models to test a diverse menu of options established from four applications with changes in boundary conditions that have influenced business model innovation. This process created space for energy policy and mobility policy to become increasingly intertwined as battery electric vehicles enter the mass market, raising questions over the future of automobility as well as electricity generation and distribution.

Keywords: Socio-technical transitions; V2G; second life battery; Li-Ion batteries; domestic energy storage; disruption.

1. Introduction

With increasing numbers of electric vehicles (EVs) and growth in electricity demand it is expected that the electricity supply system will come under strain, particularly with respect to peak demand (Aguilar et al., 2020). Growth in electricity supply is, in turn, expected to be more reliant on renewable energy sources (RES), notably highly variable sources such as solar photovoltaic (PV) and wind that may not necessarily reach peak output at times of peak demand. There will be, therefore, a need to manage or stabilise the electricity supply and demand system (Aguilar et al., 2020). Electricity generation and distribution activities have therefore become sensitive to events in the automotive industry and with automobility.

The business model is defined as how an organisation creates, delivers, and captures value, in economic, social, cultural, or other contexts. Automobility is often seen as a significant domain wherein profound socio-technical transition is an urgent priority (Brand-Correa and Steinberger, 2017). The technologies of the contemporary car, and the mobility practices that they give rise to, are widely acknowledged to result in multiple social, economic, and environmental burdens (Gössling et al., 2019). Emergent new technologies, alternative forms of mobility (Hildermeier and Villareal, 2014) for the development of sustainable transport (Berger et al., 2014) offer the perspective for the emergence of business model innovation (from the improvement of traditional business models or the emergence of an entirely new model) – and potentially herald the demise of the automobility system that has endured more than 120 years. Previously, vehicle manufacturers did not have to concern themselves about electricity supply as a factor in the demand for new cars, or with revenue possibilities arising from electricity storage or supply, but the need to charge battery packs in the vehicle has changed this perspective. Hence, there is a new confluence of interest between participants in the electricity system and the automobility system, which can influence sector policies and provide the emergence of business models innovation (BMI). That is, there is an under-researched area in which socio-technical transitions may provide the opportunities for business model innovation, while BMI may contribute to processes of socio-technical transition (Aagaard et al., 2021).

In this paper we explore the scope for business model innovation from the boundary crossing between the electricity and automotive socio-technical systems. BMI can include new organisational structures and new organisational processes. Organisational process innovations that provide the implementation of a new organisational methods in the company's business practices, are here defined as a subset of BMI. Overall, BMI can be as important as technological innovation for changes in consumption practices and environmental outcomes (Lüdeke-Freund, 2019; Lüdeke-Freund et al., 2019; Onufrey and Bergek, 2020). With established production and consumption practices, it may be necessary to create a bridge from traditional practices via business model innovations (Velter et al., 2020).

By focusing on the contextual setting of socio-technical systems, this paper seeks to identify and begin to address two significant research gaps regarding business model innovation: Boundary crossing by established incumbents; and boundary crossing in terms of socio-technical systems with potentially incompatible institutional logics. The contention in this paper is that business model innovation may be one mechanism whereby such logics are dismantled, and new institutional arrangements enacted, just as changes in boundary conditions can create the space for business model innovation (Wesseling et al., 2020).

The paper proceeds in the following manner. Section two discusses boundary spanning, conceptualised as processes to socialise organisational knowledge through the collection and codification of explicit knowledge into tacit knowledge. The contribution of business model innovation to socio-technical system transition is a neglected but emergent field of research (Aagaard et al., 2021). Section three outlines the methodology adopted and the scope of the paper. The fourth section provides a narrative on developments in the respective socio-technical systems electricity, while the fifth section gives an empirical account of business model innovation in electricity, and the automotive industry. Finally, section six provides a discussion and conclusions.

2. Boundary spanning and business model innovation in socio-technical systems

This section considers the relationship between business model innovation and socio-technical systems as an emergent area of research, notably to pursue sustainable production and consumption. It is pertinent that in a major statement on important research agendas in this area, Köhler et al. (2019:11) stated:

> "Firms and other industry actors play critical roles in sustainability transitions. As innovators, they develop new products, services, and business models, contribute to market creation for novel technologies, or work toward the formation of new industries."

Firms and other industry actors have been identified as potentially important to an understanding of socio-technical transitions, but also substantially neglected by research in this area.

Socio-technical system analysis locates organisations within wider networks of market and non-market relations, including regulatory and legal frameworks, institutional practices, and cultural attitudes and beliefs (Bohnsack, 2018). The theorisation proposes that socio-technical systems are dynamically self-reproducing but lack the 'hard' boundaries of closed systems in the physical sciences. There are multiple distinct socio-technical systems, each with dominant technologies and related institutional structures, collectively comprising functioning contemporary society (Geels, 2002; 2004). The socio-technical system concept is an abstraction deployed to reduce the complexity of multi-component, dynamic, complex reality (see https://transitionsnetwork.org).

Any socio-technical system has two important properties: It is enduringly self-organising, given coherence by the mutually supportive internal relationships of the system components; and it has a defined conceptual boundary that can be used to confine the unit of analysis. Much research has a focus on how change happens inside the system under analysis (Kemp et al., 1998; Hoogma et al., 2002; Markard et al., 2012), or on how systems can be destabilised by external forces (Turnheim and Geels, 2012; Stegmaier et al., 2014; Rosenbloom et al., 2018). There has been interest in the role of incumbents versus new entrants in system change and system stability (Wells and Nieuwenhuis, 2012; Geels, 2014), notably around the discontinuous impact of new technologies (Ansari and Krop, 2012; Bergek et al., 2013). Notwithstanding, there is a dearth of accounts of events at a corporate level as two previously distinct socio-technical systems come to coalesce or overlap.

Business model innovation can change boundaries and be an element in the processes of institutionalisation of co-evolution as new socio-technical systems are created (Hannon et al., 2013; Huijben et al., 2016; Sarasini and Linder, 2018; Onufrey and Bergek, 2020). There are multiple types of organisational boundary. The research literature has identified the science/policy boundary (Bednarek et al., 2018); the research/policy boundary (Sovacool at al., 2017); internal (hierarchal) boundaries (Duryan and Smyth, 2019); geopolitical and regulatory boundaries (Dare, 2018); supply chain boundaries (Brennan and Tennant, 2018); and the role of intermediaries in bridging between social actors (Shaw et al., 2018). Others have sought to highlight the way new entrants may engage in boundary spanning to achieve sustainable innovation (Reficco et al., 2018).

Initial work in these areas has focused on the enduring significance of mismatched institutional logics (Smink et al., 2015) which restrict boundary crossing. Boundaries can act to disrupt collaboration with other stakeholders, and business model innovation has been shown to be one mechanism by which boundaries may be managed (Velter et al., 2020; Wells, 2016). From a more narrowly business-focused perspective, business model innovation may be initiated to capture value from technological innovations (Zhang et al., 2017).

High rates of business model innovation may be indicative of a volatile context in which technological, regulatory, market or other changes reward such experimentation (McGrath, 2010). Socio-technical system confluence can therefore be understood as providing the incentive for BMI from one or both sides of the confluence, while the innovation processes are also a mechanism for furthering the degree and pace of confluence.

However, dominant incumbents from one regime can themselves be new entrants, albeit well-resourced, entrenched companies 'migrating' from their socio-technical system. Therefore, there are two related research questions in this paper:

- In what ways are instances of business model innovation cause or consequence of the confluence of two mature socio-technical systems?
- How far is system confluence managed by the cross-penetration of system incumbents?

As evidence of these processes, we would expect to observe two phenomena. First, we would expect to see dominant incumbents from one or both socio-technical systems to be engaged in business model innovation to cross into the other convergent system (Bohnsack, 2018). In conditions of system boundary asymmetry, we might observe that boundary crossing is largely one-way rather than bi-directional. Second, we would expect to see a high degree of variety or experimentation in those business model innovations commensurate with the uncertainty involved.

3. Methodology and scope

This literature review study establishes a narrative on the 'logic' of system confluence, and on the incidence of business model innovation. Following the call from Foss and Saebi (2017), for conceptual clarity this study considers BMI to refer explicitly to innovation in business structures and processes to provide new ways of creating and capturing value. BMI may require changes in the boundaries of the firm, and changes in internal organisational processes (Stieglitz and Foss, 2015).

The authors also relied on the procedures outlined by other authors for review studies (Webster and Watson, 2002) common both in the electricity sector (Aguilar et al., 2020), business model research (Wells and Nieuwenhuis, 2015), and in sustainable transport (Paulsson, 2018). Given the breadth of the issues covered, and wide geographic and temporal scope, data analysis of primary and secondary sources offers insights to pursue initial theoretical propositions (Costa et al., 2018; Dale et al., 1988; Heaton, 2008; Hakim, 1982).

The study was based on battery electric vehicles (BEVs), with all other ‘alternative’ power sources excluded. Research was limited geographically to the European Union (EU) and the period from January 2009 to June 2020 – reflecting the period since the mass marketing of BEVs started. Battery manufacturing and recycling were also both excluded, with the focus on the in-use phase of the battery lifecycle.

The searches were conducted from June to August 2019 using key words (Fig. 2) classified in two groups: (a) electricity generation and distribution analysis and (b) business model innovation within the electricity sector, and the automotive industry for academic journals, government sources, industry-specialist websites, and a diverse range of ‘grey literature’ sources necessary to identify projects and experiments (Chi et al., 2019). The literature relating to the electricity and automotive industries was classified into four themes pertinent to the research: (1) Vehicle-to-grid (V2G) – technology that allows the integration of the BEV with the electric power supply system, allowing the energy to be transferred between the BEV battery and the electricity network; (2) Domestic energy storage (DES) – home energy storage devices store electricity locally using BEV batteries; (3) Second life battery (SLB) – batteries that after fulfilling their functions in the BEVs can be used for other activities such as a stationary energy storage solution and; (4) Industrial energy storage (IES) – or a commercial energy storage system, that assists with energy security for those who adopt it, as it works as an emergency backup system providing energy when the electricity system is inoperative or expensively priced.

The search enabled the initial identification of a total of 616 items considering all the keywords adopted (Fig. 1). After screening the abstract by applying the inclusion criteria, 318 references remained. After full-text review, 190 were considered as summarised in Fig. 1. The result is a wide-ranging though not necessarily comprehensive account of initiatives at the interface between the two industries.

Fig. 1. Scheme of the research

Regarding the sources of energy generation, the analysis focused on solar PV and wind energy due to their characteristics such as low or moderate investment, possibility of decentralised production, micro-generation, and variable generation (Sovacool and Geels., 2016) as well as synergy of these two energy sources with the expansion of electric mobility (Costa, 2019; Di Silvestre et al., 2018). Hydro-electric power was excluded as it tends to be highly capital intensive, and potential energy can be stored in the water behind a dam to be released at need, reducing the requirement for electricity storage (National Academies, 2017).

4. Electricity generation and distribution, and electric cars

This section provides an account of the transformations underway in the electricity and automotive socio-technical systems that have, among other outcomes, combined to provide the rationale for confluence. Usually, the emergence of innovative business models comes from the interaction between new applications and new agents, as highlighted in Fig. 2 and underlined in the following topics.

Fig. 2. Frontier spaces in business model innovation

4.1. Electricity generation and distribution and the business environment

The grid electricity model is shifting from centralised generation in plants dominated by large public organisations to a more variegated structure including decentralised, deregulated, privatised, digitalised, small-scale, and RES (Sovacool and Geels, 2016; Kamenopoulos and Tsoutsos, 2019). The growth in the share of RES, especially solar PV, and wind, finds support in broad incentive policies in progress in most worldwide countries (IEA, 2020a). Globally, from 2019 to 2024, RES capacity is expected to grow by around 50%, with solar PV energy representing around 60% of the expected growth (IEA, 2019a).

Deregulation is expected to stimulate increased competition for dominant incumbents in the electricity sector, along with price reductions (Roberts, 2020). With greater financial pressure on state monopolies, privatisation often follows. The expansion of RES, especially solar PV and wind may accelerate the privatisation process as new operators organise to expand into the market together (Haar, 2020). For example, Japan's Tokyo Electric Power Company (TEPCO) and Denmark-based power provider Ørsted have partnership to invest together on RES projects associated with wind (Shibata, 2020). Wind and (especially) solar PV generated electricity are modular and scalable (Van de Graaf, 2019) as well as flexible, decentralised, and digitally enabled, with shared facilities composed of households and small companies (Olkkonen et. al., 2017).

Deregulation and privatisation are interconnected with decentralisation, digitalisation, and decarbonisation in the electricity industry (Bastida et al., 2019). Government policy supports the expansion of RES and citizen participation in the consumption and production of electricity (Geels et.al., 2016). Digitalisation enables new product and service offerings (Tian et al., 2021) such as Cars-as-a-Service (CaaS), Vehicle-to-Grid (V2G), Internet of Things (IoT), Smart Grid, and Virtual Power Plants (VPPs) (Di Silvestre et al., 2018) that can be collected under the umbrella term of ‘Electricity-as-a-Service’ (Zhou et.al., 2016; Mahmud et.al., 2020). Table 1 summarises the key characteristics of solar PV and wind electricity generation.

Table 1. Key characteristics of solar PV and wind electricity generation

4.1.1. Solar PV energy and the business environment

Solar PV electricity generation is often characterised by locally distributed via small and medium-sized agents, such as households and small businesses, that also meet their own energy needs. Falling prices for photovoltaic panels has enhanced their economic viability (IEA, 2019a). Distributed solar PV energy could shift economic and social gains from the national to the local scale via taxes, jobs, and an increased potential to attract new businesses to the locality (IRENA, 2019), while mitigating climate change by reduced carbon emissions (Geels et al., 2016; Rui and Lu., 2020). Financial gains in micro-generation[1] may attract small consumers. In the EU, from 2005 to 2016, electricity produced from RES increased by 107%. In 2016, 12% of renewable electricity was generated from solar PV compared with 0% in 2005 (EEA, 2019).

4.1.2. Wind energy and the business environment

Wind energy tends to be more capital-intensive than solar PV, with the involvement of large companies and government in major infrastructure projects which often stimulate social resistance, resulting in greater use of offshore installations. Despite the investments and operational challenges required wind generated electricity is a growing element of the strategic energy mix (Bompard et al., 2017).

Globally, between 2010 and 2020, there has been a dramatic improvement in the competitiveness of solar photovoltaic and wind technologies. During this period, the cost of electricity from solar photovoltaic energy fell 85%, wind (onshore) by 56% and wind (offshore) by 48%, resulting in an increase of around 350% in wind energy generation (IRENA, 2020a). In 2019, 32% of renewable electricity was generated from wind (15% in 2005) in the European Union[2] (DNVGL, 2019), and around 25% globally (IRENA, 2020b). The wind energy share expected to increase globally to around 40% by 2050 compared to 5% in 2017 (DNVGL, 2019).

4.1.3. *Business environment and crossing of borders by established operators*

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[1] This is the small-scale generation of electricity by individuals, small businesses, or communities to supply their own needs, as an alternative to the traditional electricity supply system.

[2] In this study the data from the European Union includes the United Kingdom

The innovation of business models involving the crossing of frontiers by established operators has been constant and striking. The deregulation with the decentralisation of the electricity sector, the appreciation of RES for environmental issues (decarbonisation) and energy security, technological development, and customer focus (Sovacool and Geels, 2016; Kamenopoulos and Tsoutsos, 2019), contribute to increasing competitiveness and have shaped the new business models.

An example is the virtual power plants (VPP) that are a resource to support the electricity transition involving decentralised generation collective computerised intelligence, and extensive use of online technology. The VPP concept assumes several small and medium scale virtually integrated generation facilities, consuming or producing electricity, can be a solution to increase energy efficiency. VPPs do not have power plants: they optimise the generation, consumption, and management of electricity and like the other segments, new business models might be necessary to enable the operational success of VPPs.

The transition to VPPs requires the connection of several types of flexible generation and consumption units via an energy management system capable of adding capacity to the energy system through the generation distribution system, energy storage system (ESS) and detachable loads (Pudjianto et al., 2007). The VPP application must focus on competitive and optimised commercial requirements capable of providing balance between generation and demand, as well as ensure the quality of controls and the perfect coordination of the operating system of all VPP modalities: centralised, decentralised and distributed (Peik-Herfeh et al., 2013).

VPPs incorporate many information and communication technologies and these resources generate competitive advantage to provide a high-performance control system to operate modern networks equipped with microgrids (Lopes et al., 2013). A VPP can integrate RES into the network, to balance supply and demand in real time using ‘smart’ meters (McKenna et al., 2012). VPPs integrated with innovative business models will allow energy efficiency in several ways, including the storage renewable electricity in vehicle batteries (Ju et al., 2016).

4.2. Battery electric vehicles and business model innovation

The BEV is one emergent element contributing to the potential disruption of the dominant vehicle manufacturing business model that has lasted more than a century (Wells and Nieuwenhuis, 2012; Costa, 2019).Vehicle manufacturers, the anchors of the automobility socio-technical regime (Geels, 2012), have a distinct business model characterised by large, centralised manufacturing facilities to achieve production economies of scale, dispersed inbound and outbound supply chains, networks of franchised dealers, and revenues predicated on the continued sale of new cars and associated financial services.

The BEV, as well as contemporary mobility practices framed by the set of multiple social, economic and above all environmental appeals (Gössling et al., 2019; Paulsson, 2018), challenges some aspects of the traditional vehicle manufacturer business model. Initial concerns over the range of BEVs were met with experimentation with 'usership' packages whereby consumers who bought a BEV could access another type of vehicle for occasional long-range use. An alternative is to lease the battery rather than sell it outright. With continued improvement in battery pack performance in terms of range, charge time, and longevity, these initial concerns are much reduced.

The battery electric powertrain (including the electric motor, power electronics, and battery pack) can account for around 50% of a BEV's cost (Küpper et al., 2018). Typically, the battery pack degrades over time and with use, and once it reaches about 85% of its original capacity it is no longer deemed fit for use in a car. If owners can recover some of the initial battery cost, or if vehicle manufacturers or third parties can take advantage of remaining, post-automotive, use from the battery pack, then there will be an economic and sustainability benefit (Mathews et al, 2020).

One new earning opportunity is the BEV charging infrastructure. In 2019, there were around 7.3 million charging points worldwide, with around 90% in the private sector (IEA, 2020b). After Tesla built its own charging network, other brands are taking similar initiatives. The IONITY alliance, a partnership between several brands (BMW, VW, Daimler, Ford, and others), has a high-performance charging network (around 400 points in Europe) that supports customers and generates revenue as a reseller of electricity.

Besides that, BEV super-fast charging (or extreme-fast charging) options are emerging with promise to be a further BMI option. For example, the company StoreDot from Israel claims the ability to deliver over 900 miles of driving range in an hour of charging. The average rate when charging from 10% to 80% of battery capacity is typically about half that. – Other companies such as Enevate and Sila Nanotechnologies, in addition to Tesla, are examining fast charging and super-fast charging solutions. Indeed, super-fast charging option presents some challenges (Mathews et al, 2020; Kane, 2018).

Managing the power grid for charging BEVs with super-fast equipment will be an additional challenge for operators. There is also the economic issue, as the investment cost (important component of the kWh price for the consumer) for the diffusion of this type of technology might be much higher than that of traditional charging stations. There is growing interest in the electricity sector to create distribution networks able to support large numbers of rapid-charging vehicles. Nonetheless, we can also note that for consumers this landscape has become very confusing, given the number of different technical specifications (plug types, charging rates, etc.) and providers with a wide array of charge rates and packages (Mathews et al., 2020; Wells et al., 2020)

However, the super-fast charging advocates claim that it is more environmentally friendly than its lower-capacity counterparts. Large-scale adoption will make it possible to reduce battery pack size, because being able to charge the BEV in a few minutes, there will be no need for batteries with a large charge capacity. Also, considering that most people drive well under 50 kilometres a day, it would be necessary to charge the battery (with a range of around 350 kilometres) once (or twice) a week (Mathews et al., 2020; Kane, 2018).

The BEV battery recycling business reveals revenue potential as well, as may so-called 'second life' applications in residential or commercial storage (Volkswagen, 2019). In the future another revenue opportunity may be the sale of used batteries. Nissan, for example, set up a repair and sales operation for used batteries ($ 2,850) for its Leaf models that need replacement (Evarts, 2018). This business has the potential to leverage the used BEV market as well as result in financial and environmental gains for automakers that adopt it.

In addition, the data generated by new technologies (connected vehicle and autonomous) and new services offered (CaaS) generate opportunities, never seen before (Costa, 2019; Sperling, 2018; Wells et al., 2020; Peters and Dütschke, 2014.) in the automotive industry. The extension of the vehicle into the home via domestic charging allows even more data acquisition possibilities of value to a diverse range of businesses. McKinsey (Bertoncello et al., 2016) estimates that by 2030 revenue from car data globally may reach US$750 billion. Together, these developments provide a favourable environment for additional earnings for vehicle manufacturers and the electricity industry, and others involved in data management and communication.

BEV penetration has been slow, taking only 2.6% of global sales of cars in 2018, mostly concentrated in China, USA and Europe that together represented around 90% of the total in 2019 (IEA, 2020b). However, regulatory pressures and improved supplies of battery packs has resulted in an upsurge in model offerings and, prior to the COVID-19 pandemic, significant growth in absolute and market share terms (Transport & Environment, 2019; IEA, 2020b). The increase in BEV penetration has been supported by acquisition incentives and carbon emissions reduction policies. In Europe, from 2021, phased in from 2020, the fleet-wide average emissions target for new cars is 95gCO2/km (European Commission, 2020). China's goal of carbon neutrality by 2060, the pursuit of air quality, oil security goal and global competition in the electrified mobility market make the development of BEVs a priority for the Asian country. Starting in 2018, China launched a combination of incentives and regulations to further accelerate BEV market share. Changing policies, along with increasing market openness and competition, have accelerated the share of BEVs in China, which as of 2020 became the market leader with 47% of the global BEV fleet.

The energy security and decarbonisation issues (about 90% of the energy consumed in US transportation comes from oil) makes the electrification of transportation an important geo-strategic issue in recent years in the country. Policies championed by the US federal government and led by California, have obtained support from several states in the implementation of incentives to promote the adoption of BEVs and maintain a prominent position in the dispute for leadership in new technologies (Transport & Environment, 2019; IEA, 2020b).

5. Business model innovation, electricity, and the automotive industry

This section illustrates the extension of the automotive industry into the realm of electricity supply. Four aspects have been chosen here (Fig. 3): V2G; DES; SLB, and IES. A full list of vehicle manufacturer initiatives in these areas is provided in Appendix A.

To assess innovative business models from the automotive industry's race for electrification, involving crossing borders with the generation of RES and the electricity sector, the research examined 126 projects between 2009 and 2020, as shown in Fig. 3.

Fig. 3. Automotive industry projects targeting electricity supply

The engagement of vehicle manufacturers in charging networks is a major topic not treated here and is clearly complementary to wider ‘penetration’ of these companies into the mobility lifestyles of their customers. In 2019, the charging infrastructure for EVs reached around 7.3 million public and private chargers worldwide, of which 25% were in Europe. Around 90% of the charge points are private and serve light vehicles in homes, buildings with several dwellings and workplaces (IEA, 2019b).

One aspect of BEV charging that is relevant here is the battery swap system. In this model consumers may have the option of leasing batteries and buying the cars separately, thereby greatly lowering initial purchase costs. Batteries that are swapped can then be charged at times of low demand or when RES have surplus electricity available, thereby assisting in peak shaving and grid stabilisation. This concept was initially tried by Better Place, an independent third party that failed to convince vehicle manufacturers to adopt the system.

At least two Chinese vehicle manufacturers have announced the return of the battery-swap system. The state-owned BAIC Group, the second-biggest seller of BEVs in China, started a test program with almost 200 battery-swap stations in 15 Chinese cities to service 16,000 electric-powered taxis. BAIC has plans for 3,000 swap stations, to supply a half-million EVs by the end of 2022 (AutomotiveNews, 2020).

The start-up NIO, a new entrant that intends to develop autonomous, electric, and intelligent vehicles, started a battery-swap test system with its ES8 model and intends to expand the system to other models. In May 2020, NIO celebrated reaching 500,000 battery swaps (AutomotiveNews, 2020; Garg, 2020). The battery pack can be charged in the usual manner, but the swap capability is attractive to customers because, by virtue of being designed for rapid (5 minute) battery swaps, it is also possible to upgrade the battery packs for more powerful or resilient versions.

The evaluation of BMI opportunities arising from the crossing of borders by established operators and covering the socio-technical systems of the automotive industries and the electric sector, revealed a predominant interest from automakers in processes involving V2G applications, as shown in Fig. 4. Naturally, the integration of the vehicle with the electricity network enhances the so-called vehicle-to-everything (V2X), an application capable of bringing great competitive advantages to those who master it, as it is from there that many other applications (e.g., vehicle-to-home-V2H, vehicle-to-building-V2B), leaving the vehicle covering several other needs (Costa, 2019).

Fig. 4. Cross-boundary projects by established operators

The analysis of the projects revels that the socio-technical advances in the automotive industry – as well as in the RES and electricity sector – focused of electrification revealed new applications, new players and fertile ground for the emergence of BMI, highlighted in the following topics (Fig. 4) and detailed in Appendix A.

The scope of applications related to business model innovation across system boundaries, in relation to value propositions (that is a part of business strategy), value creation and delivery (providing customer satisfaction), and value capture (process of retention of value provided by the transactions) of the analysed projects, reveal a diversity of new contributions and opportunities, as shown in Table 2.

Table.2. Value of applications related to business model innovation across system boundaries

5.1. V2G applications

V2G can work with three key attributes: unidirectional (V1G), bidirectional local V2G (V2H, V2B, V2X) or Bidirectional V2G. The first is 'peak shaving', returning electricity to the grid from the vehicle, of value at times of high demand with unidirectional V2G systems. The second is for the BEV to be a source of electricity for vehicle-to-home (V2H) or vehicle-to-building (V2B) or vehicle-to-everything (V2X). These applications do not typically directly affect grid performance, but they provide balancing mechanisms at the local level. The third is where BEVs are equipped to provide or receive electricity to the grid, helping smooth supply peaks and troughs and stabilising the grid system.

There is potential for BEV owners to earn revenues when selling electricity stored in the back to the grid, much as households with solar PV installations may do now. In turn, recharging of vehicle batteries can be allocated to times of low demand, typically at night or on weekends, when electricity prices are low. Bi-directional chargers are currently still too expensive for broader consumer acceptance, but the growth in BEV sales will assist in lowering costs for related systems such as this.

At the technical level, V2G in Europe is constrained in that only works well with the BEV charging standard developed in Japan known as CHAdeMO. Nissan uses the CHAdeMO charging protocol, whereas most European carmakers use the Combined Charging System (CCS), which does not currently enable V2G. The body promoting CCS, CharIN, said in 2019 that the standard will support V2G by 2025.

Development programmes are at the field trial stage in many cases, with commercialisation likely over the next few years. For example, EVBox, owned by French energy company Engie, has provided over 75,000 charging stations worldwide. In 2020 it started a V2G trial in the UK in a consortium consisting of Cisco, Cenex, Nuvve and Imperial College London, among others. CHAdeMO standard, there is an EDF initiative in Great Britain and France using corporate fleets of Nissan E-NV200 utility vans and Mitsubishi Outlanders that will cover a network of around 4,000 charging stations equipped with V2G technology.

5.2. Domestic energy storage applications

Domestic energy storage (DES) consists of providing battery packs independently from vehicles to provide the same storage and resupply to the grid as the V2G concept. It is best employed where the household has a renewable energy supply that is sometimes surplus to requirements (Sick et al., 2019), but in theory could also work with traditional mains electricity supply. Nissan, Renault, Volkswagen, and Tesla are the vehicle manufacturers that have revealed interest in this application. As with V2G, there are multiple trials underway for this concept.

While vehicle manufacturers may offer new battery packs for this type of application, Renault and Powervault are developing a different approach in the UK. Used batteries identified by the Renault dealer network, with a capacity above 70% remaining, are used via Powervault, in homes with PV installed (Powervault, 2020). Hence this approach treats DES as a second life application (see below). It is worth noting that the Renault Zoe is one of a few BEVs designed for easy battery removal, which allows the dealership network to participate in the scheme. Battery packs sent to Powervault are re-assembled into (smaller) battery packs. Consumers get the battery packs at a discount, about 70% of the full price if new modules were used (e.g., around £3,000 rather than £4,300 for a typical domestic system). The results show household electricity bills were lower and 20% of carbon emissions were cut from electricity consumption. In addition to reducing the peak domestic demand for electricity by up to 60%, the initiative prevents companies that look after the electricity grid from having to excavate to replace electricity cables (Powervault, 2020).

5.3. Second life battery applications

In so far, as the battery pack has viable operational capability beyond the application in the vehicle there may be 'second life' opportunities. In principle, the storage, peak use, and resupply options can also apply to second life uses. It is anticipated that the financial costs to the user would be lower due to depreciation. One application of interest is emergency back-up supply for hospitals, telephone networks and other related functions that require emergency generators at present. Tesla, Volkswagen, and the triple alliance Renault-Nissan-Mitsubishi are among the vehicle manufacturers that lead investments in this segment.

Stationary or static storage is anticipated to be less than 10% of total new battery demand as the supply of used batteries expands (Transport & Environment, 2019). However, the performance limitations of used batteries may still necessitate the use of new batteries.

5.4. Industrial energy storage applications

Industrial applications simply extend the scale of the household battery storage concept, but in doing so may allow more sophisticated services to be utilised. There are two main markets: Electricity generation and supply companies may want large back-up capability in case of grid failure or to store surplus renewable electricity; and large-scale users may want may lower total electricity costs by purchasing at low demand times and then storing. Some vehicle manufacturers are investing in projects in this field, but BYD and Tesla (Sick et al., 2019) have products specific to industry applications (Appendix A). Such schemes may help vehicle manufacturers, or their suppliers, attain economies of scale in battery production. Large-scale applications of this type could of course utilise second life battery packs, albeit with some performance limitations. As of 2020 the very limited supply of second life battery packs makes such a strategy infeasible. In many respects, industrial applications provide environments that are not as demanding as automotive applications. Issues of temperature, humidity, vibration, and other operational environment parameters are not as variable in industrial applications. It could be argued that using new automotive battery packs for large-scale installations is inappropriate when the design conditions are so different.

6. Findings and discussion

This findings and discussion section highlights three aspects: The electricity-automotive interface; business model innovation; and the relationship of these activities with socio-technical system confluence.

6.1. The interface between BEVs and the electricity supply system

The diffusion of electric mobility has caused some uncertainties related to the interface between BEVs, and the electricity supply system. The plethora of initiatives, shown in Appendix A, are illustrative of commercial experimentation as companies in the two sectors, and especially the automotive industry, search for the right ‘formula’. In turn, this means that there are multiple policy implications over issues such as the regulatory framing of markets for selling or reselling electricity.

In seeking to make BEVs a practical reality, the companies in (primarily) the automotive industry have sought to create a bridge between two previously distinct socio-technical systems, with BMI as a key mechanism. At the confluence between these two previously distinct socio-technical systems the research has shown that there is a new socio-technical system emerging. This new system is facilitated by BMI – from 2012 to 2020, 17 vehicle manufacturers and 38 electric cars (Appendix A) revealed a diverse menu of options. BMI includes the vehicle manufacturers, automotive suppliers, the battery industry, second life battery applications, mobility-as-a-service providers, power providers, renewable electricity suppliers, transmission and distribution system operators, energy storage systems (commercial and residential), BEV vehicle owners, BEV second-hand markets, fleets, aggregators, grid operators, virtual power providers, software suppliers, and participants from the information and communication services among others.

It is recognised that there have been previous efforts to manage the interface between BEVs and the electricity supply system, revealing that developing an innovative business model is a challenging and iterative process. Electricity supply companies have tended to take a passive or enabling role in the establishment of partnerships to enable features such as V2G, while retaining the core focus on the production and / or distribution of electricity. While electricity suppliers will be beneficiaries from the greater uptake of BEVs (via the sale of more electricity), they will also be beneficiaries from measures such as grid stabilisation and peak capacity reduction.

The threat for electricity suppliers comes from a growth in 'off-grid' applications that are more or less self-contained. This is already an attractive prospect in more isolated or impoverished locations (see www.afreecar.org) and could become established elsewhere. Battery swap systems, if further embedded, could offer the prospect of bulk purchasing power for vehicle manufacturers or third parties operating such systems.

6.2. Business model innovation in the automotive and electricity industries

The paper shows that there has been a wide range of business model innovation at the interface between the automotive and electricity industries, with battery technologies as the fulcrum. The paper also shows that there is no 'agreed' formula for success, and that not all vehicle manufacturers or electricity suppliers are participating in equal measure. At present, the experimentation revealed in this paper is small scale and tentative, but the growth trajectory remains clear. The automotive industry has the prospect of seamless integration between the home and the car from which multiple commercial advantages may flow. Whether remaining on the car or in some post-automotive situation, it is evident that battery packs are envisaged as a valuable resource from which further revenues could be derived. The emergent business model innovation identified in this paper is intended to control and capture some of these revenue opportunities by providing additional or new services to consumers.

6.3. Socio-technical system confluence

Is the BEV simply another electric product, an extension of the electricity consumption practices of households? Or is the BEV a 'Trojan horse' device, a means to enable vehicle manufacturers to penetrate, learn about and even control not just mobility, but also domestic and business energy use? The decline of fossil fuel use in cars will take decades to become apparent, but ultimately will result in a fully electric fleet. This process is likely to be mirrored in other applications such as domestic heating and cooking as electrification at point of use progresses.

In these conditions the two socio-technical systems are conjoined, but their elements are still distinct and separate. In so far as the automotive industry develops other technologies such as hydrogen fuel cells, there will remain a degree of independence between the two systems. However, the overall thrust of development is to create a combined or unitary automobility-energy system.

While the electricity socio-technical system has seen changes arising from the growth in BEV usage, it is apparent that the automotive industry that has been more active in seeking to capture and exploit the revenue and other opportunities arising. In this sense, confluence to date has been more about the automotive industry entering the electricity industry. The extension into the use of batteries beyond the car certainly blurs the boundary between the two systems. If fragmentation of the electricity system continues then the traditional 'cornerstone' industrial giants of generation and distribution could be displaced, with the automotive industry being one of the beneficiaries.

Thus, system confluence of this type creates new uncertainties and possibilities around changes in technology, governance, regulation, and markets. This paper shows that forces for change both within the two socio-technical systems and between them are at work, prompting business model innovation.

7. Conclusion

This study aimed at exploring the scope of business model innovation originating at the crossing of boundaries between the electric and automotive socio-technical systems. It showed multiple business experiments motivated by new applications, attracting new entrants, and providing new business models. For example, the V2G application required new institutional arrangements and attracted to the operation, in addition to the vehicle and electricity supply, the need for smart meter systems, smart grids, virtual application interfaces, home applications, management servers, communication systems, payment management systems, and related software. These features were incorporated to exploit changed boundary conditions thereby creating space for BMI.

From a regulatory perspective, the industrial confluence highlighted in this paper may be advanced or hindered by the regimes in force. There are wider considerations of energy security, safety, and the need to avoid consumer lock-in for example that might arise around business model experimentation. In a broad sense, policy packages that simultaneously address the electricity and automotive dimensions are needed, which in turn will feed into policy on transport, infrastructure, housing, and related fields. In a dynamic situation with high levels of technological and business model innovation, policy frameworks also need to be dynamic and fast response while providing sufficient continuity to encourage the needed investments.

The confluence of the automotive and electric socio-technical systems brings multiple policy implications for the design and management of electricity generation and distribution, particularly at the local scale where distribution networks may not be able to withstand peak demand clusters. It is also evident that regulatory frameworks are critical for BMI and in enabling or constraining the extent to which BEVs can be beneficial active participants in grid management.

Thus far the question of pricing has hardly been broached, while technical experimentation is under way. For household consumers or for corporate fleets a key concern will be whether the limited number of battery cycles available on each car should be ‘squandered’ in V2G or V2H applications, and whether the price paid for resupply to the grid will compensate for the accelerated depreciation of the battery pack asset? This may be an essential issue for the spread of BMI.

Furthermore, while there may be consumer beneficiaries of systems such as V2G what about those households that lack a BEV or the space for one to be charged? There is an equity issue here for disadvantaged households. Households lacking a BEV or access to one may be disadvantaged both in mobility terms and in terms of energy costs.

Another aspect to be highlighted in the context of BMI is the balancing the cost-benefit equation of running the electricity grid will need to be considered in parallel with resource utilisation of vehicle battery packs. Perhaps second-life applications for battery packs will encourage the premature retirement of BEVs as end-of-life vehicles. Given the resource intensity of battery packs and of vehicles generally it is important that both are fully utilised. Policy needs to be mindful of the resource costs of under-utilisation.

Perhaps also the use of BEVs in electricity systems and with an eye to second life applications will result in the use of larger than necessary battery packs, resulting in a waste of resources. It is already evident that the average size of battery packs has increased over the first ten years or so of market sales, with large sports cars and cross-over SUVs popular model applications for vehicle manufacturers.

Innovations such as battery swap will become more plausible as battery packs become standardised in form factor and chemistries and could then reduce the need for frequent rapid charging with the attendant stresses that places on battery management. Given the high rate of innovation in battery packs at present, standardisation remains elusive. Nonetheless, the multiple benefits of standard battery pack design, as well as installation and removal processes, should be an important policy target with direct impacts on BMI.

Finally, a relevant aspect regarding of BMI is that there is often an underlying assumption that ‘RES’ is the same as ‘infinite’ in energy discussions. Yet it remains a societal choice if we decide to use scarce RES to construct and operate large fleets of heavy, energy intensive vehicles. Even with distributed power sources such as PV, and at a household level, a key concern for policy must therefore be with the efficiency of electric mobility solutions. Despite the many contributions provided by the study, the authors recognise that the scarcity of published data from the projects limited the appreciation of the scope of innovative business models. The authors recommend that future studies can incorporate other RES in addition to solar PV energy and wind sources.

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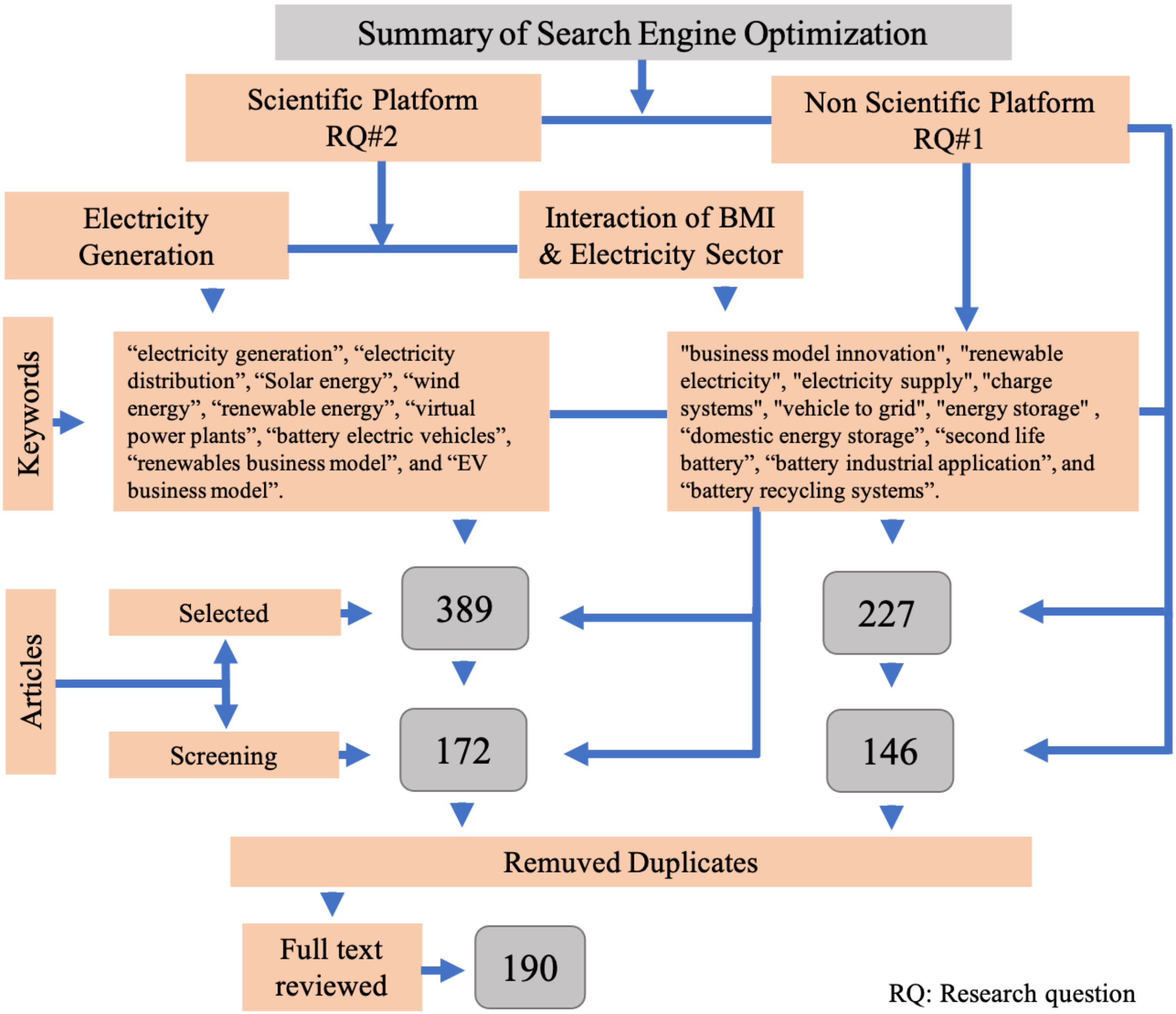

Figure 1

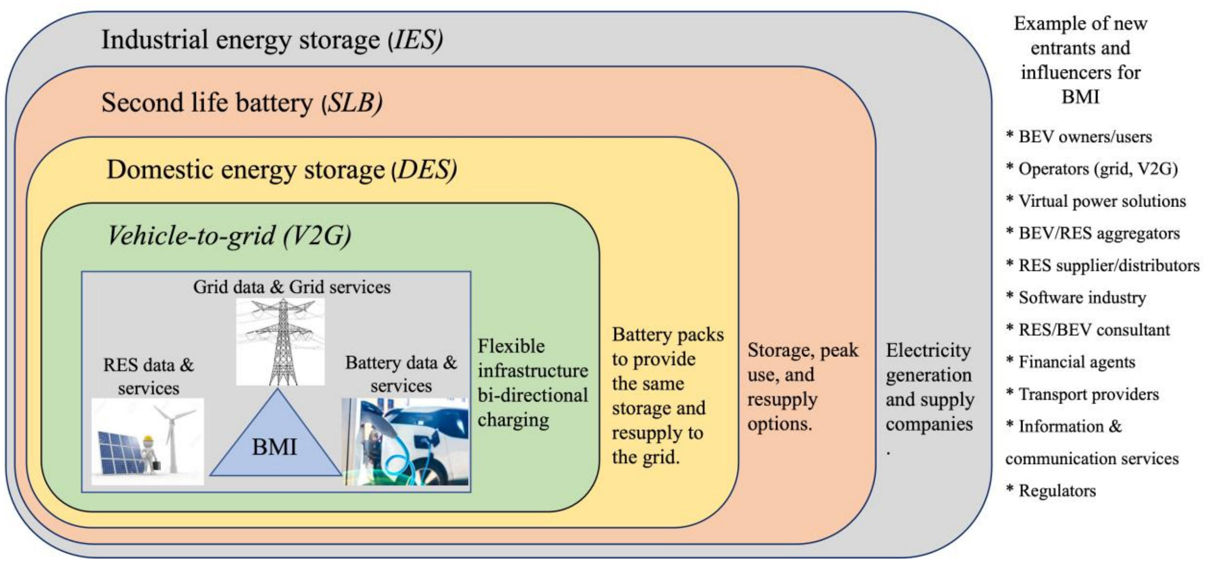

Figure 2

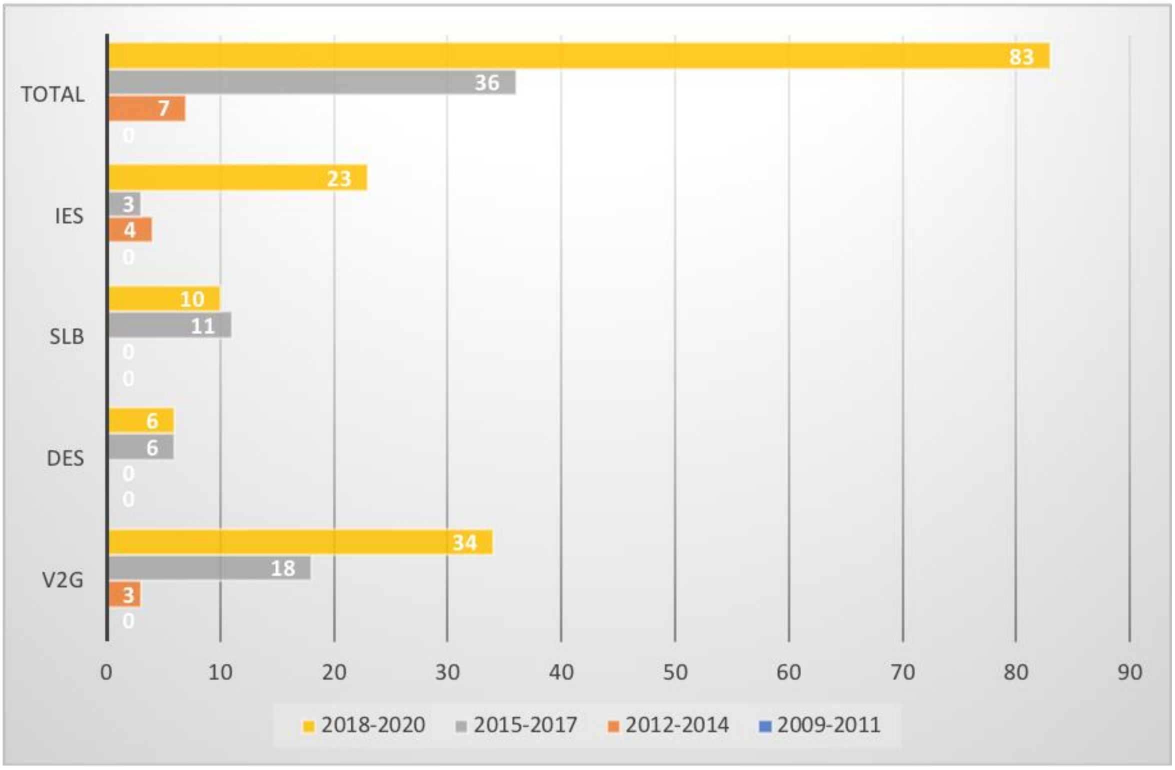

Figure 3

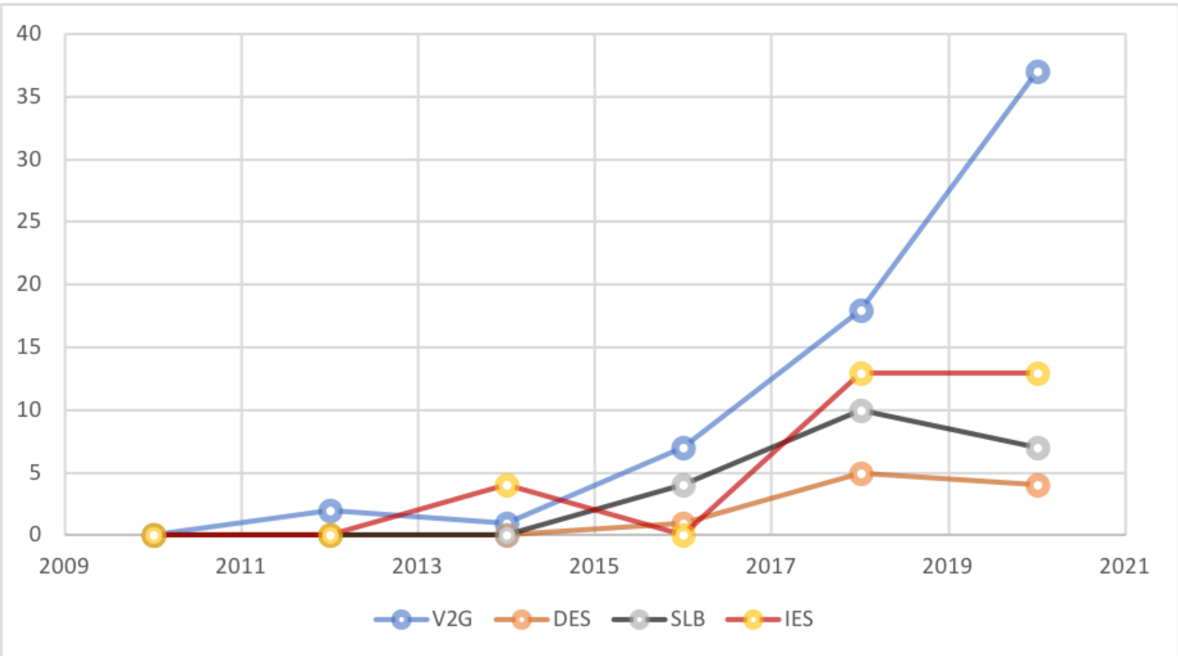

Figure 4

Table 1. Key characteristics of solar (PV) and wind electricity generation

Solar (PV)	Wind
Solar and wind energy are abundant but intermittent (Bompard et al., 2017).	
Both systems are modular (Van de Graaf, 2019).	
Both systems do not directly release harmful emissions (Rikki, 2019)	
Both systems offer rapid construction and payback (IRENA, 2012).	
Both are dependent on solar radiation, but wind energy is influenced by other variables (Rikki, 2019)	
Both are becoming more flexible and decentralized (Olkkonen et al., 2017)	
Solar (PV)	Wind
Solar constrained by aspect, latitude, seasonality, and climate. Concentrated Solar Power (CSP) works without direct sunlight but is expensive (Rikki, 2019).	Wind is an abundant resource and it is not limited by nights. Therefore, it can work 24 hours a day – but it is limited by weather patterns such as lack of wind (Rikki, 2019).
Low to medium investment (Bompard et al., 2017).	Medium to large investment (Bompard et al., 2017).
Large transmission network not required (National Academies, 2017).	Transmission network requirement (National Academies, 2017).
PV charges directly into electricity system (Rikki, 2019).	Wind farm generated electricity needs a transmission substation to increase voltage (Rikki, 2019).
PV easily installed in diverse locations (Gavhane, et.al., 2017; Rikki, 2019).	Wind turbines have restrictions e.g. distant from residential areas, trees, tall buildings, or low-wind areas. (Borch, 2018; Rikki, 2019)
PV requires only periodic dirt removal (Gavhane et al., 2017).	Wind turbines require regular maintenance check-ups (Borch, 2018; Rikki, 2019).

Large ‘solar farms’ rarely stimulate social resistance. PVs silent in operation (Gavhane, et.al., 2017; Rikki, 2019).	Large ‘wind often stimulate social resistance due to noise, visual pollution, and threat to wildlife. (Borch, 2018; Rikki, 2019).
PV is less efficient than wind turbine, converting 14% to 22% of available energy into power (Peng, et.al., 2017; Rikki, 2019).	Wind turbines are highly efficient, converting up to 60% of kinetic energy into power. (Rikki, 2019).

Table 2. Value of applications related to business model innovation across system boundaries

Applications	Value Proposition	Value Creation & Delivery	Value Capture
V2G	Provide intelligent energy management solutions integrating the vehicle with the electricity network to optimize the management of the network allowing greater penetration of renewables, reducing energy consumption and optimizing financial energy expenses of the consumer.	Generation of opportunities for new applications, e.g., software, hardware and virtual communication	Wider use of BEV (energy provider / manager). New BEV sales opportunities

DES	Provide energy consumption flexibility, eventually to reduce energy consumption and reduce consumer costs.	Provide flexibility, adding multiple consumer homes with more flexibility to the power grid and consumption of renewables.	Alternative revenue sources by winning over energy consumers. Scale and flexibility gains.
SLB	Provide energy consumption flexibility to eventually reduce energy consumption with low investment	Provide flexibility in energy consumption. Enable greater use of renewables and cost reduction.	Additional gains from using used batteries.
IES	Provide energy consumption flexibility to large consumers. Possibility of large-scale RES storage	Consumption flexibility for large consumers. Possibility of better consumption management with a reduction in energy costs.	Less dependence on power supply. Better management mechanism. Gains through flexible buying and selling.

Appendix A

Table A1: Projects involving automakers and renewable energies

Vehicle Manufacturer	Brand	BEVs	Vehicle to Grid (V2G)	Domestic Energy Storage (DES)	Second Life Battery (SLB) Applications	Industrial Energy System (IES) Applications
BMW	BMW	i3 Mini-E Mini Coopers iPerformance EV i8	* V2G, UCSD Invent, smart grid, California, USA (Manthey, 2020). * V2G, Willett Kempton, University of Delaware Florida, USA (Morris, 2014). * V2G, PG&E project, battery energy storage with PV, California (Szymkowski, 2017). * V2G, NREL, integrate project, back up battery with PV and wind, USA (NEREL, 2017).		* PG&E project, battery energy storage with PV, California (Szymkowski, 2017). * Vattenfall and Bosch, energy storage, Hamburg, Germany (GreenCar, 2016). * EVgo fast charging with second-life battery storage and PV, Los Angeles, USA (Kane, 2018).	* South Wales windfarm energy storage (Beckwith, 2018). * Onshore wind farm “Princess Alexia”, Netherlands (Lambert, 2017a).
BYD Group	BYD	e2 e5 e6 Quin EV Song EV				* UCSD, energy storage project, San Diego, USA (Margoni, 2014). * Amphora energy storage project, Ontario, CA (Kane, 2014). * Terna energy storage project, Italy (Cecchini, 2014). * RES Americas energy storage project, Ohio, USA (Giovinetto, 2014). * Doha energy storage project, Doha, Qatar (EnergyStorage, 2020). * Zenobe energy storage project, Essex, UK (BYD, 2018a).

Vehicle Manufacturer	Brand	BEVs	Vehicle to Grid (V2G)	Domestic Energy Storage (DES)	Second Life Battery (SLB) Applications	Industrial Energy System (IES) Applications
						* ML energy storage system, Poland (BYD, 2018b). * MIRIS energy storage project, CMI Energy, Belgium (Colthorpe, 2018a). * Novato energy storage project, Antelope Valley, USA (Holbrook, 2020). * Qinghai energy storage project, China (Colthorpe, 2018b).
Daimler	Mercedes	EQC			* Westphalian town of Lünen, project, GETEC, REMONDIS, battery storage, Lünen, Germany (Kane, 2015).	* Stationary energy storage and balancing of the grid (Lambert, 2017b). * Energiewende project, stationary storage facility, a Living Spare Parts Depot, Elverlingsen, Germany (Mobility House, 2018).
Fiat Chrysler Automobiles (FCA)	Fiat	Fiat 50 EV Panda EV	* FCA and Engie EPS at its Mirafiori plant, Turin, Italy with storage and PV (Hampel, 2020).			
General Motors	GM	Volt	* ABB, back-up second-life power storage system, San Francisco, USA (ABB, 2012).			
Honda	Honda	Fit-EV	* V2G, Moixa (EVTEC-GridShare), Project, UK (Mioxa, 2020). * Offenbach-EVTEC on the project, Germany (Autobeat, 2017)			
Hyundai Group	Hyundai Mobis	Ioniq	* V2G, KEPCO project, back up battery, Korea (Hwang, 2017).			

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Hyundai Group	Kia Motors	e-Soul e-Niro	* V2G, APEP project with Irvine University, USA (SmartEnergy, 2016).			
PSA Group	Peugeot	e-2008 e-Traveller iOn Citroen C-Zero	* PARKER, V2G and energy storage, Denmark (Nurve, 2020). * Goal, V2G and energy storage, France (Nurve, 2020). * V2G, Grid Motion Project, Energie, Enel, Nuvve, Proxiserve et l'Université Technologique du Danemark (Torregrossa, 2017).			
Renault-Nissan-Mitsubishi	Mitsubishi	i-MiEV	* UCSD Invent, smart grid, California, USA (Nurve, 2020). * PARKER, V2G and energy storage, Denmark (Nurve, 2020). * V2G and PV energy storage, Tokyo Electric Power and TEPCO Energy, Japan (Mitsubishi Motors, 2019). * V2G and PV solar storage, NewMotion and TenneT and Enel, 3rd phase, Netherlands (Newmotion, 2020). * V2G with battery storage, Alliander and Engie Smart City, Netherlands (AmsterdamSmartCity, 2020). * V2G with battery storage, Energie, Alliander, Amsterdam Smarty City and Universitatea de Stiinte, Netherlands (AmsterdamSmartCity, 2018).		* Mitsubishi (MMC), PSA, EDF, Forsee Power, storage system, France (Mitsubishi Motors, 2015).	

Vehicle Manufacturer	Brand	BEVs	Vehicle to Grid (V2G)	Domestic Energy Storage (DES)	Second Life Battery (SLB) Applications	Industrial Energy System (IES) Applications
			* V2G, e4Future project, and innovate, UK (UK Research, 2018). * V2G, SMERC project, UCLA, stationary battery, USA (Smartgrid, 2017).			
Renault-Nissan-Mitsubishi	Nissan	Leaf e-NV200	* V2G, SEEV4-City project, back up with PV, Netherlands (Costa, 2019). * V2G, Energy Storage and management Lab project, WMG, Ametek, UK (Clements, 2020). * V2G, WPD and CrowdCharge, UK (Schmidt, 2020). * V2G trials, Nuvve, Frederiksberg Forsyning, and Energinet, Denmark (PVEurope, 2016). * Nissan and Ugesi Energy, PV with EV battery, Africa (Kuhudzai, 2020). * Nissan and Fermata Energy, smart grid system, USA (Paroway, 2018). * V2G, TenneT and project, SINTEG, PV and battery store, Germany (Manthey, 2020). * UCSD Invent, smart grid, California, USA (Nurve, 2020). * ACES, V2G and energy storage, Bornholm, Denmark (Nurve, 2020).	* Solar panels and domestic battery pack, Netherlands (Costa, 2019). * UK Energy Storage Lab project (Clements, 2020). * Leaf_To_home project, Japan (Nissan, 2015). * WMG and University of Warwick for battery storage for domestic and industrial purpose, UK (Scott, 2020).	* R4 JV with Sumitomo, Japan (Nissan, 2018). * SEEV4-City project, Netherlands (Costa, 2019). * UK Energy Storage Lab project (Clements, 2020). * Nissan and Fermata Energy, storage system, USA (Paroway, 2018). * V2G Johan Cruyff Arena (*ArenA) in* Amsterdam (Colthorpe, 2019). * CEC, RMI, BWF And UC Davis, second-life battery storage with PV, USA (UC Davis, 2016). * Project ELSA. Nissan and Gateshead College second-life battery storage with PV, UK (ELSA, 2017).	* R4 JV with Sumitomo, stationary power storage (Nissan, 2018) * UK Energy Storage Lab project (Clements, 2020). * Project to reduce cost for larger manufacturing volumes (Stringer, 2020). * V2G Johan Cruyff Arena (*ArenA) in* Amsterdam (Colthorpe, 2019). * WMG and University of Warwick for battery storage for domestic and industrial purpose, UK (Scott, 2020). * Project ELSA. Nissan factory in Barcelona, project with 42 Nissan EV (ELSA, 2017).

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			* PARKER, V2G and energy storage, Denmark (Nurve, 2020). * Overview project, vehicle-grid integration, PV store system, Namibia (Nurve, 2020). * EDF and Nuvve, V2G, PV storage, UK (Field, 2018a). * V2G Johan Cruyff Arena (*ArenA*) in Amsterdam (Colthorpe, 2019). * V2G, The Mobility House, PV and storage system, Hagen, Germany (Kane, 2019a). * V2G, Enel X and Energy Sustainability Agency, PV and storage system, Chile (Manthey, 2019). * V2G, Invade project, stationary battery system, Belgium (ElaadNL, 2019). * V2G, Enel Energia and ITT, Italy (SmartEnergy, 2017). * V2G, ITHECA project, Energie, Cenex and Aston University, energy storage with PV, UK (Aston, 2016). * V2G, Magnum Cap project, EDF and Nuvve, back up battery, Japan (Magnumk, 2017). * V2G, Hitachi project, battery back-up with PV and wind, Hawaii (NEDO, 2018).			

Vehicle Manufacturer	Brand	BEVs	Vehicle to Grid (V2G)	Domestic Energy Storage (DES)	Second Life Battery (SLB) Applications	Industrial Energy System (IES) Applications
			* V2G, Delf project, TKI Urban Energy, battery back-up with solar and wind, Netherlands (Ram, 2017). * V2G, Delf project, TKI Urban Energy, battery back-up with solar and wind, Texas, USA (Ram, 2017). * V2G, Suvilahti project, Helen utility, battery back-up with PV, Finland (Aalto, 2017). * V2G, Power Networks and Northern Powergrid, power back-up, UK (Manthey, 2018). * V2G, zeem2All project, Endesa, back-up PV and wind, Spain (Reve, 2015). * V2G, NYSERDA project, Queen college and City University of New York, Battery back-up, USA (Nuvve, 2019). * V2G, WPD and CrowdCharge, Southwest and South Wales, UK (FleetNews, 2020). * V2G, Enel, Nuvve, E. ON Project, Netherlands (Steitz, 2019). * V2G, Enel, Nuvve, E. ON Project, Rome (Steitz, 2019). * V2G, Enel, Nuvve, E. ON Project, Genoa (Steitz, 2019).			

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			* V2G, ABB, 4R Energy and Sumitomo, USA (Tweed, 2012). * V2G, ReFLEX project, Scotland's Orkney Islands, UK (Dzikiy, 2019).			
Renault-Nissan-Mitsubishi	Renault	Zoe. Twizy. Fluence BEV. Renault Z.E. Kangoo Z.E.	* Porto Santo island with Madeira energy supply, Zoe-PV (Junceiro, 2019). * Utrecht, Zoe with We Drive (PV) Solar, Netherlands (Hunt, 2019). * Renault, Next Kraftwerke and Jedlix Cologne, Next Kraftwerke. V2G, PV and house integration, Germany (Field, 2018b). * V2G, IRIS project, Utrecht Lighhouse City, battery back-up with PV, Netherlands (IRISsmartcity, 2020). * V2G, Umicore project, to stability of the network, Belgium (Colthorpe, 2020).	* JV with Powervault (Beckwith, 2017). * Project ELSA. Kempton houses, stationary storage system (PV), Germany (ELSA, 2017). * EUREF Campus Renault project, stationary storage system (PV) for households, Germany (Mobility House, 2018).	* JV with Powervault using solar panels for houses and schools (Beckwith, 2017). * all-electric passenger boat appliance (Kane, 2019b). * Connected Energy, E-STOR, second-life storage energy, Belgium and Germany (Billancourt, 2017). * The stationary storage system, The Mobility House, Mitsui and Demeter Mitsui, Germany (Grundy, 2019). * Project ELSA. Stationary storage system (PV). United Technologies Research Centre, France (ELSA, 2017). * Project ELSA. E. ON-ERC and Aachen University, stationary storage system (PV), Germany (ELSA, 2017). * Project ELSA. ASM TERNI, stationary storage system (PV), Italy (ELSA, 2017).	
SEAT	SEAT	SEAT	* V2G, SUNBATT project, Endesa, UPC, IREC and CIRCE,			

Vehicle Manufacturer	Brand	BEVs	Vehicle to Grid (V2G)	Domestic Energy Storage (DES)	Second Life Battery (SLB) Applications	Industrial Energy System (IES) Applications
			back up battery, Spain (Colthorpe, 2020).			
Tesla	Tesla		* Tesla and TransAlta, WindCharger project, Canada (Lambert, 2020).	* Solar panels and domestic battery pack, Puerto Rico (Stephen, 2017). * Tesla SolarCity with Powerwall, USA (SolarCity, 2020).		* Tesla and PG&E Emergency Power system, Australia (Lambert, 2018a). * Tesla SolarCity with powerwall, USA (SolarCity, 2020). * Tesla and TransAlta, WindCharger project, Canada (Lambert, 2020). * Tesla and Amazon, PV with powerpack storage battery system, UK (Lambert, 2018b). * Tesla and MSP, with powerpack storage battery system, UK (Lambert, 2018c). * Tesla and DP with powerpack to manage power system, Africa (Kuhudzai, 2019). * Tesla gigafactory, Shanghai, China (Alvarez, 2020a). * Tesla gigafactory, Nevada, USA (Alvarez, 2020b). * Tesla gigafactory, Tilburg, Netherlands (Lambert, 2019). * Tesla gigafactory, Berlin, Germany (Tesla, 2020).
Toyota	Toyota	Camry Hybrid	* V2G, Toyota City and Chubu Electric Power project, Japan (Toyota, 2018). * V2G, Yellowstone Park project, with PV, California, USA (Toyota, 2015).			

Vehicle Manufacturer	Brand	BEVs	Vehicle to Grid (V2G)	Domestic Energy Storage (DES)	Second Life Battery (SLB) Applications	Industrial Energy System (IES) Applications
Volkswagen	Audi	e-Tron	* Smart grid solution, *Switzerland*[2]. * V2G, energy storage facility, EUREF campus, Berlin (Randall, 2019).	* Solar panels and domestic battery pack, *Switzerland (*Malony, 2018)	* Stationary energy storage facility, EUREF campus, Berlin (Randall, 2019).	
Volkswagen	VW	e-UP	* V2G, INEES project, SMA solar, battery back-up with PV, Germany (Kane, 2016).		* Limit peak electricity demand at the bus depot, Germany (Kane, 2020).	

PV = Photovoltaic panel