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Actors, business models, and innovation activity systems for Vehicle-to-Grid (V2G) technology: A comprehensive review

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Abstract: This study is motivated by the prospect of needing to harness significant flows of investment and finance, along with private sector commitment, towards decarbonizing passenger transport in Europe. It asks: what types of actors and stakeholder groups, business models, and resulting innovation activity systems might vehicle-to-grid (V2G) technology create or accelerate? Based primarily on qualitative research interviews and focus groups in five countries—Denmark, Finland, Iceland, Norway and Sweden, and a comprehensive literature review, the study assess stakeholder perceptions of primary and secondary business models for V2G. It identifies at least twelve meaningful stakeholder types and corresponding business markets: automotive manufacturers, battery manufacturers, vehicle owners, energy suppliers, transmission and distribution system operators, fleets, aggregators, mobility-as-a-service providers, renewable electricity independent power providers, public transit operators, secondhand markets and secondary markets. These business models fall into the five clusters of equipment, grid services, aggregation, bundling, and secondary markets. We then examine how these business models differ by innovation activity systems—that is, by content, structure, and governance. We lastly translate these findings into policy recommendations of relevance for all types of countries.

Keywords: business models; vehicle-to-grid; electric mobility; electric vehicles; vehicle-grid-integration

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1. Introduction

The decarbonisation of passenger transport in Europe represents a vexing public policy problem set to only worsen between now and 2050. For example, the European Commission notes that while greenhouse gas emissions from other combined sectors including buildings, electricity, and industry fell 15% from 1990 levels, transport emissions increased by more than 33%.¹ Looking to the future, the most recent reference scenario from the European Commission estimates an *increase* in demand for passenger-kilometers of 40% between 2015 and 2050.²

Enabling a transition to meet this growing demand for passenger transport, but also to remain low carbon and meet existing energy and climate targets, is an immense challenge of finance, because it can require “hugely ambitious” and “unprecedented” levels of upfront investment.³ Homes et al. project that €8.6 trillion needs to be invested in low-carbon transport, buildings, and electricity by 2020.⁴ Moreover, the nature of how transport, freight and mobility infrastructure are currently funded requires a mix of private and public commitment, especially for options such as electric vehicle charging stations which cut across public and private rationales.⁵

This study is motivated by the prospect of needing to harness significant flows of investment and finance towards electric vehicles, in ways that motivate both public and private actors. We ask: what types of actors and stakeholder groups, business models, and resulting innovation activity systems might vehicle-to-grid (V2G) technology create or accelerate? An automobile capable of “vehicle-to-grid” (V2G) interaction, sometimes referred to as “mobile energy,” “smart charging,” or “vehicle-grid integration” (VGI), mates an automobile with the existing electric utility system.^{6 7} A growing body of evidence suggests that such intelligent, two-way communication between the electricity grid and the vehicle could enable utilities and suppliers to manage electricity resources better, and it can

empower vehicle owners to earn money by selling power back to the grid.^{8 9 10 11 12 13 14 15}

Essentially, a V2G configuration means that personal automobiles have the opportunity to become not only vehicles, but mobile, self-contained resources that can manage power flow and displace the need for electric utility infrastructure. They operate as “vehicles” when drivers need them but switch to “storage sources” when connected to the power grid.¹⁶

Indeed, as illustrated in Table 1, Noel et al.¹⁷ argue that V2G technology remains a pivotal point where it could proceed along pathways of no to low diffusion, or instead revolutionize transport according to medium to high levels of penetration.

Table 1: Five global and highly contingent V2G pathways as of 2019

<u><i>Scenario</i></u>	<u><i>Renewable Energy Level</i></u>	<u><i>Role of Conventional Energy</i></u>	<u><i>Role of V2G</i></u>	<u><i>Potential Drawbacks</i></u>
<i>Conservative backlash</i>	Low to none	Remains the dominant (or even sole) actor in the electricity market	Low to none	Return to cars powered by fossil fuels or non-electrical sources not suitable to V2G such as biofuel
<i>V2G Remains a Niche</i>	Low-Medium	Remains primary actor in the electricity market	Largely remains ancillary service actor	Electricity grid misses out on cheap form of storage, potentially less EV diffusion
<i>High V2G, Dirty Grid</i>	Low	Remains primary actor in the electricity market	Dominates ancillary service market, acts as backup storage to renewable, but in a limited fashion	V2G storage capacity is underutilized, could be used for more renewable energy
<i>High V2G, Renewables in a Traditional but Decarbonized Grid</i>	Medium-High	Backup capacity to renewable energy, rarely used	Provides ancillary service and frequently provides a variety of storage and flexibility to renewable energy, high utilization rates	Electricity grid is highly dependent on V2G, and runs the risk of interfering with EV owner’s driving demands (or prove unreliable)
<i>The Super-Smart Grid</i>	High	Play no or a very limited role, most electricity is renewable	Focuses on local balancing, ancillary services, and emergency backup, one of many smart grid actors	V2G system receives less economic benefits, but society benefits more, super-smart grid also difficult to implement

Source: Noel et al.¹⁸

In this paper we provide a comparative and mixed methods assessment of the business models for V2G drawing from research interviews and focus groups in five countries—Denmark, Finland, Iceland, Norway and Sweden—as well as a comprehensive literature review. In doing so, we offer a compendium of business models grounded in mixed methods data, a rarity in the field; we help identify different actors and how they connect to emerging industrial networks and business models; and we tease out policy implications as well as how they intersect with compelling issues of temporality and timing, structural drivers, and governance. More specifically, the paper aims to make four contributions.

First, it expands our lexicon of the diversity of V2G business models. In their overview of the V2G market, for instance, Quinn et al. argue that two ancillary services markets with two corresponding stakeholders of the grid system operator and the vehicle owner are the most salient.¹⁹ Hein et al. identify three different business model segments for V2G: selling storage capacity, selling their old batteries, and using new batteries in stationary modes.²⁰ Similarly, in their marketing material, Nuvve, a V2G company, frames possible customers across four different stakeholder types:²¹

- Car manufacturers, eager to sell more vehicles;
- Vehicle owners and fleet managers, eager to drive more cheaply or sustainably;
- Transmission system operators, interested in grid services;
- Distribution service or network operators, also interested in grid services;
- Policymakers, interested in less pollution or more jobs.

Building and extending this work, we identify at least 12 meaningful stakeholder types and corresponding business markets: automotive manufacturers, battery manufacturers, vehicle owners, energy suppliers, transmission and distribution system operators, fleet operators,

aggregators, mobility-as-a-service (MaaS) providers, renewable electricity independent power providers, public transit operators, secondhand markets, and secondary markets.

Second, across these 12 different actors, we examine primary business models, such as selling equipment or vehicles, and secondary business models, such as energy services or software, for V2G as well as a variety of services and contexts, and we also translate these findings into policy recommendations. Wesseling compellingly writes that the process of EV diffusion needs to be steered by strong policies.²² Whether a government was classified as “hands-off,” an “enabling facilitator,” or an “interventionist director” strongly impacted adoption rates. However, Kester et al.^{23 24} imply that too frequently policy for electric vehicles and V2G is conflated as being the same thing, when in fact each require a very distinct and nuanced set of different policy mixes. Geske and Schumann affirm the necessity of policy support specifically for V2G, when they note that the transition from batteries to mobility control needs to be facilitated by third parties, i.e. beyond merely vehicle manufacturers and adopters.²⁵ Uddith et al. add that strong policies are needed to ensure better battery management in vehicle and electrical grid applications.²⁶

Third, rather than relying on a narrow conceptualization of business models as only related to value and revenue, we draw on recent research suggesting such models are embedded within innovation “activity systems.”^{27 28 29 30} Innovation activity systems underscore that for business models for V2G to be successful, they must simultaneously promote content (such as charging and grid services), structure (integration of supply chains), and governance (stable rules and policies).

Fourth and lastly, the paper seeks to address a puzzle that has emerged over the potential business case of V2G and VGI electric vehicles (EVs). On the one hand, there are ample studies suggesting strong profits, market potential, and revenues. Looking at South

Korea, for instance, Hong et al. conclude that maximum profits for V2G service providers could equal 1.27 trillion won (or about \$112 million).³¹ Noel et al. analyze V2G pathways in Denmark, and note that at an optimal penetration rate of 75% by 2030, \$34 billion in social benefits would be accrued (due to displaced pollution) or a cost savings of \$1200 per vehicle.³² In the United States, Li et al. argue that EVs could generate an annual profit for providing regulation services of \$318 to \$454 per automobile.³³ Kempton and Tomic calculate that the market promise for V2G could be substantial, given that the market for grid services in the United States, equals roughly \$12 billion per year.³⁴ In a separate simulation of the United States, Quinn et al. calculate that after an initial investment of \$500 to \$800 to upgrade a home power connection, and a utility infrastructure upgrade of \$2,000, V2G infrastructure has a net positive return ranging from \$3,268 to \$7,942³⁵—meaning it pays for itself in less than a year. Noting the value-creation opportunities from offering V2G capability on private passenger vehicles, V2G can act as an attribute to foster wider EV adoption.³⁶ When operated as fleets of vehicles that can aggregate the services they provide, the economic and social benefits of V2G can only multiply beyond those of individual cars.³⁷

On the other hand, such evidence is contrasted with multiple studies, with varying methodologies and units of analysis, suggesting much smaller to negligible benefits. In Sweden and Germany, it is projected that maximum average profits for simulated V2G benefits are low to nonexistent.³⁸ In Germany particularly, the monthly revenues of V2G are projected to be less than €5 per month per vehicle.³⁹ In Western Australia, Mullan et al. conclude that “most variants of vehicle-to-grid currently require too much additional infrastructure investment, carry significant risk and are currently too costly to implement in the light of alternative options.”⁴⁰ In Ireland, V2G is argued to have only nominal potential to improve grid efficiency, and rather negligible contributions to emissions reduction and financial savings for drivers.⁴¹ In Singapore, profits from simulated V2G are also “not

expected to make V2G a viable business case.”⁴² Our study therefore seeks to contextualize and situate such variance across this body of puzzling evidence.

The study begins by elaborating more on business model definitions and frameworks before we explain its application to V2G through the notion of innovation activity systems. It then discusses key “Results” organized by twelve categories of actors (stakeholder types or market players), and analyzes “Results” according to the innovation activity systems dimensions of content, structure, and governance. It concludes with twelve priority areas for energy and transport policy.

2. Conceptual framework: V2G Business Models and Innovation Activity Systems

At its most basic level, a business model refers to how a private sector or market-based entity—a company, a firm, a business, or even public or social enterprise—tries to generate or capture value. Chesbrough defines business model innovation as “a series of activities from raw materials through to the final consumer that yield a new product or service with value being added throughout the various activities.”⁴³ A business model thus links the workings inside a company to outside elements such as consumers or financiers or investors, and it also creates, captures, or monetizes value.⁴⁴ Business models are usually or at least often designed with acquiring a competitive edge in mind, with Afuah writing that “A business model is the set of activities a firm performs, how it performs them, and when it performs them as it uses its resources to perform activities, given its industry, to create superior customer value (low-cost or differentiated products) and put itself in a position to appropriate the value.”⁴⁵ In their survey, Kley et al.⁴⁶ break “classic” business models down into three elements:

- Value proposition: the presumed or expected value of a product or service offered by the manufacturer to the client beforehand (e.g., a traditional car manufacturer delivering a Model T to a customer with the specific features they wanted);
- Value chain configuration: The possibilities to design the product offered with regard to the different shareholders involved in a business model (e.g., for that Model T, the manufacturer provides the car but the owner or driver must complete maintenance, check-ups, fueling, etc.);
- Revenue model: This stipulates the type of payment the customer makes to the supplying shareholder as part of the offer, designed to cover costs (and risks) and also generate a profit (e.g., for the Model T, it may be a leasing model where the customer pays for the vehicle in instalments, with other services such as fueling and maintenance offered by other providers).

The ever-growing literature on business models suggests that business models can include not only rationales for delivering or capturing value, but also conceptual frames that better articulate the logic behind what firms do and the strategies they employ when they compete.⁴⁷ A number of sub-topics often fall within the business model theme, including business strategy, value creation, online and e-business models, and the role of business models in research, sociotechnical innovation, or sustainability.

In the application of business model frameworks to EVs, Kley et al. argue that a continuum of three basic business model types will likely operate, summarized by Figure 1.⁴⁸ When applied to electric mobility, two results exist for a mobility customer: buying the product in the form of a vehicle (product oriented, things like financing, insurance, inspection and repair services) or the service in the form of a taxi or carpool (service oriented). Between these two “extremes” however are other dimensions, including use-oriented options (such as mobility guarantees) or result oriented options (such as transport services).

The diagram illustrates the classification of business models and their relationship to product and service content.

Business Models Hierarchy:

- Business Models**
 - Product-oriented**
 - Financing
 - Insurances
 - Inspection and repair services
 - Service-oriented**
 - Use-oriented**
 - Mobility guarantee
 - Car Sharing
 - Fleet concepts
 - Result-oriented**
 - Transport service

Content Spectrum:

A horizontal bar at the bottom represents the spectrum of content, ranging from **Product content** on the left to **Service content** on the right.

Given that conventional or even new business models may not apply directly or completely to emerging innovations such as V2G, we focus not only on value creation, revenues, and mobility services, but also the “activity system” behind the design of business models and entrepreneurial firms, drawing from Zott and Amit.^{50 51 52 53} According to them, a business model can also be conceived of “a system of interdependent activities that transcends the focal firm and spans its boundaries”, hence their term “activity system.”⁵⁴ Rather than focusing only on a single firm—say, a V2G provider or EV manufacturer—their framework instead demands that one assesses interdependencies and interactions between multiple forms and associated networks of suppliers, partners, and customers. Successful business models are often able to incorporate these diverse elements into key components of a system that has *content*, *structure*, and *governance*. Content refers to the actual business or entrepreneurial activities performed, such as (for the V2G case) vehicle charging, electricity

supply, or provision of ancillary grid services. Structure refers to how such activities are linked together, perhaps via supply chains or different infrastructural configurations. Governance refers to the institutions, parties, rules and norms that manage these activities. Business model innovation, according to this view, can occur not only by delivering new products or services (content) but by reforming or challenging infrastructural configurations (structure) or rules, norms, and policies (governance). We will return to these themes later in the manuscript, after explaining our research design and presenting our results.

3. Research design: Nordic Expert research interviews, focus groups, and a literature review

To collect original data on V2G business models and activity systems, we first selected the Nordic region for examination, given high per capita adoption rates and strong decarbonisation-related policies in place there. We then relied on three primary methods across all five Nordic countries: interviews with V2G experts, focus groups with the public, and a literature review. The interviews and focus groups in particular used a congruent methodology that asked the same questions across both types of respondents, in an attempt to better triangulate data and ultimately findings.

3.1 Case study selection

The five Nordic countries of Denmark, Finland, Iceland, Norway, and Sweden were selected for analysis because the region remains the world leader in the per capita deployment of battery-powered electric vehicles, or EVs. When we started our field research, the Nordic region saw the total stock of EVs reach 250,000 cars by the end of 2017, meaning that the region accounted for 8% of the global total, the third-largest share after China and the United States.⁵⁵ Trends have further accelerated since then; in 2018, the global electric car fleet exceeded 5.1 million, up 2 million from the previous year and almost doubling the number of

new electric car sales. While China was the largest electric car market, Norway remained the global leader in terms of electric car market share.⁵⁶ Fully electric cars made up 42.4% of sales in Norway in 2019, a global record, rising from a 31.2% market share in 2018 and just 5.5% in 2013.⁵⁷ Thus, the per capita diffusion of EVs across the Nordic region is the highest in the world at 10.6% in 2018; the growth rate the highest in the world (up 57% from the previous year); and Norway saw EVs representing 39% of annual new car sales.⁵⁸

However, the Nordic countries do indeed have very different regimes for automobility and thus EVs and electric mobility, exhibiting variation across markets and policies. As Table 2 overviews, at the time of our fieldwork the countries showcase fairly radically distinct levels of EV incentive programs and markets.⁵⁹ This makes them an interesting testbed to examine innovation profiles and possible business models.

Table 2: An overview of the electricity and mobility regimes in the Nordic region

	Iceland	Sweden	Denmark	Finland	Norway
Per capita income	56.990	54.630	56.730	44.730	82.330
CO₂ emissions (metric tons per capita)	6.08	4.62	6.78	8.51	11.74
% Renewable Energy Supply	88.5%	45.9%	28.4%	32.3%	44.6%
Relation to European Union	EEA	EU	EU	EU (EURO)	EEA
Climate Targets (in relation to Transport)	<ul style="list-style-type: none"> •2020: 10% RES share in transport. •2050: 50-70% reduction in GHG (comp. 	<ul style="list-style-type: none"> •2030: 63% reduction (to 1990 levels). •2040: 75% reduction. 	<ul style="list-style-type: none"> •2020: 20% (comp. to 1990 levels) in non-ETS sector (incl. transport). 40% ETS sector. 	<ul style="list-style-type: none"> •2030: Reduce transport GHG emissions by +- 50% (compared to 2005). First replacing 	<ul style="list-style-type: none"> •2025: No new traffic growth in cities and all new passenger vehicles Zero-Emission •2030: over 50% of

	to 1990 levels)	<ul style="list-style-type: none"> •2045: complete carbon neutrality (= 85% reduction to 1990 levels). •Transport: 70% reduction by 2030 compared to 2010. 	<ul style="list-style-type: none"> •2030: 50% renewable energy •2050: complete carbon neutrality. Copenhagen's target = 2025. 	current fuels (with biofuels). then alternative technologies and services. targeting 250.000 PEVs / 50.000 gas-fueled vehicles. •2050: 80-95% reduction in GHG (compared to 1990).	heavy/commercial transport zero-emission and 50% reduction of GHG emissions (Oslo = 95%) •2050: 100% reduction
EV Incentives	<ul style="list-style-type: none"> •Purchase. VAT. Annual Ownership tax exemptions •Support for charging infrastructure 	<ul style="list-style-type: none"> •Subsidy on new BEV (4000e) and PHEV (2000e) •Company car reduction •Five-year exemption of annual ownership tax 	<ul style="list-style-type: none"> •20% purchase tax until 5000 cars or 2019 (revising the phase out of tax exemptions (up at 40%) •Differentiated parking. •Tax rebates for chargers 	•EVs pay minimal technical purchase tax and ownership tax. no other special arrangements.	<ul style="list-style-type: none"> •Purchase tax. VAT exemptions; •50% company car tax •Since 2015 local authorities decide on pricing level of PEV parking. toll roads. ferries and HOV lanes (max 50% of highest price). •Infrastructure support on national and local level.

Source: Authors, modified from⁶⁰

3.2 Semi-structured expert interviews

With our case study countries selected, we then conducted 227 semi-structured expert interviews with 257 participants from over 200 institutions in the five Nordic countries. As shown in Table 3, the experts represent a diverse array of stakeholders involved in transportation, energy and the environment. These interviews generally lasted between thirty

and ninety minutes, and participants were asked several questions about the benefits and barriers of both EVs and V2G. More specifically, we asked them:

1. What do you see as the Nordic region's greatest energy or transport policy challenges?
2. What is the history of EV or V2G use in the Nordic area?
3. What benefits does a V2G transition offer the Nordic region and/or particular countries?
4. What challenges remain to be addressed?
5. What policy mechanisms can accelerate adoption?

Naturally, the topic of business models arose within the interviews—with surprising frequency in some cases—across questions 3, 4, and 5. After collection of the interview data, each interview was subsequently fully transcribed, and then coded. We refer to each respondent here with a unique respondent number (e.g., R257).

Table 3: Characteristics of Nordic research interview sample

Classifications	Interviews (n=227)	Respondents (n=257)	% of Respondents
Country			
Iceland (Sept-Oct 2016)	29	36	14.0%
Sweden (Nov-Dec 2016)	42	44	17.1%
Denmark (Jan-Mar 2017)	45	53	20.6%
Finland (Mar 2017)	50	57	22.2%
Norway (Apr-May 2017)	61	67	26.1%
Gender			
Male	160	207	80.5%
Female	40	50	19.5%
Groups	27		
Expertise			
Transport or Logistics	73	81	31.5%
Energy or Electricity System	63	75	29.2%
Funding or Investment	10	12	4.7%
Environment or Climate Change	12	16	6.2%
Fuel Consumption and Technology	22	23	8.9%
Other	13	14	5.4%
EVs and Charging Technology	34	36	14.0%
Sector			
Commercial	68	70	27.2%
Public	37	46	17.9%
Semi-Public	40	51	19.8%
Research	37	39	15.2%
Non-Profit and Media	12	13	5.1%
Lobby	23	25	9.7%
Consultancy	10	10	3.9%

Source: Authors.

3.3 Public focus groups

Although expert interviews provided in-depth discussion of electric vehicles, focus groups were concomitantly organized in order to complement expert perspectives with more public or laypersons perspectives. In total, eight focus groups were conducted, using the same questioning protocol as the interviews, with a total of 61 participants across six Nordic cities, as shown in Table 4. Interestingly, none of the focus group participants actually owned an EV, although 13.1% had at least driven or ridden in one. Nonetheless, given that effective business models for V2G must convince current adopters as well as non-adopters and members of the general public, the focus group results offer crucial insight into the more general and mass market attitudes concerning the technology. In addition, two of these focus groups were exclusively a single gender (one all-male, one all-female) and asked additional questions about how gender affects EVs and V2G. Each focus group was asked similar questions as those asked the experts, namely about their perceptions of EVs and V2G benefits and barriers to adoption. However, the free-flowing nature of focus groups also allowed the discussion to cover various other relevant topics. Similarly, after data collection was complete, each focus group was fully transcribed and coded. We refer to each focus group here by name and number, e.g. “FG4 Finland.”

Table 4: Characteristics of Nordic focus group sample

Classifications	Participants (n=61)	% of Participants
F1: Iceland (Oct 2016)	5	8.2%
F2: Sweden (Nov 2016)	6	9.8%
F3: Denmark [Mixed Gender] (Feb 2017)	10	16.4%
F4: Finland 1 (Mar 2017)	9	14.8%
F5: Finland 2 (Mar 2017)	7	11.5%
F6: Denmark [Male] (Jun 2017)	7	11.5%
F7: Denmark [Female] (Jun 2017)	8	13.1%
F8: Norway (Sept 2017)	9	14.8%
Female	32	52.5%
Driver's license	50	81.9%
Currently own or regular access to a car	29	47.5%
Experience with an EV	8	13.1%

Source: Authors

3.4 A qualitative literature review

Our third and final method was a qualitative review of the academic literature on V2G, business models, and markets. We searched the titles, abstracts, and keywords of articles in leading energy and transport journals using the Scopus database for the words “business model” or “market” and “finance” alongside “vehicle-to-grid,” “V2G,” “vehicle-grid-integration,” “VGI,” “smart charging,” “electric vehicles,” and “electric mobility.” We limited our search to articles published in the previous twelve years, e.g. from 2008 to 2019. Our search resulted in a corpus of 98 initial studies. We cite the most relevant of these studies in the article.

In the next section, we present our initial results, drawn from all three methods (interviews, focus groups, and literature review) and organized inductively along an actor based approach. This is because, as Noel et al.⁶¹ argue, most sociotechnical aspects of V2G adoption center on actors such as EV owners, aggregators, grid operators, governments, EV manufacturers, and electricity suppliers (see Table 5). We then move to a discussion section that connects these actor based results back to our innovation activity systems framework.

Table 5: Actors and the sociotechnical nature of V2G adoption

<u><i>Sociotechnical Dimension</i></u>	<u><i>EV Owners, Consumers</i></u>	<u><i>Aggregators</i></u>	<u><i>Electricity Grid Operators</i></u>	<u><i>Government</i></u>	<u><i>EV Industry</i></u>	<u><i>Electricity Producers</i></u>
Technical	Acceptance of battery degradation	Develop algorithms to minimize technical impacts and maximize privacy	Develop security and privacy standards of V2G	Invest R&D in battery technology	Increased research into battery degradation, charger efficiency	Limited or no role
Economic/Business	Increasing willingness to pay for EVs and V2G, higher awareness	Developing sound business model; convincing consumers of	Avoid double taxation rules, clarify role in business models	Reduce regulatory barriers to business model, clarify roles of	Reducing marginal cost of EVs and EVSEs in general, as well as	Potentially contribute to business model as partners in electricity markets

	of V2G revenues	economic benefits		actors in business model, incentivize EVs and V2G	marginal V2G costs	
Regulatory/Political	Beneficiaries of policies aimed to increase EV adoption and V2G participation	Need clarification before can participate in certain markets, removal of barriers like double taxation, definition of responsibilities	Develop fair and clear regulations for the participation of V2G in various markets	Authorize and instruct TSOs and DSOs to develop reasonable spaces for V2G to participate in their markets	Lobby government to take regulatory action and design markets for V2G, increase policies favoring EVs and V2G	May play a role as third-parties in electricity market participation, such as balance responsible parties (BRPs)
Societal/Consumer	Active user-engagement, tinkering and reinvention, increasing consumer knowledge and acceptance	Take a more active role in including research of social barriers during early pilot projects, encourage user tinkering and engagement, target specific user types	Can play a role in information campaigns with regards to electricity markets	Engage with and target user types, provide policies to target consumer, provide grants for social research	Allow and encourage users to experiment by standardizing V2X in EVs	Can play a role in information campaigns with regards to electricity markets

Source: Noel et al.⁶²

4. Results: Twelve actors and business models for V2G electric mobility

Building on our primary data from the interviews and focus groups, as well as the literature review, this section of the paper classifies our results into actor groups (twelve stakeholder types or market players): automotive manufacturers, battery manufacturers, vehicle owners, energy suppliers, transmission and distribution system operators, fleets, aggregators, mobility as a service providers, renewable electricity independent power providers, public transit operators, secondhand markets, and secondary markets. This relates both to how we coded the data (by actor category) as well as the thickness of thinness of the empirical data on each topic, with frequency counts conducted across our interviews and

focus groups in Table 6. This enables readers to also see how prominently, or not, each theme emerged across the primary data.

Table 6: Summary of Actors and V2G Business Models by Interviews (N=257) and Focus Groups (N=8)

Business model	Frequency in interviews (N=257)	Frequency in focus groups (N=8)	Description
<i>Automotive manufacturers</i>	51%	75%	Making, selling, maintaining, and developing V2G automobiles
<i>Battery manufacturers</i>	50%	62.5%	Designing, making, and distributing batteries and improving battery performance
<i>Vehicle owners</i>	47%	62.5%	Provision of energy or energy services to the grid
<i>Energy suppliers</i>	43%	62.5%	Electricity sales or electricity charging infrastructure
<i>Transmission and distribution system operators</i>	43%	62.5%	Grid management and flexibility services
<i>Fleets</i>	40%	62.5%	Third-party entities that consolidate benefits across multiple vehicles.
<i>Aggregators</i>	40%	50%	Third-party entities that manage fleets
<i>Mobility as a service providers</i>	39%	50%	Bundling of V2G with automation, ride-sharing (carpooling), and mobility as a service
<i>Renewable electricity independent power providers</i>	35%	37.5%	Bundling of V2G with renewable electricity
<i>Public transit operators</i>	19%	25%	Bundling of V2G with public transit
<i>Secondhand markets</i>	7%	12.5%	Reselling of used vehicles or components such as batteries
<i>Secondary markets</i>	3%	0%	Peripheral software and information security, private protection, third party financing, marketing and advertising

Source: Authors.

While this section presents our initial findings across these actors (12 stakeholder groups) in order of frequency, the next section, the discussion, is where these are tied back to our conceptual approach of innovation activity systems.

4.1 Automotive manufacturers, vehicle design and sales

The first—and perhaps most obvious—business market is the sale of V2G enabled EVs. At the moment, while most of the major automotive Original Equipment Manufacturers (OEMs) currently do not supply V2G cars, there are some like Nissan that does offer a V2G-capable EV in their Leaf, as well as many other manufacturers that sell battery electric

vehicles (such as Mitsubishi, BMW, Volkswagen, and Renault alongside the much newer Tesla) that could be easily configured for V2G. The potential size of a V2G-capable EV market is large, considering both the size of the automotive market, with more than 73 million commercial vehicles built by 47 OEMs in more than 40 nations in 2017⁶³, and also the expected growth in the international EV market, with an estimated 130 million EVs on the road by 2030.⁶⁴ Additionally, significant market growth for vehicle ownership in particular is expected in the BRICS economies (Brazil, Russia, India, China, and South Africa) as well as Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, South Korea, Turkey, and Vietnam.⁶⁵

Narrowing down to EVs in particular, according to the International Energy Agency, annual sales of new EVs—inclusive of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—exceeded 1 million units in 2017, the largest of any year yet, and representing a 54% growth rate over 2016, and resulting in a total global stock of more than 3 million vehicles.⁶⁶ Dijk et al. note that EVs in particular require more manufacturing attention (and innovation) in areas such as electric propulsion, light-weight plastic bodies, as well as batteries and range; they also caution that EVs undercut in some ways the conventional industry's reliance on modular design, as EVs need new parts (electric motors, larger batteries) but do not require other parts (internal combustion engine, exhaust gas system) which may reduce the overall number of parts from 30,000 to only 10,000 or less.⁶⁷

The automobile industry thus must design, refine, and orchestrate complex supply chains necessary to create a high value mass product that spans multiple other industries including plastics, steel, electronics, and rubber, fiberglass, and information and communication systems.^{68 69} In addition, we would argue based on a number of statements in our interviews that they exclude V2G aspects as well. For instance, R83 stated:

Right now, it's only Nissan and Mitsubishi that can do standard V2G. Nissan is the only OEM meaningfully participating in V2G. So until we get more OEMs on this, it's still going to be a niche, because some companies say "oh we never buy Nissan, we always buy Ford, because we get very good service, we have our own car mechanics, and blah blah blah. When we get more range and when we get more OEMs on this, the price of the charger will go down because they can be mass produced, so this is some of the challenge we're seeing right now. And of course, switching to AC would be fantastic, from our point of view. It's still a problem because if we have AC charging, the charger is going to be inside the car, and that's maybe a two or three hundred dollar extra cost on producing the car. And that's a lot of money on OEMs, they think that's very expensive—but they are certainly important gatekeepers.

This lack of involvement on the EV and V2G market can be attributed to different elements, although R140 adds that it is in particular due to the legacy of the OEM product lines:

We don't have more EVs today because those companies like BMW, Mercedes, Volkswagen, and General Motors are protecting their existing product lines.

R226 further noted the limitations on EVs (and V2G) coming not only from the supply industry, but also due to the embedded supporting networks and the jobs these generate. In other words, currently too many livelihoods are tied up to the success of the internal combustion engine vehicle market:

The OEMs are a big deal. Even if Volkswagen is selling one million EV cars it's just a small part of their total production, and as long as the other countries are not having these benefits, and the other countries are still selling the combustion engines more than the chargeable cars, they will not be able to change anything. Because it's money, and so many people depend on the OEMs. Volkswagen alone has something like 550,000 employees, all around the globe. It's big company, and most of the customers are buying combustion engines.

And, lastly, R238 alluded that incumbent manufacturers face barriers when thinking on transitioning their production to EVs, considering the nested investments on internal combustion engine vehicles, which have to be reported and continued to recuperate and/or maximize returns for their investors:

Yes, the current transition to EVs took a while. Of course, for the newcomers it is much easier because a company like Tesla only has EVs to sell. But the problem with the car industry, while they may want to test the market of EVs, and I assume there is a lot of discussions in the boardroom in the large vehicle OEMs, they cannot announce they are fully committed to EVs because all their intellectual property, all their valuation of the balance sheet is based on technology related to a combustion

engine. If they say that that the way forward is EVs then their stock value will go down 90% or something because their balance sheet is worthless.

These perceived barriers for EV adoption relate to the legacy of the petrol and diesel car industries.

4.2 Battery manufacturers

A second market—integrated but still distinct from automotive manufacturers—are those designing, making, and distributing batteries. Battery performance (including range, recharging time, durability and lifetime) is critical to the performance of an EV for driving purposes but also for its relationship with the power system when providing V2G services, which means those OEMs already manufacturing V2G-capable EVs tend to work closely with battery first-tier suppliers such as Bosch, Denso, Valeo and Delphi. As R41 noted:

Right now, the battery is where the real cost is for EVs. But you also see the huge business advantage of going for bigger batteries for storage. That's where the profits are.

R55 added that:

Batteries represent the true turning point for the future of EVs. Battery development just over the last few years has been massive. I just saw something in the last year or two, battery prices have decreased by 30%, and that is a big difference.

Some OEMs have even focused on promoting their own in-house production of batteries. For example, Toyota and Matsushita (currently Panasonic) created a joint venture for battery development in March 1995, allowing them to share the risks associated with battery technology.⁷⁰ Similarly, Nissan created a joint venture in 2007 to produce lithium ion batteries with NEC; Mitsubishi motors one (called Lithium Energy Japan) with GS Yuasa in 2007; and Honda entered into a collaboration (called Blue Energy) with GS Yuasa in 2009.⁷¹

The market technological leaders of lithium batteries manufacturing as a whole include Panasonic Sanyo (dominating the global market with a 33% share) followed by the Chinese BYD and the Korean LG Chem. Driven initially by investment in telecommunications and the mobile phone market, both private and public actors are

investing heavily in batteries and energy storage technology, meaning that not only are battery prices falling, but their energy density (and thus performance quality) is increasing. Further contributions to this effort are to come from “Gigafactories” currently being developed in China and the United States by Tesla. R41 noted the attractiveness of bringing such factories to Europe:

We need 200 Gigafactories, but where are you going to get the materials? I don't see the government. It will be private investment, investors. We do have a fine infrastructure for investment in Sweden in particular and there are huge international contacts. Sweden could attract private investors and we are talking big money, something like five times the defense budget, would be what be needed to get a real battery industry here. And if you multiply that many Gigafactories, it would be sensible to have at least a few in Scandinavia. One in the west coast of Denmark, one somewhere here in Sweden and one in Norway to satisfy the EV needs. Are we going to produce the cars? Why not. It's going to be a simpler technology and Sweden is producing the electric motors via Ericsson and ABB. They are world leaders and they know about these things.

As a result of the efforts of battery manufacturers, Figure 2 shows how battery costs for EVs continue to decline while performance (in terms of energy density, or cost) improves.

Figure 2: EV Battery cost and energy density, 2008 to 2022

Note: USD/kWh = United States dollars per kWh. Wh/L= watt-hours per liter. PHEV = plug-in hybrid electric vehicle. Source: International Energy Agency.⁷²

Moreover, V2G participation potentially contributes to additional strain on the battery due to increased cycling, which marginally reduces the battery’s capacity.⁷³ Considering the overall importance of the battery to EVs and vehicle users, battery manufacturing must not

only consider the requirements of EV owners for the purpose of travel demand, but also recognize the additional requirements for a V2G systems to be feasible. Battery manufacturers, whether in-house or otherwise, are thus an important stakeholder group in realizing a V2G configuration.

4.3 Vehicle owners

A third fairly obvious business model are those that emphasize the vehicle owners—who can either provide energy services to the grid. As FG2 (Sweden) indicated,

If there was a business model where we could sell back the electricity to the grid that would be nice. As long as that does not negatively impact the lifecycle of the battery, I would seriously consider that.

The types of services V2G automobiles can offer vary by scope and extent. Vehicle owners could in theory use them as sources of distributed electricity supply, but they could also use them (where feasible) as flexible, optimizable loads offering grid services; or, in other situations, distributed forms of energy storage. Mullan et al. for example list an array of options including ancillary services, spinning reserves, load following, bulk storage, distributed storage, bulk supply, and demand-side management and load shedding (when needed).⁷⁴ Turton et al. classify possible V2G services in terms of peak power, spinning reserves, or regulation services;⁷⁵ Han and Han emphasize the V2G benefits of frequency regulation and spinning reserves, especially when optimized to charge batteries during off-peak periods, and to then feed power into the grid during expensive peak periods.⁷⁶ Brown et al. lastly divide possible grid services from EVs across Grid-to-Vehicle, Vehicle-to-Buildings, and Vehicle-to-Grid platforms shown in Figure 3.⁷⁷

Figure 3: Visualizing Grid-to-Vehicle, Vehicle-to-Buildings, and Vehicle-to-Grid Energy Services

Source: ⁷⁸

Our data however is more critical and discriminating as to which types of such services would be best suited for V2G. R83 for instance strongly argues that only frequency balancing is valuable:

In our discussions with TSOs in the Nordic region, we always hear that frequency balancing is very, incredibly important for them. They say that two thousand EVs could be a big and valuable resource for frequency balancing. One of the reasons is that the EVs can react so fast. They have a time delay of about five seconds right now. And that is extremely fast compared to other sources that do frequency balancing.

Kempton and Tomic⁷⁹ as well as Noel et al.⁸⁰ are also critical about which services are best matched to V2G. Given continuous energy demand, long time frames of market participation, and very competitive costs per kilowatt-hour (kWh) of energy, battery based V2G has been argued to be a bad fit for baseload power (see Figure 4). Though peak power can be of high value, it is infrequently used, and when used, is very energy intensive, meaning V2G participation in this market runs the risk of draining the energy from an EV's battery, preventing EV owners from completing trips, or when peak power is not used, the

V2G system typically does not receive any economic remuneration. This makes peak power only a moderately good fit. Ancillary services such as spinning reserves or power regulation are argued to be the best cases for V2G. Both coincide better with V2G's advantages, namely high availability and a higher valuation of power over energy capacity. Spinning reserves, also known as synchronized reserves, is a market that helps an electricity grid respond to unexpected outages or other contingency events. Because spinning reserves are used infrequently, and, more importantly, can drain batteries when used due to the larger amount of energy required in such instances (e.g., a failing coal plant), the overall fit for V2G is considered to be good, but not great. Frequency regulation goes by a variety of other names, such as automatic generation control (AGC), frequency control, frequency containment reserves, among others. The value of frequency regulation to V2G is that it is continuously needed and used, requires high power capacity but limited energy capacities, and requires quick reactions, all of which coincide with the advantages of V2G described above. As a result, frequency regulation is considered the highest value service that V2G can participate in. This market can be quite valuable. Looking at the United States, one study projected total⁸¹ revenues of a V2G owner providing frequency regulation over 16 years in five electricity grid operators, and it found that total revenues could range from just under \$20,000 to over \$45,000 (perhaps exceeding the capital cost of the vehicle itself!).

Figure 4: V2G and Optimal Energy Services

Source: ⁸²

4.4 Conventional energy suppliers

Our fourth market player relates to energy supply, more specifically electricity sales (usually done by centralized electric utilities) as well as those building electricity charging infrastructure. Since at least 2010, Dijk et al.⁸³ estimate that national and local governments were promoting “thousands of projects” with large budgets attempting to build electric charging stations for EVs; many of these were done in partnership with electric utilities, including EDF (France), EOS (Switzerland), ESB (Ireland), TEPCO (Japan), and various utilities in the United States.

In the United States, for instance, Scott et al. assessed the impacts of a V2G transition on the revenue and cost streams of two sample utilities, Cincinnati Gas & Electric (CGE) and San Diego Gas & Electric (SDGE).⁸⁴ The first company primarily generates its own power, while the second utility mostly serves as a power marketer. They concluded that with 60 percent penetration, EVs would generate income during off-peak hours and help the companies recover their fixed costs and borrowing expenses more quickly than if they did not sell power to vehicles. By doing so, the utilities could reduce overall rates by as much as 0.4

cents per kWh for CGE and 5.0 cents per kWh for SDGE. CGE could boost profits in the short term, enabling it to invest more in infrastructure; SDGE could use its transmission and distribution capital more effectively in off-peak periods, meaning that its cost of power would decline. In other words, sales of power to V2G cars would improve the companies' load factors (i.e., allow the companies to use their equipment more effectively) and reduce the overall cost of service on a per kilowatt-hour basis. As the cost of service declines, so could prices to customers.

Roma et al. emphasize that electric utilities are not the only ones that can provide charging services.⁸⁵ They note that business models specifically for EV charging could relate to privately owned charging areas with private or public access for EV owners, but also public charging areas with public access for EV owners or even hybrid public-private partnerships that work with EV supplier aggregators (EVSAs) or charging point managers (CPMs, also referred to as charging point operators).

Complicating matters, different permutations of these three business models could exist, even if one only considers the "EV" aspect of V2G. These include:

- An ordinary home owner who installs an EV charging point at his/her home garage for private use, but lets friends borrow it;
- An office building owner who installs several EV charging points in the office parking area for free private use of its employees, but for a fee for public users;
- A commercial building operator who installs several charging stations exclusively for clients;
- An entrepreneur who installs several charging points with different options (fast charging, multiple charging) with different pricing schemes. Other examples include school bus operators, casino resort fleet managers, universities, etc.

Guiding these various permutations, Roma et al. envision three types of charging markets summarized by Table 7. Although these do cut compellingly across our actor types, such business models could only be complemented (or disrupted) by various independent forms of third-party charging (see section 4.6 and 4.7 in particular).⁸⁶ In the EU in particular, DSO led efforts and initiatives are heavily restricted as part of a recently approved electricity sector directive part of the Clean Energy for All European policy package. These new regulations only allow DSO participation in such activities in very specific case (no other commercial players, a need for market development, and always subject to regulatory approval and oversight).

Table 7: EV and V2G Charging Markets and Business Models

Model	Short description	Primary actor	Agents involved	Contracts	Optimization
<i>Home charging</i>	Charged at home as other domestic appliance Separate, sub- or on-board metering arrangements one unique supply contract for electricity	EV owner	EV owner Supplier DSO	EV owner with supplier Supplier with DSO	Local autonomous Local optimization Remote optimization
<i>Public or street charging</i>	Public property with public access for parking with multiple EV charging points; Low cost and fast installation of chargers Multiple suppliers have access to manage different customers at the same CP	DSO	EV owner EVSA DSO Supplier or Market	Each EV owner with custom EVSA EVSA with DSO EVSA with market or intermediate Supplier	Fast charging does not allow for load management optimization Long term street parking may allow remote optimization managed by EVSAs
<i>Public-private charging</i>	Public access to charging station on private property with option to have local generation, storage devices and fast charge services	CPM	EV owner CPM DSO Supplier	Each EV owner with custom CPM CPM with DSO CPM with market	Fast charging does not allow for load management optimization Stationary storage and generation allow for local

Source: Authors, modified from ⁸⁷. Note: EV = electric vehicle. CPM = charge point manager. EVSA = electric vehicle supplier aggregator. DSO = distribution system operator.

Confirming this diversity of business models, although also questioning the vitality of some, R73 said that:

There is not always a strong business case for charging models [for EVs by themselves or in a V2G configuration]. Sometimes it works for apartment complexes with tenants, when tenants insist on it and are willing to pay for it within their monthly mortgage. But in other situations, public parking and charging spaces are starting to become taken for granted and shopping malls and others see it as a way to attract customers, not to make direct revenue. When it comes to specific charging stations at petrol stations, I don't see that business model developing very well. Those that try to charge for charging along the main highways find very few customers, so the best model has been Tesla, which Tesla made us all believe that it is free, which it is not, we just paid it in advance when we bought the car.

Nonetheless, some of our data did support the contention that charging business models themselves also generate their own set of secondary service markets. R74 for instance noted that:

Our major business opportunity is not selling electricity to clients, it is more related to supporting owners of charging infrastructure, that's how we make money. We sell our cloud system and our support system to charging firms. It could be support and basic services in the backend system where we manage and monitor, handle chargers, manage payment service for those who want to have payment, sometimes the maintenance of chargers. So, make money via a different pool of services related to supporting those who own charging points, not owning them ourselves.

In this way, charging business models could open up new avenues of data management, monitoring, and maintenance.

4.5 Transmission and distribution grid operators

This stakeholder type involves transmission system operators, distribution system operators (called distribution network operators sometimes in Europe) using V2G to better manage various levels of the electricity grid. Admittedly, TSOs and DSOs are technically distinct; even though these two stakeholders operate grids, the technical characteristics of these grids, applicable regulatory frameworks and possibilities to use flexibility services are significantly different. Nonetheless, given that our respondents conflated transmission and

distribution together in their responses, we have kept them combined for this section of the paper.

As noted above, V2G automobiles can help with better grid management, especially demand management and response. R48 emphasized that:

TSOs and distribution grid operators need to handle high volumes of grid services, and are therefore well placed to benefit from V2G integration. They can use electrical cars more as ancillary services, contributing directly to the intra-day market, depending on the situation. If you have high wind generation then power is cheap, then the TSO [sic.] knows to charge vehicles, then discharge them during optimal times of peak demand.

R74 noted that:

We believe that the promise of V2G is that it leads to smarter solutions, where we can handle the load in the grid by reducing the demand for certain periods in order to not ramp up a short term coal plant or gas plant. We could be using electric vehicles integrated with having smarter management systems.

Figure 5 for example presents six different challenges or tasks that grid operators need to manage (some of them already catalogued in section 4.3 on services from Vehicle Owners).⁸⁸

V2G can compete with, or complement, the other resources grid operators use to manage these different forms of management, especially flywheels, pumped hydro, flow batteries, and compressed air energy storage, all used for very short or intermediate storage. Indeed, the transmission and distribution benefits of V2G have been confirmed and modelled by a slew of supportive studies, all showing that V2G can enhance the optimization of electric utility transmission and distribution assets.^{89 90 91 92}

Figure 5: Grid system optimization and categories of demand management

Source: ⁹³

4.6 Third party fleets

So far, we have explored business models from the perspective of primary manufacturers (for cars and batteries) or direct system users and managers (such as vehicle owners, electric utilities, or grid operators). But third-party entities can also benefit from coordinating fleets of V2G automobiles or consolidating benefits across multiple vehicles.

R134 noted that:

We're not interested in V2G services from a single car. We want multiple vehicles providing multiple storage services that make value together, not one individually.

At the corporate level, such fleets could also serve as important anchors and intermediaries that both pilot and experiment with new technologies (in various configurations) and business models, and aggregate benefits across multiple scales. ⁹⁴

Kempton and Tomic call this the “fleet ownership model.”⁹⁵ Such fleets can vary greatly in scale and scope, with Hill et al. suggesting fleets as small as ten units to as large as hundreds of thousands.⁹⁶ This modularity makes them scalable to the needs of particular

markets and it also enables the aggregation of multiple vehicles into a single entity that can achieve megawatt scale power services (which can be more familiar for grid operators or suppliers to work with, and also can achieve a larger volume of revenues). Fleets also help address some of the transaction costs and information challenges involved in distributed V2G diffusion—working with a single aggregator may be more attractive (and efficient) than working with hundreds of different entities.

The fleet market sector can be diverse, involving parking garages with high density of EVs⁹⁷ but also delivery trucks, carpools, taxis, school buses, and trains – any vehicle with a usage profile that is not in use 24/7. Delivery trucks, for instance, could recharge during deliveries and when otherwise parked.⁹⁸ Carpools or clubs could also be well economically rational purchasers and adopters of V2G technology⁹⁹, especially when vehicles charge overnight. Taxis represent another potentially lucrative area, with pilots in China (BYD's all-electric cab in Shenzhen city) already saving an estimated 14,000 liters of fuel per year (along with corresponding carbon dioxide reductions).¹⁰⁰ V2G-capable electric school busses also pay for themselves fairly quickly compared to conventional diesel options—Noel et al. project a net present benefit of \$5700 per school bus seat (without externalities) or savings as high of \$38 million for a typically sized school district.¹⁰¹ One final assessment calculated the strong business potential integrating V2G systems into trains—where better energy management can be used to feed other trains on the same line, store energy onboard or in stationary storage systems at train stations, or feeding back into the electricity grid.¹⁰²

4.7 Aggregators

Each of the aforementioned stakeholder characterizations could exist with fleet managers handling interactions with other agents in the business model chain, or working through another intermediary, and aggregator, who manages fleets (fleets of fleets).¹⁰³ R157 made this point explicitly, when they noted that:

Of course independent aggregators can play an important role in promoting V2G, but which markets will they participate in, and how will they be managed? Information exchange is needed between the energy suppliers, the TSOs, the distribution companies, and the aggregators. Somebody needs to aggregate and coordinate the aggregators.

Such aggregation of fleets could, or more likely will need to, occur at a variety of possible scales and service different types of markets.

There are many reasons for why an aggregator may be preferred instead of a direct communication from the electricity grid operator to an individual EV. First and foremost, many of the markets that V2G can make the most economic value participating in (such as frequency regulation), requires a minimum power capacity in order to participate.¹⁰⁴ In many cases, in order to bid on an ancillary services market, the minimum bid is 100 kW, or worse yet, 1 megawatt (MW). If an individual V2G-capable EV is using a Level 2 charger, a V2G system would require approximately 6–9 EVs together to reach 100 kW, depending on actual power capacity of the charger.¹⁰⁵ On the other hand, a Level 3 charger would only require 1–2 V2G-capable EVs, though this would be a substantially more expensive system (and still insufficient for markets with a minimum capacity of 1 MW). Thus, an aggregator can offer a more economically efficient means for a V2G system to participate on electricity grid markets by creating a pool of V2G-capable EVs.

Beyond the technical and market required grouping capacity of an aggregator, an aggregator with a fleet of V2G-capable EVs can also offer stability and flexibility as a market participant through the implementation of predictive and/or control algorithms. An aggregator can optimize its aggregated capacity and develop a control strategy that balances energy flows between different vehicles and their driver's needs and maximize revenues by choosing to participate among the various electricity grid services, such as frequency regulation.¹⁰⁶ Furthermore, since EVs are also used for driving and charging, aggregator algorithms can use statistical predictions in order to account for EV behaviour patterns¹⁰⁷,

thus potentially optimizing energy flows among vehicles (charging the vehicle that is about to leave, but relying on others to discharge). Aggregators lastly have the opportunity to learn from previous EV charging behaviour in order to predict the maximum available V2G resources during future market participation.¹⁰⁸

4.8 Car-sharing organizations and mobility service providers

These business models couple EVs and/or V2G with other things, such as automation, ride-sharing (carpooling), and mobility as a service. Kley et al.¹⁰⁹ note that EVs could be integrated with mobility guarantees where a third-party provider supplies a normal, combustion vehicle for longer journeys, or information about the next available charging points that could be integrated with vehicle navigation systems. R38 for example said that:

A car in Sweden stands still for 23 hours a day and runs for 1h. Can we use it in another way? Can we use the same amount of cars but share them in different ways? Maybe different kinds of Airbnb services but for cars? So you share each other's cars? Because of the smart phone, it is possible now, to book and find the cars. It is opening a new world where sharing an EV for 30 minutes—or more—is feasible. It also offers a way for people who have never driven an electric car before to actually try one. To just get one on the street and just drive one for half an hour.

R60 stated that:

I believe very much in car sharing for the future. I mean, it's so smart, we use cars so little, for only a fraction of the time each day, and it's just silly that everyone has their own. Both with electric cars and with other cars, car sharing is the future, definitely.

Dijk et al.¹¹⁰ add that car sharing organizations can offer a variety of car services in combination with other services. Car sharing, where a single vehicle is owned or shared across multiple people, is not the same as ride-sharing, where people share the same ride or journey¹¹¹. As Dijk et al. argue:

The rise of mobility operators in the field of car mobility has implications for the choice of car that is being used. Electric vehicles, especially battery electric vehicles, are attractive for mobility operators because of low operating costs, which compensates for the higher purchase prices ... It can be expected that the considerable rise of car-sharing organizations will continue in the future, with

positive effects for electric mobility. A high purchase price has been a burden for electric vehicles, whereas car-sharing membership eliminates the purchase price of cars and reduces the costs associated with car ownership, such as insurance, maintenance and depreciation, while giving the customers the possibility of owning several cars.

Car sharing organizations (such as Zip Car) often offer a range of vehicles, attenuated to customized choices (to reflect clients that care more about say environmental sustainability or affordability)—these groups could easily integrate V2G into their operations. Zip Car in particular is already marketing elements of their fleet that run on electricity in Northern Europe, as shown in Figure 6.

Figure 6: A Zip Car Advertisement for Electric Vehicles as part of their Car-Sharing Service on the London Underground, October, 2018

Source: Authors

4.9 Decentralized renewable energy suppliers

V2G need not benefit only traditional energy supplies or grid operators—because it offers a decentralized form of storage, V2G could also benefit—or be bundled with—

independent and decentralized power providers such as those generating electricity from wind turbines or solar panels. V2G here can benefit renewable energy providers, and enable better overall *sustainable* management of grids.¹¹² In FG6 (Denmark), a respondent noted that:

I find the idea of power companies using my vehicle, or our land for batteries for storage attractive, but only if the energy is sustainable, like solar panels.

Concomitantly, in FG7 (Denmark) another respondent said:

Electricity is not completely green. Vehicles that run on electricity are not necessarily doing any good for the environment. Knowing that such electricity comes from clean or renewable sources is a branding advantage.

Habib et al.¹¹³ note in particular that V2G enabled EVs offer an extremely attractive source of backup power to help integrate and balance fluctuations in decentralized solar and energy supply. Fernandes et al. simulate that in Spain, use of V2G would displace centralized pumped storage and also enable more efficient integration of intermittent renewables such as wind and solar.¹¹⁴ Of course, when providing such services—especially storage—V2G does not exist in a vacuum. It must also compete with an array of other available (and emerging) technologies whose performance features continue to evolve. Table 8 compares the technical attributes of V2G to other commonly-discussed forms of electricity storage for renewables.

Table 8: Technical Attributes of Renewable Energy Storage Technologies

<u>Storage Technology</u>	<u>Cost of Storage</u>		<u>Response Time</u>	<u>Roundtrip Efficiency</u>	<u>Cost to Match U.S. V2G Capacity (\$bn)</u>	<u>Other Notes</u>
	<u>\$/kW</u>	<u>\$/kWh</u>				
V2G	N/A	1-40	A few seconds	70-85%	N/A	By far the cheapest system, diffusion process long and complex, depends on consumers
Hydrogen	1,500-3,200	260-540	Seconds to minutes	40%	\$6,200	Lowest efficiency and high capacity costs
Purpose-built Batteries	1,100-2,500	500-800	A few seconds	70-90%	\$7,020	Without secondary use, battery energy capacity is very high cost
Flywheels	870	4,800	A few seconds	94%	\$41,200	Highly efficient but cost limits overall energy capacity, preferred for short-term storage
Power-to-Gas	850	N/A	Seconds to minutes	50%	\$2,300	Low efficiency, gas infrastructure must preexist, contributes to gas-related emissions

<i>Compressed Air Energy Storage</i>	900-1,300	40-109	9-12 minutes	70-90%	\$2,800	Dependent on local geology to compress air into, proven technology,
<i>Pumped Hydroelectric</i>	1,400	68	A few seconds to minutes	70-82%	\$4,300	Most prevalent storage, but geographically dependent, environmental implications

Source: Authors compilation, based partly on ^{115 116 117 118 119}. Note: Roundtrip efficiency is the amount of energy that is retained after energy is put into the storage system and subsequently retrieved, expressed as a percentage.

As interesting as we find Table 8, it does neglect one critical aspect: availability.

Whist the other storage solutions are built solely for that purpose, an automobile's battery will almost always primarily be used for transport. Therefore their reliability as a storage source, depends on the number of vehicles connected to V2G chargers at any one time, the amount of charge in the battery, and the willingness of the user or owner to allow the battery to be charged or discharged at key points. Hence, availability mediates the efficacy of these different energy storage technologies.

4.10 Public transit operators

A particular type of fleet ownership—public transit operators—could also benefit from EVs (with or without V2G) by integrating it into their portfolio. Instead of using a private car or light duty vehicle for an entire trip, it can be integrated with other modes, especially rail or bus, and especially when integrated into park-and-ride schemes, especially when they offer free or public charging stations.¹²⁰ R7 noted how EVs could complement, rather than disrupt, intermodal transport when they said:

EVs can be complementary with enhancing public transportation. Policies to encourage public transportation or biking are mostly complementary to electric vehicle or vehicle use in general, not replacing it, especially if you drive part of the way and then cycle, or vice versa. Same with long trips where you may drive to the train station, and then take the train on your vacation, maybe the bus too. Everything helps.

In many European cities, public transportation has been extended with or synergized with public bicycle, electric scooter, and EV charging stations, intended to increase the intermodal nature of trips. In the Netherlands, for example, Mobility Mixx offers business travelers with intermodal options combining rail, taxis, rental cars, public bikes and parking payment, with more than 45 million passenger kilometers driven per year.¹²¹

Electric buses could be a final area where public transit operators utilize V2G. The global stock of electric buses totals at least 425,000 units¹²², the vast majority of which are used by Chinese companies, stimulated by government subsidies and local conversion programmes. The city of Shenzhen, for instance, switched its entire urban bus fleet (of more than 16,000 buses) to all-electric models.¹²³ London in the United Kingdom is also seeking to fully electrify its bus fleet by the end of 2020 according to its “Ultra Low Emissions Zone” program.¹²⁴ A similar pilot of “bus-2-grid” has also been ongoing since 2018 within UK Power Networks.¹²⁵

4.11 Secondhand users

Our penultimate business market is secondary usage—where components no longer being used (such as the battery) are used in secondary applications (such as stationary storage). Debnath et al. write that such applications are attractive, given that “second use of [V2G] batteries, after their automotive life, can generate some revenue for the owners to recover a part of their battery purchase cost.”¹²⁶ R34 for instance noted that second hand “used” EVs could be attractive for students or those that cannot afford a new one:

You don't have to buy an EV new. Like any car, you can buy it used. We buy electric cars on auctions, we buy used electric cars, we make sure their batteries are ok, they have a clean report, and then we resell them far more cheaply than a new vehicle.

R206 went as far as to argue:

Many companies only make money the second time they sell an EV. The first time you sell the car as a private leasing, you're giving a low interest rate, and of course the

buyback value and so on, so actually, you might earn more of the money the day the car is returned to you by the private leaser and you're selling it out to the market as a normal used car.

Batteries as well with capacities too low for driving purposes can still be reconfigured for electricity storage, since it can be generally assumed that 70%–80% of its capacity is still available after its use in an electric car. This remaining capacity can be used to store energy for stationary applications in homes.¹²⁷

Affirming this point, Drabik and Rizos examined industry growth trends for EVs and concluded that “battery recycling will become crucial” in terms of a “key sector” where “value can be created through jobs and materials.”¹²⁸ They noted that Europe could become a market leader for the recycling of lithium ion batteries and that there is a “huge opportunity for EU industry,” projecting that by 2030 1.2 million EV batteries are expected to be at their end of life, a number that grows to 5.4 million batteries by 2040.¹²⁹ That same year, Drabik and Rizos estimated that the EV battery recycling industry could involve as many as approximately 12,000 jobs to collect and dismantle batteries and another 3000 to recycle them.¹³⁰

It is likely that secondhand markets would also exist for insurance, warranties and components such as V2G chargers.

4.12 Secondary market providers

Our final stakeholder type, perhaps the most prosaic because it is relatively uncertain (until V2G becomes more deployed) and certainly the least frequently mentioned, is secondary markets. These markets would encompass things like software and information security, private protection, third party financing, marketing and advertising, back office programs for charger operation and the like. R57 framed this as more of a problem than a benefit, at least insofar as it relates to security:

I have major concerns over privacy and how future digital citizens will interact in a V2G society. I imagine a world where companies can monitor and track your every move. Everyone could see where you are and stuff like that, if you're a one-person household people could see that the car is away. They could come into your house. It's a problem—and it opens up intimately private lives not only to companies but to others who could use or misuse the system as mass surveillance.

Such issues not only pose regulatory challenges, but certainly also give rise to a need for business solutions and hence could come to create viable business opportunities.

5. Discussion: The content, structure, and governance of V2G business models

As predicted by our activity systems framework, the emerging markets for V2G-capable EVs differ meaningful in their content, structure, and governance. However, we also note inductively that issues of temporality, complexity, and futurity become blended with a discussion of these attributes. We explore each in turn.

5.1 The temporality of content

The breadth of business activities that could be linked to V2G are striking, and multidimensional (including vehicle and battery manufacturing, grid services, fleet management, car sharing organizations and more). Richards et al. even estimate that “transportation-to-grid” business models could capture as much as \$200 billion in annual revenue in 2028 across different stakeholder groups.¹³¹ Although they use a different way of classifying business models than we do, they divide this revenue across infrastructure developers, charging service providers, aggregators (which they call “load orchestrators”), and mobility providers in Table 9.¹³²

Table 9: Integrated Business models, barriers, and solutions for Vehicle-to-Grid

Business model	Potential barriers	Potential solutions
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Infrastructure Developer	<ul style="list-style-type: none"> • Structuring charging options for homes without parking spaces or multi-dwelling units • Commercial property owners may not understand the value proposition • Market and regulatory constraints 	<ul style="list-style-type: none"> • Siting community charging hubs in right-of-way locations near high traffic flows • Exploring fleet electrification opportunities • Educating individuals and businesses about the individual and collective benefits of PEV ownership and charging
Charging Service Provider	<ul style="list-style-type: none"> • Primary charging (home) and secondary charging (workplace) skew demand away from public charging networks • Public charging must compete against low cost, high convenience home charging • Costs for services and subscriptions can outweigh potential benefits for many would-be EVSE owners • Business proposition varies across jurisdictions relative to urban densities, access to public 	<ul style="list-style-type: none"> • Focusing on intercity travel and expanding the customer base of PEV owners without primary charging locations • Exploring fleet electrification opportunities • Working with utilities that have an interest in networking residential charging stations to better manage PEV load
Load Orchestrator	<ul style="list-style-type: none"> • A single vehicle provides limited value to grid services and major grid services markets have minimum capacity requirements • VGI technology is in its infancy with lack of uniformity in communication protocols, standards, and commercial applications • VGI business case can be confusing because PEVs are road-facing assets first, grid- 	<ul style="list-style-type: none"> • Focusing on aggregation • Exploring opportunities to use electrified fleets • Demonstration projects in markets with high or increasing solar and wind penetrations that are likely to value VGI more due to higher electricity generation costs attributed to renewable generation intermittency issues
Mobility Provider	<ul style="list-style-type: none"> • Need to ensure vehicles are recharged at appropriate times • Decreased utilization due to limited range and downtime for charging • Real-estate costs for service depots around city to minimize wasteful miles 	<ul style="list-style-type: none"> • Understanding vehicle use cases, vehicles with more predictable patterns can provide a jump-start for mobility efforts • Considering how MaaS can bring scale with PEV fleets to improve the viability of V2G • Swapping battery to decouple charging and operation, enables short downtime and V2G • Providing vehicle subscription service model to allow consumers to have the desired vehicle at

Source: Modified from ¹³³. Note: VGI = Vehicle Grid Integration. PEV = Plug-In Electric Vehicles. MaaS = Mobility as a service. V2G = Vehicle-to-Grid.

Interestingly, however, is that there is a temporality to this content and its potential – in at least three senses. One, some of the benefits of V2G and possible markets are more

near-term, others more long-term. For example, Weiller and A. Neely argue that the residential applications of V2G such as vehicle-to-home for smart home systems are realizable in the near future, but they caution that grid-scale uses of EV batteries for generation, storage or for V2G will only be deployed in the long-term when sufficient vehicle adoption rates justify the implementation of new control architectures.¹³⁴

Two, there is a temporal issue of continued innovation and technology development—that as V2G systems improve, and couple with faster response times from batteries, they could also be integrated with other options such as solar PV. Indeed, Tesla recently framed their EVs as key to a “self-powered home” where an EV becomes integrated with solar panels and a Powerwall, as Figure 7 indicates. The latest V2G developments such as supercharging in less than 10 minutes (7 minutes for about 300 miles in some locations), improved battery life, the diffusion of household or decentralized storage systems, and a greater variety of V2G-capable models being offered by OEMs could all significantly shape the pace and scope of V2G adoption.

Figure 7: Tesla Advertisement for a “Self-Powered Home,” London, September 2018

Source: Authors

Three, the benefits to be captured by V2G—its market potential—are not static. The more people that adopt V2G, the more such benefits (especially for things like grid services, network effects, or secondary markets) become distributed to more actors (each gets a smaller share of the pie) as the markets become more saturated. Paradoxically, the more people that adopt V2G, the less viable its business case becomes at an individual or company level, assuming there is more than one V2G company on the market. In this way, V2G will also compete with other forms of storage-provision such as heat-pumps or stationary batteries.¹³⁵ These temporal tradeoffs could even occur *within* an actor group in addition to *between* groups of actors and business models.

Because of this dynamic and at times paradoxical relationship about the temporality of business opportunities for V2G, its promise could be limited to extremely particular types

of markets (at least in the short term). Kempton and Tomic infer as much when they suggest that they expect V2G diffusion to be limited to distinct types of power-related markets:¹³⁶

- Those that are willing to value and monetize higher reliability and more frequency stability but prefer to avoid constructing new sources of supply or transmission (e.g., California);
- Those in geographic areas where the population of vehicles are on peninsulas or islands with severe transmission constraints (e.g., Ireland, Japan) or with fragmented grids (e.g., Australia);
- Those with higher costs for regulation and spinning reserves or at least some sort of market for them (e.g., New York or Hong Kong);
- Those that have a single or coordinated government unit (at state, nation, or ministry) with jurisdiction over both transportation and electricity;
- Those that are committed to rapid growth of distributed renewable electricity supply and/or a rapid reduction of greenhouse gas emissions (e.g. Germany, Denmark);
- Those in geographic areas where large fleets of vehicles are located close to distributed renewable resources (e.g. offshore wind and the Eastern Coast of the United States, the United Kingdom).

The implication here is that while V2G may eventually thrive in a variety of markets within power provision, its participation in such segments will be tied to elements of temporality, as the technology matures and its diffusion in society. Continuing from our example above, ancillary services markets may offer a more attractive short-term segment for V2G, but seasonal storage provision could be the more viable option long-term, at least for fleets or aggregators, depending on battery and infrastructure development.¹³⁷ As a result, business

models must vary from region to region, depending on local contexts, but also need to be flexibly designed to allow for the temporality of the benefits of V2G

5.2 The complexity of structure

In addition to its temporality, the structure that links together the various stakeholder types and market players—and their relevant actors—is also complex. Each of the twelve stakeholders can interact in almost countless possible permutations. This complexity cuts across different parts of the V2G supply chain and across types of services and customers. Table 10 illustrates this complexity in terms of how it impacts specific V2G design choices and characters. Such complexity means V2G business models will unfold differently in practice across urban versus rural areas as the value of local grid services differs, whether they are provided by individual vehicles or fleets, and the degree to which they are integrated with other transport modes of companies (such as car sharing, taxis, public transit, and secondary markets). Most of the complexity however stems from different car ownership models and the vehicle’s travel and charging patterns across (potentially) multiple V2G chargers with different ownership and payment structures offset against the variability of V2G services and their revenue potential.

Table 10: The Complexity of V2G Business Models by Characteristics and Design Possibilities

Characteristic		Design options				
Property	<i>Vehicle</i>	Private customer	Fleet operator	Independent Provider (lease)	Shared	
	<i>Battery</i>	Private customer	Fleet operator	Aggregator	Car Manufacturer	Battery producers
	<i>Charger</i>	Private customer	Fleet operator	Aggregator	Utility	Independent Charger operator
Payment	<i>Vehicle</i>	Pay for equipment	Fixed rate	Pay per use		
	<i>Battery</i>	Pay for equipment	Fixed rate			
	<i>Charger</i>	Pay for equipment	Fixed rate	None	Pay per use	Pay per kWh/minute

After-sales services	<i>Vehicle</i>	Private customer	Fleet operator	Independent Provider (lease)		
	<i>Battery</i>	Private customer	Fleet operator	Aggregator	Car Manufacturer	Battery producers
	<i>Charger</i>	Private customer	Fleet operator	Aggregator	Utility	Independent Charger operator
Exclusiveness of use	<i>Vehicle</i>	One driver	More than one driver			
	<i>Battery</i>	One vehicle	More than one vehicle			
	<i>Charger</i>	One customer	More than one customer			
Second-hand markets	<i>Vehicle</i>	Private consumers	Fleet operators	Dealerships		
	<i>Battery</i>	Private consumers	Storage companies	Battery producers	Traders	
	<i>Charger</i>	Private consumers	Utilities	Independent Charger operator	Traders	
Secondary Markets	<i>Vehicle</i>	Car manufacturer	Hardware suppliers	Software suppliers	Customizers	
	<i>Battery</i>	Car manufacturer	Battery manufacturer	Battery management system supplier	Hardware/resource supplier	
	<i>Charger</i>	Charger manufacturer	Hardware supplier	Monitoring software supplier	Communication software	Payment software
Accessibility of V2G charger		Private	Semi-public	public		
Power connection		Level 3 AC	Level 3 DC (CCS)	Level 3 DC (CHAdeMO)		
Aggregator		Third party	Utility	Balance Responsibility Party	Distribution System Operator	
V2G services (amongst others)		Frequency regulation	Spinning reserves or reserve services	Peak power	Local RES storage	Emergency backup
Type of billing V2G service		None	Fixed/flat rate	Pay per use	Pay per grid service	Pay per kWh
Metering		At charging station	In vehicle			

Source: Modified from ¹³⁸ Note: Power connection (level 3), with bidirectional power and information flows, real-time communication and wired connection assumed.

Interestingly, within this milieu of actors, mobility and V2G services and market segments, some relationships are radial—an OEM sells a V2G enabled EV directly to a

consumer—whereas others are reciprocal—such as decentralized renewable energy providers being dependent on aggregators or vehicle owners to provide services, and vice versa.

Particular entities may differ across market segments, but the roles they fulfill can remain more or less traditional—selling vehicles, electricity, grid services, and maintenance. Other market segments are more radical, entering new domains such as car sharing, mobility as a service, secondhand batteries and storage and secondary markets for software or monitoring (We will explore the incremental versus radical nature of V2G markets more in the section to come on governance).

In a positive way, the interconnected nature of these technologies and services means that innovations in one domain—say, a battery—can cascade across multiple business models and dimensions. R83 put it elegantly when they stated that:

From the perspective of a grid operator, it's important when you get a large amount of EVs configured as V2G, because they can contribute meaningfully to frequency balancing, and that's a market where you can earn money. The value of both grid services and aggregation depends on batteries. As you know, the technology on batteries are moving very, very fast ahead, and one of the things that are moving very fast is to get the ability of the batteries to charge faster. I expect that in the future we can do maybe thirty or forty kilowatts up and down on each car without damaging the battery, because the chemistry just gets better. That obviously triples or quadruples money we can make on each car, as well as the equivalent amount of grid services those cars can do. There's huge potential for doing all sorts of other grid services at that point.

This comment also underscores a positive temporal dimension to business models; that as batteries get bigger and better, other types of energy services become potentially lucrative.

At the same time, it may prove difficult to move across the various 12 market segments listed in section 4 above to increase the overall capacity of V2G, particularly given the inherent complexity therein. Clearly, though benefits of V2G increase as the system is up-scaled, so too does its complexity.

Such complexity is further evidenced by the number of actors involved, the nature of these actors, and the relationships between them. This has clear implications to the potential

V2G business models available, whether it's on its current centralized form via an independent aggregator operating in a V2G-EV fleet space, or if V2G is widely diffused socially and progresses into passenger vehicles. Figure 8 shows the potential complexity in organizing these V2G business models, considering that on each of these models, robustness increases as do the number of actors: whether a V2G-EV is connected to an EVSE (and therefore to the grid) at home (Model 1), at work (Model 2) or at a public charging spot (Model 3). On the latter model for example, the type of V2G services can differ depending the power-capacity of each charging point, and each of these connection points could have different ownership, whether it's a power utility, an EVSE provider or a combination of these. Thus, the benefits (and revenues) of the system, and of each V2G transaction, could be allocated into a number of players.

Figure 8: V2G business models for fleets vs. private passenger vehicles

Source: Authors. Note: EVSE = electric vehicle supply equipment.

In addition to this distinction of fleets vs private vehicles, as the V2G market evolves and the technology is diffused, V2G business models can further increase in complexity, particularly in three ways: when there is more than 1 aggregator operating in the market and the form of aggregator evolves in nature (whether power utilities, EVSE providers or IT-based companies become V2G aggregators); when a V2G-EV fleet is large enough that it can participate directly on different types of power markets without the need of an aggregator; and when power markets evolve to allow peer-to-peer services and V2G can maximise the use of other V2X configurations, such as vehicle-to-building, vehicle-to-community and allow V2G to full-fill local needs of power.¹³⁹

5.3 The futurity of governance

A V2G transition also somewhat dramatically challenges some of the conventional business models being adhered to by incumbent firms, especially automakers and electric utilities. The classic business model for OEMs is anchored in the vehicle viewed as a product the consumer buys for a fairly high fixed cost, and profits accrue to the automobile manufacturer and dealership accrue mostly at the point of sale (and later, in occasional situations, for maintenance). R9 essentially said as much when they noted:

You have to understand how the business model of a company like Volkswagen works. They sell you a car, and then they have this massive distribution network and support network, that lives on and thrives on support, spare part sales and lubricating the car and changing this and changing that. You buy a new car and for you to maintain your guarantee you have to visit the dealership every 3 or 6 months or whatever for check-ups so they can charge you every time. But if you have an electric car and you don't ever have to come back, it's a massive change in business model. Volkswagen knows that for every car they sell, they've essentially sold a subscription to certain revenue over the lifetime of a vehicle, usually for seven or even fifteen years. Volkswagen knows their dealership network support network will continue to make money on service and spare parts. They may even blow up prices so they will continue to get revenue from that vehicle. If it is an electric vehicle, that business case is gone: You don't hear from the client again.

Thus, although other parts of the vehicle will still need maintenance, V2G can somewhat radically and completely challenged conventional norms of automotive design and

manufacturing, as EVs require a different body, made of different frames and composites to handle lighter weight, and may also be used in business models that focus more on mobility as a service, rather than a car as a product.¹⁴⁰

For electric utilities, V2G subverts the entire paradigm about building centralized, deterministic, radial power systems architecture with a more decentralized, dynamic, and circular power system architecture (depicted in Figure 9). V2G could replace a relatively simple, one-way flow of electricity grid with little active power control or peak shaving with a bidirectional and more complex grid with extra degradation due to frequent cycling and higher investment costs¹⁴¹ and a multitude of small market bids.

Figure 9: Conventional centralized V2G Grid Architecture (left panel) vs. Aggregated and Decentralized V2G Architecture (right panel)

Source:¹⁴²

V2G therefore potentially requires a reconfiguration of the governance and structure of markets as well as the operational strategies (and business models) of those participating in both transport and power systems.^{143 144} Incumbents might resist such shifts in governance and structure, especially given the history of the automobile industry for suppressing patents on more fuel-efficient vehicles¹⁴⁵ as well as actively seeking to stymie the expansion of public transit and alternatives to cars, especially rail, in the United States.¹⁴⁶

At the same time, these challenges to the current electricity and transport business regime also present opportunities for new ventures. As conventional business models are upended, new ones can be developed in their place. For example, while EVs are expected to greatly reduce the maintenance revenues of OEMs (and threaten their business case), OEMs can gain new revenues by becoming part of the V2G environment. Alternatively, traditional electric utilities can employ V2G to their benefit by providing services that were currently unavailable in the previous more centralized system, such as voltage support and congestion relief.¹⁴⁷ Finally, V2G can also usher in entirely new actors and business models, such as V2G aggregators, who can act as intermediaries between the transport and electricity sectors to provide value to EV owners by providing access and value to services previously unavailable to average consumers¹⁴⁸. In short, while V2G undermines existing business paradigms, it can also contribute to the emergence of novel paradigms.

6. Conclusion and Policy Implications

To conclude, a V2G transition could empower vehicles to simultaneously improve the efficiency (and profitability) of electricity grids, reduce greenhouse gas emissions, accommodate low-carbon sources of energy, and reap cost savings for owners, drivers, and other users.

Indeed, we identified no less than twelve distinct stakeholder types—cutting across industrial firms, households, electricity suppliers, transmission operators, and other third party actors—impacting activity systems across content, structure, and governance. These market players involve a rich collection of actors at different scales—from OEMs and dealers to households and community fleets—offering a mix of traditional business models such as vehicle sales and electricity consumption to more radical business models such as mobility as a service or aggregator grid services (see Figure 10 which places these in five distinct clusters). We also see business opportunities expanding beyond primary markets for cars, electricity sales, and services to secondary markets for software and digital protection and secondhand markets for batteries, storage, and other devices. In short: the potential for V2G business segments extend well beyond vehicle owners and electric utilities, and well beyond grid services. The role of aggregators, fleet operators, public transit operators and small-scale renewable energy power providers in particular have important, though less explored so far in the literature, roles to play. Complicating matters, however, the innovation activity systems framework suggests these business models are temporally dynamic, with costs and benefits shifting over time; structurally complex, with possibilities for overlaps and permutations between them; and exceedingly challenging to govern, given they involve multiple actors and disrupt traditional practices.

Figure 10: V2G Business Models across the Five Clusters of Equipment, Grid Services, Aggregation, Bundling, and Secondary Markets

Source: Authors

The innovation activity systems associated with V2G also lead to the 12 hypothetical policy implications summarized in Table 11. Although not directly reflected in our empirical data, involving users in discussions about grid services, providing substantive and attractive tariffs, incentivizing mobility as a service and car-sharing, and validating secondary and secondhand markets could materially improve the design specifications and performance parameters—the content—of V2G technology. In terms of structure, better integration of stakeholders, market entry for aggregators, optimization of transmission planning and grid services, and the creation of secondhand markets are recommended. In terms of governance, coordination, the publication of information, harmonization of planning and stability of rules and regulations are suggested.

Table 11: Innovation activity systems and potential policy priorities for V2G technology

Business model component	Policy implication
<i>Content</i>	<ul style="list-style-type: none"> - Involve users and potential adopters in discussions about charging and grid services - Provide attractive tariffs for V2G grid services - Offer incentives for mobility as a service platforms and car-sharing - Validate and standardize secondhand markets for V2G automobiles as well as batteries
<i>Structure</i>	<ul style="list-style-type: none"> - Promote better integration between automobile manufacturers, dealer franchises, and battery supply chains - Remove barriers to entry for V2G aggregators - Optimize collaboration between transmission operators, district network operators, and grid service providers - Ensure adequate markets for secondhand and secondary services
<i>Governance</i>	<ul style="list-style-type: none"> - Coordinate cooperation between energy suppliers, transmission operators, and third party fleets and aggregators - Publish and verify reliable information on mobility as a service platforms and car-sharing - Harmonize energy and mobility planning so that decentralized renewable energy operators and public transit operators can contribute across both sectors - Offer stable rules and regulations for secondhand and secondary markets

Source: Authors

Therefore, when we think about the future promise of a V2G transition, we need to focus beyond batteries, grids and vehicles to business models, markets and policies. The business case for V2G is strong but contingent: mobility patterns, emerging regulations, business models and the strength and weakness of our constellation of actors will all determine the extent to which V2G unfolds, and the degree to which it is sustainable. The future of V2G may very well hinge on its financial, economic and business dimensions as much as its technical innovations and attributes.

7. References

- ¹ European Commission. 2018. “Transport.” Brussels: EC. Available at https://ec.europa.eu/clima/policies/international/paris_protocol/transport_en.
- ² European Academies' Science Advisory Council. 2019. Decarbonisation of transport: options and challenges. EASAC policy report 37. March
- ³ Ingrid Holmes, Jonathan Gaventa, Nick Mabey and Shane Tomlinson. 2012. Financing the Decarbonisation of European Infrastructure 30 percent and beyond. E3G. June.
- ⁴ Ingrid Holmes, Jonathan Gaventa, Nick Mabey and Shane Tomlinson. 2012. Financing the Decarbonisation of European Infrastructure 30 percent and beyond. E3G. June.
- ⁵ European Academies' Science Advisory Council. 2019. Decarbonisation of transport: options and challenges. EASAC policy report 37. March
- ⁶ Sovacool, BK, J Axsen, and W Kempton. “The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda,” Annual Review of Environment and Resources 42 (October, 2017), pp. 377-406.
- ⁷ Chen, CF, GZD Rubens, L Noel, J Kester, and BK Sovacool. “Assessing the Socio-demographic, Technical, Economic and Behavioral Factors of Nordic Electric Vehicle Adoption and the Influence of Vehicle-to-Grid Preferences,” Renewable & Sustainable Energy Reviews 121 (April, 2020), 109692, pp. 1-13.
- ⁸ Kempton W, Letendre S. 1997. Electric Vehicles as a new source of power for electric utilities, Transportation Research 2(3), pp. 157-175.
- ⁹ Letendre, Steven E. and Willett Kempton. 2002. “The V2G Concept: A New Model for Power?” Public Utilities Fortnightly (February 15, 2002), pp. 16-26.
- ¹⁰ Willett Kempton, Jasna Tomic, Vehicle-to-grid power fundamentals: Calculating capacity and net revenue, Journal of Power Sources 144 (2005) 268–279
- ¹¹ Willett Kempton, Jasna Tomic, Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy, Journal of Power Sources 144 (2005) 280–294
- ¹² Tomic, Jasna and Willet Kempton. 2007. “Using Fleets of Electric-Drive Vehicles for Grid Support.” Journal of Power Sources 168, pp. 459-468.

-
- ¹³ Lund, Henrik and Willett Kempton. 2008. "Integration of Renewable Energy Into the Transport and Electricity Sectors Through V2G." *Energy Policy* 36, pp. 3578-3587.
- ¹⁴ Benjamin K. Sovacool and Richard F. Hirsh, "Beyond Batteries: An Examination of the Benefits and Barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-Grid (V2G) Transition," *Energy Policy* 37(3) (March, 2009), pp. 1095-1103.
- ¹⁵ Christophe Guille and George Gross, A conceptual framework for the vehicle-to-grid (V2G) implementation, *Energy Policy* 37 (2009) 4379–4390
- ¹⁶ Sovacool, BK, L Noel, J Axsen, and W Kempton. "The neglected social dimensions to a vehicle-to-grid (V2G) transition: A critical and systematic review," *Environmental Research Letters* 13(1) (January, 2018), 013001, pp. 1-18.
- ¹⁷ Noel, L, J Kester, G Zarazua de Rubens, and BK Sovacool. *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility* (Basingstoke: Palgrave, 2019).
- ¹⁸ Noel, L, J Kester, G Zarazua de Rubens, and BK Sovacool. *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility* (Basingstoke: Palgrave, 2019).
- ¹⁹ Casey Quinn et al., The effect of communication architecture on the availability, reliability, and economics of plug-in hybrid electric vehicle-to-grid ancillary services, *Journal of Power Sources* 195 (2010) 1500–1509
- ²⁰ Robert Hein, Paul R. Kleindorfer, Stefan Spinler, Valuation of electric vehicle batteries in vehicle-to-grid and battery-to-grid systems, *Technological Forecasting and Social Change*, Volume 79, Issue 9, 2012, Pages 1654-1671
- ²¹ Nuvve. 2017. Nuvve Smart Grid V2G Brings value to Many Players. (January).
- ²² Wesseling, Joeri H. Explaining variance in national electric vehicle policies, *Environmental Innovation and Societal Transitions* 21 (2016) 28–38
- ²³ Kester, J, L Noel, G Zarazua de Rubens, and BK Sovacool, "Promoting Vehicle to Grid (V2G) in the Nordic Region: Expert advice on policy mechanisms for accelerated diffusion," *Energy Policy* 116 (May, 2018), pp. 422-432.
- ²⁴ Kester, J, L Noel, G Zarazua de Rubens, and BK Sovacool. "Policy Mechanisms to Accelerate Electric Vehicle Adoption: A Qualitative Review from the Nordic Region," *Renewable & Sustainable Energy Reviews* 94 (October, 2018), pp. 719-731.
- ²⁵ Geske, Joachim and Diana Schumann. 2018. Willing to participate in vehicle-to-grid (V2G)? Why not! *Energy Policy*, Volume 120, September 2018, Pages 392-401
- ²⁶ Uddin, Kotub et al. 2018. The viability of vehicle-to-grid operations from a battery technology and policy perspective. *Energy Policy*, Volume 113, February 2018, Pages 342-347
- ²⁷ Zott, C., Amit, R., 2007. Business model design and the performance of entrepreneurial firms. *Organ. Sci.* 18 (2), 181–199.
- ²⁸ Zott, C., Amit, R., 2010. Business model design: An activity system perspective. *Long Range Planning* 43, 216–226
- ²⁹ Zott, C., Amit, R., Massa, L., 2011. The business model: recent developments and future research. *J. Manage.*, 37.
- ³⁰ Amit, R., Zott, C., (2012). *Creating Value Through Business Model Innovation*. MIT Sloan Management Review
- ³¹ Junhee Hong et al., Ex-ante evaluation of profitability and government's subsidy policy on vehicle-to-grid system, *Energy Policy* 42 (2012) 95–104

-
- ³² Noel, L, G Zarazua de Rubens, and BK Sovacool. "Optimizing innovation, carbon and health in transport: Assessing socially optimal electric mobility and vehicle-to-grid (V2G) pathways in Denmark," *Energy* 153 (June, 2018), pp. 628-637.
- ³³ Zi Li et al., Optimizing the Performance of Vehicle-to-Grid (V2G) Enabled Battery Electric Vehicles through a Smart Charge Scheduling Model, *International Journal of Automotive Technology*, Vol. 16, No. 5, pp. 827–837 (2015)
- ³⁴ Willett Kempton, Jasna Tomic, Vehicle-to-grid power fundamentals: Calculating capacity and net revenue, *Journal of Power Sources* 144 (2005) 268–279
- ³⁵ Casey Quinn et al., The effect of communication architecture on the availability, reliability, and economics of plug-in hybrid electric vehicle-to-grid ancillary services, *Journal of Power Sources* 195 (2010) 1500–1509
- ³⁶ Zarazua de Rubens, G. "Who will buy electric vehicles after early adopters? Using machine learning to identify the electric vehicle mainstream market," *Energy* 172 (April, 2019), pp. 243-254.
- ³⁷ J. Tomic, W. Kempton, Using fleets of electric-drive vehicles for grid support, *J. Power Sources* 168 (2) (2007) 459–468
- ³⁸ SL Andersson et al., Plug-in hybrid electric vehicles as regulating power providers: Case studies of Sweden and Germany, *Energy Policy* 38 (2010) 2751–2762
- ³⁹ Johannes Jargstorf and Manuel Wickert, Offer of secondary reserve with a pool of electric vehicles on the German market, *Energy Policy* 62 (2013) 185–195
- ⁴⁰ Jonathan Mullan et al., The technical, economic and commercial viability of the vehicle-to-grid concept, *Energy Policy* 48 (2012) 394–406
- ⁴¹ Aoife Foley et al., Impacts of Electric Vehicle charging under electricity market operations, *Applied Energy* 101 (2013) 93–102
- ⁴² Dominik Pelzer et al., A price-responsive dispatching strategy for Vehicle-to-Grid: An economic evaluation applied to the case of Singapore, *Journal of Power Sources* 256 (2014) 345-353
- ⁴³ Chesbrough, H., 2006. *Open Business Models; How to Thrive in the New Innovation Landscape*. Harvard Business School Press, Boston, Massachusetts.
- ⁴⁴ Hiteva, R and BK Sovacool. "Harnessing Social Innovation for Energy Justice: A Business Model Perspective," *Energy Policy* 107 (August, 2017), pp. 631-639.
- ⁴⁵ Afuah, A., 2004. *Business Models : A Strategic Management Approach*. McGraw-Hill/Irwin, Boston
- ⁴⁶ Kley, F., Lerch, C., Dallinger, D. 2011. New business models for electric cars—a holistic approach. *Energy Policy* 39, 3392–3403
- ⁴⁷ Ronan Bolton, Matthew Hannon, Governing sustainability transitions through business model innovation: Towards a systems understanding, *Research Policy* 45 (2016) 1731–1742
- ⁴⁸ Kley, F., Lerch, C., Dallinger, D. 2011. New business models for electric cars—a holistic approach. *Energy Policy* 39, 3392–3403
- ⁴⁹ Kley, F., Lerch, C., Dallinger, D. 2011. New business models for electric cars—a holistic approach. *Energy Policy* 39, 3392–3403
- ⁵⁰ Zott, C., Amit, R., 2007. Business model design and the performance of entrepreneurial firms. *Organ. Sci.* 18 (2), 181–199.
- ⁵¹ Zott, C., Amit, R., 2010. Business model design: An activity system perspective. *Long Range Planning* 43, 216–226

-
- ⁵² Zott, C., Amit, R., Massa, L., 2011. The business model: recent developments and future research. *J. Manage.*, 37.
- ⁵³ Amit, R., Zott, C., (2012). *Creating Value Through Business Model Innovation*. MIT Sloan Management Review
- ⁵⁴ Zott and Amit, 2010
- ⁵⁵ International Energy Agency. 2018. *Nordic EV Outlook 2018: Insights from leaders in electric mobility* (Paris: OECD).
- ⁵⁶ International Energy Agency. 2019. *Global EV Outlook 2019: Scaling up the transition to electric mobility*. Paris: OECD, May.
- ⁵⁷ Reuters. After Tesla's record year in Norway, rivals gear up for 2020. January 3, 2020.
- ⁵⁸ International Energy Agency. 2018. *Nordic EV Outlook 2018: Insights from leaders in electric mobility* (Paris: OECD).
- ⁵⁹ Kester, J, L Noel, G Zarazua de Rubens, and BK Sovacool, "Promoting Vehicle to Grid (V2G) in the Nordic Region: Expert advice on policy mechanisms for accelerated diffusion," *Energy Policy* 116 (May, 2018), pp. 422-432.
- ⁶⁰ Kester, J, L Noel, G Zarazua de Rubens, and BK Sovacool, "Promoting Vehicle to Grid (V2G) in the Nordic Region: Expert advice on policy mechanisms for accelerated diffusion," *Energy Policy* 116 (May, 2018), pp. 422-432
- ⁶¹ Noel, L, J Kester, G Zarazua de Rubens, and BK Sovacool. *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility* (Basingstoke: Palgrave, 2019).
- ⁶² Noel, L, J Kester, G Zarazua de Rubens, and BK Sovacool. *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility* (Basingstoke: Palgrave, 2019).
- ⁶³ International Organization of Motor Vehicle Manufacturers, *World Motor Vehicle Production and OICA 2017 Production Statistics*, 2018
<http://www.oica.net/category/production-statistics/2017-statistics/>
- ⁶⁴ International Energy Agency. 2018. *Global EV Outlook 2018: Towards cross-modal electrification* (Paris: OECD/IEA).
- ⁶⁵ Marc Dijk, Renato J. Orsato, Rene Kemp, The emergence of an electric mobility trajectory, *Energy Policy*, Volume 52, January 2013, Pages 135–145
- ⁶⁶ International Energy Agency. 2018. *Global EV Outlook 2018: Towards cross-modal electrification* (Paris: OECD/IEA).
- ⁶⁷ Marc Dijk, Renato J. Orsato, Rene Kemp, The emergence of an electric mobility trajectory, *Energy Policy*, Volume 52, January 2013, Pages 135–145
- ⁶⁸ Orsato, R.J. and P. Wells, The Automobile Industry & Sustainability, *Journal of Cleaner Production* 15 (2007) 989-993.
- ⁶⁹ Mitchell, William J., Christopher E. Borroni-Bird, and Lawrence D. Burns, *Reinventing the Automobile: Personal Urban Mobility for the 21st Century* (Cambridge: MIT Press, 2010), pp. 12-13.
- ⁷⁰ Marc Dijk, Renato J. Orsato, Rene Kemp, The emergence of an electric mobility trajectory, *Energy Policy*, Volume 52, January 2013, Pages 135–145
- ⁷¹ Marc Dijk, Renato J. Orsato, Rene Kemp, The emergence of an electric mobility trajectory, *Energy Policy*, Volume 52, January 2013, Pages 135–145
- ⁷² IEA/OECD (International Energy Agency) (2016) 'Global EV Outlook 2016: Beyond one million electric cars', page 5. Available at:
https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf

-
- ⁷³ Dai Wang, Jonathan Coignard, Teng Zeng, Cong Zhang, Samveg Saxena, Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services, *Journal of Power Sources*, Volume 332, 2016, Pages 193-203
- ⁷⁴ Jonathan Mullan et al., The technical, economic and commercial viability of the vehicle-to-grid concept, *Energy Policy* 48 (2012) 394–406
- ⁷⁵ H. Turton, F. Moura, Vehicle-to-grid systems for sustainable development: an integrated energy analysis, *Technol. Forecast. Soc. Chang.* 75 (8) (2008)
- ⁷⁶ Sekyung Han, Soohye Han, Development of short-term reliability criterion for frequency regulation under high penetration of wind power with vehicle-to-grid support, *Electric Power Systems Research* 107 (2014) 258– 267
- ⁷⁷ Marilyn A. Brown et al., Smart grid governance: An international review of evolving policy issues and innovations, *WIRES Energy and Environment*, Volume7, Issue5 September/October 2018 e290
- ⁷⁸ Marilyn A. Brown et al., Smart grid governance: An international review of evolving policy issues and innovations, *WIRES Energy and Environment*, Volume7, Issue5 September/October 2018 e290
- ⁷⁹ Kempton W, Tomić J. Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *J Power Sources*. 2005 Jun;144(1):268–79.
- ⁸⁰ Noel, L, J Kester, G Zarazua de Rubens, and BK Sovacool. *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility* (Basingstoke: Palgrave, in press, 2019).
- ⁸¹ Noori M, Zhao Y, Onat NC, Gardner S, Tatari O. Light-duty electric vehicles to improve the integrity of the electricity grid through Vehicle-to-Grid technology: Analysis of regional net revenue and emissions savings. *Appl Energy*. 2016 Apr;168:146–58.
- ⁸² Noel, L, J Kester, G Zarazua de Rubens, and BK Sovacool. *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility* (Basingstoke: Palgrave, in press, 2019).
- ⁸³ Marc Dijk, Renato J. Orsato, Rene Kemp, The emergence of an electric mobility trajectory, *Energy Policy*, Volume 52, January 2013, Pages 135–145
- ⁸⁴ Scott, Michael J., Michael Kintner-Meyer, Douglas B. Elliott, William M. Warwick. 2007. “Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 2: Economic Assessment,” Pacific Northwest National Laboratory Report, available at http://www.pnl.gov/energy/eed/etd/pdfs/phev_feasibility_analysis_combined.pdf.
- ⁸⁵ Tomas Gomez San Roma et al., Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships, , *Energy Policy* 39 (2011) 6360–6375
- ⁸⁶ Mindy Blank and Kevin Jones, Electric Vehicle Charging: Tariffs and Tradeoffs, *Public Utilities Fortnightly* (March, 2015), pp. 43-59.
- ⁸⁷ Tomas Gomez San Roma et al., Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships, , *Energy Policy* 39 (2011) 6360–6375
- ⁸⁸ Francis Mwasilu et al., Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration, *Renewable and Sustainable Energy Reviews* 34 (2014) 501–516
- ⁸⁹ Hamed Hashemi-Dezaki et al., Risk management of smart grids based on managed charging of PHEVs and vehicle-to-grid strategy using Monte Carlo simulation, *Energy Conversion and Management* 100 (2015) 262–276
- ⁹⁰ G. Haddadian et al., Security-constrained power generation scheduling with thermal

generating units, variable energy resources, and electric vehicle storage for V2G deployment, *Electrical Power and Energy Systems* 73 (2015) 498–507

⁹¹ Taisuke Masuta et al., Electric vehicle charge patterns and the electricity generation mix and competitiveness of next generation vehicles, *Energy Conversion and Management* 83 (2014) 337–346

⁹² Salman Habib et al., Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks - A review, *Journal of Power Sources* 277 (2015) 205–214

⁹³ Francis Mwasilu et al., Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration, *Renewable and Sustainable Energy Reviews* 34 (2014) 501–516

⁹⁴ Alexander Kihm, Stefan Trommer, The new car market for electric vehicles and the potential for fuel substitution, *Energy Policy* 73 (2014) 147–157

⁹⁵ Willett Kempton, Jasna Tomic, Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy, *Journal of Power Sources* 144 (2005) 280–294

⁹⁶ Davion M. Hill et al., Fleet operator risks for using fleets for V2G regulation, *Energy Policy* 41 (2012) 221–231

⁹⁷ Mahdi Kiaee et al., Estimation of cost savings from participation of electric vehicles in vehicle to grid (V2G) schemes, *J. Mod. Power Syst. Clean Energy* (2015) 3(2):249–258

⁹⁸ Mom, Gijs P.A. 2004. *The Electric Vehicle: Technology and Expectations in the Automobile Age* (Baltimore: Johns Hopkins University Press, 2004).

⁹⁹ David Addison, Malek Al-Chalabi, Cliff Elwell, Mark Evans, Neil Salmond, Rob Saunders, *Open Roads, Anxious Drivers: A Technology and Policy Assessment for Long Range Electric Vehicles in the UK*, Energy Policy Project, 2010

¹⁰⁰ Tyfield, D., Zuev, D., Ping, L. and Urry, J. (2014) *Low Carbon Innovation in Chinese Urban Mobility: Prospects, Politics and Practices*, STEPS Working Paper 71, Brighton: STEPS Centre

¹⁰¹ Lance Noel and Regina McCormack, A cost benefit analysis of a V2G-capable electric school bus compared to a traditional diesel school bus, *Applied Energy* 126 (2014) 246–255

¹⁰² Maria Carmen Falvo et al., Energy management in metro-transit systems: An innovative proposal toward an integrated and sustainable urban mobility system including plug-in electric vehicles, *Electric Power Systems Research* 81 (2011) 2127–2138

¹⁰³ Quinn et al. 2010

¹⁰⁴ Noel et al. 2019.

¹⁰⁵ Noel et al. 2019.

¹⁰⁶ Han S, Han S, Sezaki K. Development of an optimal vehicle-to-grid aggregator for frequency regulation. *IEEE Trans Smart Grid*. 2010;1(1):65–72.

¹⁰⁷ Jang S, Han S, Han SH, Sezaki K. Optimal decision on contract size for V2G aggregator regarding frequency regulation. In: *IEEE*; 2010 [cited 2018 Jul 4]. p. 54–62. Available from: <http://ieeexplore.ieee.org/document/5510464/>.

¹⁰⁸ Vandael S, Claessens B, Ernst D, Holvoet T, Deconinck G. Reinforcement learning of heuristic EV fleet charging in a day-ahead electricity market. *IEEE Trans Smart Grid*. 2015;6(4):1795–805

¹⁰⁹ Kley et al. (2011)

-
- ¹¹⁰ Dijk et al. 2013.
- ¹¹¹ Nielsen, JR, H Hovmøller, P Blyth, BK Sovacool. “Of ‘White Crows’ and ‘Cash Savers:’ A Qualitative Study of Travel Behavior and Perceptions of Ridesharing in Denmark,” *Transportation Research Part A* 78 (August, 2015), pp. 113-123.
- ¹¹² Francis Mwasilu et al., Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration, *Renewable and Sustainable Energy Reviews* 34 (2014) 501–516
- ¹¹³ Habib et al. 2015.
- ¹¹⁴ Camila Fernandes et al., Impact of vehicle-to-grid on power system operation costs: The Spanish case study, *Applied Energy* 96 (2012) 194–202
- ¹¹⁵ Zakeri B, Syri S. Electrical energy storage systems: A comparative life cycle cost analysis. *Renew Sustain Energy Rev.* 2015 Feb;42:569–96.
- ¹¹⁶ Noel L, Brodie JF, Kempton W, Archer CL, Budischak C. Cost minimization of generation, storage, and new loads, comparing costs with and without externalities. *Appl Energy.* 2017 Mar;189:110–21.
- ¹¹⁷ McDonagh S, O’Shea R, Wall DM, Deane JP, Murphy JD. Modelling of a power-to-gas system to predict the levelised cost of energy of an advanced renewable gaseous transport fuel. *Appl Energy.* 2018 Apr;215:444–56.
- ¹¹⁸ Apostolaki-Iosifidou E, Codani P, Kempton W. Measurement of power loss during electric vehicle charging and discharging. *Energy.* 2017 May;127:730–42.
- ¹¹⁹ Hedegaard K, Meibom P. Wind power impacts and electricity storage – A time scale perspective. *Renew Energy.* 2012 Jan;37(1):318–24.
- ¹²⁰ Dijk et al. 2013.
- ¹²¹ Dijk et al. 2013.
- ¹²² IEA. 2019. Global Electric Vehicle (EV) Outlook 2018: Towards crossmodal electrification, Paris: International Energy Agency.
- ¹²³ IEA. 2019. Global Electric Vehicle (EV) Outlook 2018: Towards crossmodal electrification, Paris: International Energy Agency.
- ¹²⁴ Transport for London. July 15 2015. More than 50 all-electric buses to enter service in London. Available at <https://tfl.gov.uk/info-for/media/press-releases/2015/july/more-than-50-all-electric-buses-to-enter-service-in-london>.
- ¹²⁵ Chris Randall. Project Bus2Grid will explore V2G charging with buses. March 7, 2018. <https://www.electrive.com/2018/03/07/project-bus2grid-will-explore-v2g-charging-buses/>
- ¹²⁶ Uttam Kumar Debnath et al., Quantifying economic benefits of second life batteries of gridable vehicles in the smart grid, *Electrical Power and Energy Systems* 63 (2014) 577–587
- ¹²⁷ Kley et al. 2011.
- ¹²⁸ Drabik, Eleanor and Vasileios Rizos. 2018. Prospects for electric vehicle batteries in a circular economy. CPES Research Report. No 2018/05, July 2018
- ¹²⁹ Drabik, Eleanor and Vasileios Rizos. 2018. Prospects for electric vehicle batteries in a circular economy. CPES Research Report. No 2018/05, July 2018
- ¹³⁰ Drabik, Eleanor and Vasileios Rizos. 2018. Prospects for electric vehicle batteries in a circular economy. CPES Research Report. No 2018/05, July 2018
- ¹³¹ Richards, H. Christine, Ted Walker, and Derek Jones. 2019. Transportation-to-Grid: New Business Models to Capture Value in the Energy Cloud. Navigant Consulting.
- ¹³² Richards, H. Christine, Ted Walker, and Derek Jones. 2019. Transportation-to-Grid: New Business Models to Capture Value in the Energy Cloud. Navigant Consulting.

-
- ¹³³ Richards, H. Christine, Ted Walker, and Derek Jones. 2019. *Transportation-to-Grid: New Business Models to Capture Value in the Energy Cloud*. Navigant Consulting.
- ¹³⁴ C. Weiller and A. Neely, Using electric vehicles for energy services: Industry perspectives, *Energy* 77 (2014) 194-200.
- ¹³⁵ (Noel et al. 2019)
- ¹³⁶ Willett Kempton, Jasna Tomic, Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy, *Journal of Power Sources* 144 (2005) 280–294
- ¹³⁷ Noel et al. 2019
- ¹³⁸ Kley et al. 2011.
- ¹³⁹ Noel et al. 2019.
- ¹⁴⁰ Sovacool, BK, LD Noel, and RJ Orsato. “Stretching, Embeddedness, and Scripts in a Sociotechnical Transition: Explaining the Failure of Electric Mobility at Better Place (2007-2013),” *Technological Forecasting & Social Change* 123 (October, 2017), pp. 24-34.
- ¹⁴¹ R. Romo, O. Micheloud, Power quality of actual grids with plug-in electric vehicles in presence of renewables and micro-grids, *Renewable and Sustainable Energy Reviews* 46(2015)189–200
- ¹⁴² Quinn et al. 2010.
- ¹⁴³ Matthias D. Galus et al., On integration of plug-in hybrid electric vehicles into existing power system structures, *Energy Policy* 38 (2010) 6736–6745
- ¹⁴⁴ Tomas Gomez San Roma et al., Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships, , *Energy Policy* 39 (2011) 6360–6375
- ¹⁴⁵ Saunders, Kurt M. and Linda Levine, “Better, Faster Cheaper—Later: What Happens When Technologies are Suppressed,” *Michigan Telecommunications and Technology Law Review* 11 (Fall, 2004), pp. 23-69.
- ¹⁴⁶ Goddard, Stephen B. *Getting There: The Epic Struggle Between Road and Rail in the American Century*. University of Chicago Press. pp. 69–70. 1996.
- ¹⁴⁷ Eyer J, Corey G. *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide* [Internet]. Albuquerque, New Mexico: Sandia National Laboratories; 2010 Feb p. 232. Report No.: SAND2010-0815. Available from: <http://www.sandia.gov/ess/publications/SAND2010-0815.pdf>
- ¹⁴⁸ Noel et al. 2019.