Energy Research & Social Science 57 (2019) 101241

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Expert perceptions of enhancing grid resilience with electric vehicles in the United States

Marilyn A. Brown, Anmol Soni*

Georgia Institute of Technology, Georgia State University, United States

ARTICLE INFO

Keywords:
Electric vehicles
Vehicle-grid integration
Expert survey
Grid resilience

ABSTRACT

Electricity and transportation systems in industrialized countries are undergoing transformations that, if coordinated, could improve the resilience and environmental performance of energy systems. The electrification of transportation and the expansion of renewable electricity can be leveraged by the bidirectional smart charging of electric vehicles, called "vehicle-grid integration" (VGI). Studies to date have focused on simulations and pilot studies to estimate the technical potential of VGI. We survey members of the U.S. Department of Energy's Electricity Advisory Committee using a Delphi approach to assess VGI's market potential and challenges. Building on the tradition of managing real-time demand with energy efficiency and load control, we extend the concept to consider grid resilience services with VGI. The survey results are examined in tandem with a targeted review of the literature, current policies, and the ecosystem of stakeholders. We find that experts rate grid-to-vehicle integration as the most valuable mode, and they rate battery degradation and warranty issues as the most important integration challenges. Our expert respondents also noted the need to create markets for ancillary grid services in vertically integrated utility systems. Managing electricity and transportation as complementary systems could help to address the growing need for grid resilience and carbon mitigation.

1. The resilience services of mobile storage as a transition enabler

Global energy markets are undergoing two major transformations – the electrification of transportation and the growth of renewable energy resources. If these shifts continue to evolve independently and without coordination, they will require costly infrastructure investments and cause service disruptions that could otherwise be averted. On the other hand, if these transformations are coordinated to take advantage of cross-cutting supply chain benefits, significant grid resilience and cost benefits could result.

In utility territories and states where variable renewables command substantial market share, grid resilience is being challenged. For example, small residential transformers have been identified by Hanrahan [1] and others as presenting a notable risk. In cities with significant fleets of electric vehicles, daytime EV charging is straining electricity reserves and is triggering the dispatch of natural gas generation along with the real-time purchase of costly power. At the same time, a largely untapped major opportunity for coordinating these green electricity and transportation trends is emerging with the development of grid-integrated vehicles.

The electrification of transportation globally and in the U.S. is well underway. The Annual Energy Outlook 2018 projects a modest expansion of electric vehicle (EV) sales in the US – growing from less than 2% of total vehicle sales today to 15% by 2040[1] [2]. In contrast, Bloomberg New Energy Finance [3] forecasts a more rapid fleet transformation, with EVs reaching 60% of new car sales by 2040, driven largely by declining battery costs. Battery prices have already declined significantly (from \$1000/kWh in 2010 to \$273/kWh in 2016), and further reductions are anticipated [4]. This rising share of EVs will impact electric grid infrastructure and operations. In addition, as the share of EVs increases, alternative business models to integrate the vehicles with the grid will emerge and generate potential for new revenue streams.

With the EV market on a steady foundation, automakers are beginning to develop a range of offerings and technologies that will likely accelerate market acceptance.

As a result, the load on the electric grid from EVs is expected to grow. This makes it timely to examine the potential impact of EVs on grid resiliency. With foresight, the investments needed to integrate EVs into the electric grid can also be leveraged as a means of strengthening the resilience of the grid. While EVs offer well-to-wheel greenhouse gas and local pollution reductions [5], they may also be a key to enhancing grid security.

* Corresponding author at: School of Public Policy, 685 Cherry Street NW, Atlanta, GA, 30313, United States.
E-mail address: asoni33@gatech.edu (A. Soni).

[1] This number is calculated at the total of all the new electric vehicle sales (100- 200- and 300-mile range) as a share of the total new car sales in 2040.

https://doi.org/10.1016/j.erss.2019.101241
Received 6 February 2019; Received in revised form 15 July 2019; Accepted 18 July 2019
2214-6296/

The share of renewable energy resources in electricity generation is also growing. EIA [2] forecasts that total net electricity generation will rise from 630 BkWh in 2016 to 1651 BkWh in 2050, an annual growth rate of 2.7%. In some areas that already have significant penetration of variable renewables, grid operators are already experiencing challenges, such as more frequent negative pricing events [6]. Layered on top of these concerns, natural and man-made disasters also threaten the grid's ability to deliver reliable, high-quality power, as demonstrated by Superstorm Sandy in 2012, the Polar Vortex in 2014, and Hurricane Irma in 2017 [6]. As the U.S. economy becomes increasingly dependent on information and communication technologies, access to reliable high-quality electricity is essential to maintaining competitiveness in the global marketplace.

A resilient grid can absorb shocks to prevent interruptions, manage disruptions as they occur, and return to normal operation quickly. To be resilient, the grid must have the capability to (1) anticipate, (2) absorb, (3) adapt to and (4) rapidly recover from disrupting events [7]. The U.S. Federal Energy Regulatory Commission (FERC) characterizes grid resilience as the ability of the bulk power system to withstand or recover from disruptive events [8].

Many analysts have examined each of these issues – the decarbonization of electricity generation, electrification of the transportation sector, and the increasing need for grid resilience. However, the interaction between these trends is unclear. Little is known about the potential role of EVs as contributors to the electric grid, their possible participation in markets for resilience services, and their ability to help manage stresses to the grid across highly variable states and regions. We were offered the unique opportunity to query a set of U.S. experts to determine their views on the impact of electric vehicles on the resilience of electricity systems. The results are presented in this paper, which represents the culmination of our preparatory research and the findings of our survey.

The remainder of this paper is organized as follows. In the next section, we provide a brief motivation and description of our approach. Section 3 highlights the state of the literature and describes the different modes of integration and the polycentric policy ecosystem that supports the expanding EV marketplace. This is followed by a discussion of pilot case studies in Section 4. In Section 5, we describe our survey and its findings. Section 6 envisions the potential co-evolution of electricity and transportation systems in the U.S. and summarizes the study and our conclusions.

2. Motivation and approach

We deploy a multi-pronged research approach to assess the technology, business, and policy challenges and identify the opportunities for grid-integrated vehicles in the U.S. Specifically, we review the literature and the policy landscape, interview participants leading pilot projects across the U.S.,[2] and survey members of the U.S. Department of Energy's (DOE) Electricity Advisory Committee (EAC).

The EAC was established by the DOE to advise in implementing the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007. EAC members are appointed by the U.S. Secretary of Energy to two-year terms. They represent different fields relevant to the electricity industry including utility regulators, grid operators, electricity suppliers, academics, and NGOs. These experts deliberate and advise the DOE on matters relating to the power sector. The range of issues includes science and technology, regulations, and policy aspects of the electricity sector. Different subcommittees within the EAC take on various projects to examine the current state and future pathways of the sector and provide the DOE with recommendations that help prepare the sector and the economy for emerging trends and changes. As a two-term member of the EAC, the first author of this paper led the Smart Grid Subcommittee's activities in 2017–18, participating in assessments of the state of energy storage, modernizing the electric grid, and valuation of distributed energy resources.[3]

Envisioning a future where transportation not only draws its energy needs from the electric power sector, but also helps supports the resilience of the electricity system, the Subcommittee elected to focus on grid-integrated vehicles and the value of mobile battery storage. This decision was motivated in part by the devastation caused by Hurricane Maria in Puerto Rico in September 2017, which caused a half-year when significant parts of the island experienced sustained blackouts.

3. EV-grid integration: state of the literature

Theoretically, integration with EVs can contribute to the reliability and resilience of electric grids [9,10]. Reliability encompasses adequacy – the ability of the electricity system to meet the aggregate electrical demand and energy requirements of end-use customers at all times, as well as maintaining operating reliability – the ability to withstand sudden disturbances, such as electric short circuits or the unanticipated loss of system elements [7]. Resilience ensures that the system can bounce back from disturbances and minimizes damages. A resilient system acknowledges that outages can occur, prepares to deal with them, minimizes their impact, and is able to restore service quickly. Grid-connected vehicles can support reliability through demand response services and can help restore power in case of emergency [7].

Again, in theory, grid integration of EVs can potentially reduce costs for the power sector. The National Renewable Energy Laboratory used California's Low Carbon Grid Study to quantify the grid-value from managed charging by using three levels of managed loads for 13 TWh of annual load from three million EVs in 2030. Simulation results showed that management of the EV fleet's aggregate load from "unmanaged" to "100% managed" could result in savings of $210 million to $660 million annually in generation system costs, depending on grid conditions [11]. Vehicle-grid integration also offers the possibility of savings from distribution deferral—shifting line upgrades and component capacity into the future.

This paper identifies and examines the different modes of grid-integrated vehicles, along with their technology, business, and policy challenges and opportunities. We explore the possibility of a transportation system where vehicles not only draw power from the grid but can also:

- Provide mobile storage to make the grid more resilient
- Offer other grid services with smart charging
- Charge from distributed energy sources
- Be used as a source of back-up power for homes and businesses

The evolving power grid operations and increasing penetration of EVs would be mutually beneficial if EVs were grid integrated. With such an integration, the mobile storage of EVs could be used to meet grid service requirements such as those defined in Table 1.

[2] Valuable inputs were also provided by participants in a meeting on "Grid-Integrated Vehicles," co-hosted by Chattanooga's Electric Power Board and the Georgia Institute of Technology on March 1, 2018. https://cepl.gatech.edu/projects/sgp/GIV.

[3] The EAC Smart Grid Subcommittee has a statutory basis in the Energy Independence & Security Act (§1303). The Subcommittee advises DOE on "The development of smart grid technologies, the progress of a national transition to the use of smart-grid technologies and services, the evolution of widely-accepted technical and practical standards and protocols to allow interoperability and inter-communication among smart-grid capable devices, and the optimum means of using Federal incentive authority to encourage such progress." Its reports and memos can be found here: https://www.energy.gov/oe/services/electricity-advisory-committee-eac/electricity-advisory-committee-reports-and-memos.

Table 1
Grid resilience services and definitions.

Resilience Services	Definitions
Demand Response	Responding to changes in prices or high demand by charging vehicles when system demand is low
Valley Filling	Building loads during off-peak hours to help load shifting
Negative Demand Response	Dynamic charging can be used to expand demand during low-demand periods to support base load power
Coordinated Charging	Synchronizing the charging process in order to avoid demand surges
Demand Charge Reduction	Switching to car batteries during high demand periods can help reduce demand charges for users
Reserves	The low ramp-up speeds allow vehicle batteries to provide spinning, non-spinning and supplementary reserves
Emergency Back-up	The battery of the vehicle can be used as a storage device that feeds back into the grid in the event of outages
Capacity Firming	Using storage facilities to manage the variable generation, especially with the integration of renewables in the power generation mix
Voltage Control	Using EV battery storage and two-way flow help maintain the voltage at the users' end
Frequency Regulation	Ramping up or down based on changes in frequency and the difference between power demand and supply

3.1. Modes of EV integration

The interactions between EVs and the power grid can be categorized into three modes based on the functionality and the values that can be extracted from vehicle-grid integration [12].

- **Grid-to-Vehicle (G2V)** is based on unidirectional flow of power from the grid to the EV; it does not require the bi-directional flow of power between the grid and the vehicle. Smart and coordinated EV charging for dynamic balancing can make vehicle charging more efficient by regulating and coordinating the charging, a myriad of benefits could be achieved. G2V based modes of integration rely on coordinated charging (advanced/delayed) to provide demand response services to the grid. The service delivery usually takes place during the hours of the day/night when the vehicle is idle.
- **Vehicle-to-Building (V2B)** requires a bi-directional flow of power. The car needs to be charged from a source of electricity such as the grid or a distributed energy resource such as solar panels; in addition, the car needs to be able to discharge power to the building. The discharging of electricity from EVs to building energy management systems can provide backup and emergency services to homes and businesses. It can also reduce the building's demand charge by providing power to the building during the utility's hours of peak demand.
- **Vehicle-to-Grid (V2G)** requires the bi-directional flow of power to enable cars to provide the grid with access to their battery storage. It involves power flows back to the grid and the ability to support advanced grid services such as voltage control, frequency regulation and capacity firming. Providing frequency and balancing services to the local distribution system requires the advanced control of power flows from the vehicle.

Each mode of EV integration has a unique set of grid resilience attributes. The need for these grid services will vary across states and regions, depending on existing infrastructures and institutional regimes that create "path dependencies" [13]. Current levels of reserve margins and shares of variable renewable energy will influence the potential revenue opportunities for EVs from reserve, voltage control and frequency regulation markets. For instance, in the Southeast, reserve margins are large and therefore markets for reserves may not be substantial; however, the need for voltage control and frequency regulation could grow in stride with the region's share of variable renewable energy.

3.2. Players and markets: a stakeholder analysis

The market for grid-integrated vehicles involves a complex socio-technical system [14] of players – some that will be threatened by the integration of transportation and electricity sectors, and others that could benefit. The broad categories include manufacturers (of cars, batteries, and solar photovoltaic systems), energy suppliers, new market entrants, government agencies and consumers (Fig. 1).

A stakeholder analysis is a useful tool to examine the values, positions and resultant strategies of different players. It has been used widely in many energy environment contexts [15,16]. We apply this tool with a descriptive and instrumental purpose [17] to help situate and contextualize issues and formulate our expert survey. The boundary of our stakeholders includes all participants who are directly or indirectly involved in the manufacturing, operation and usage of EVs, and those who are impacted by their societal consequences. We ask four questions for each stakeholder – what are their interests and objective? What is their expected position? What types of resources do the stakeholders have access to? What strategies and venues of influence will they leverage? (Table 2).

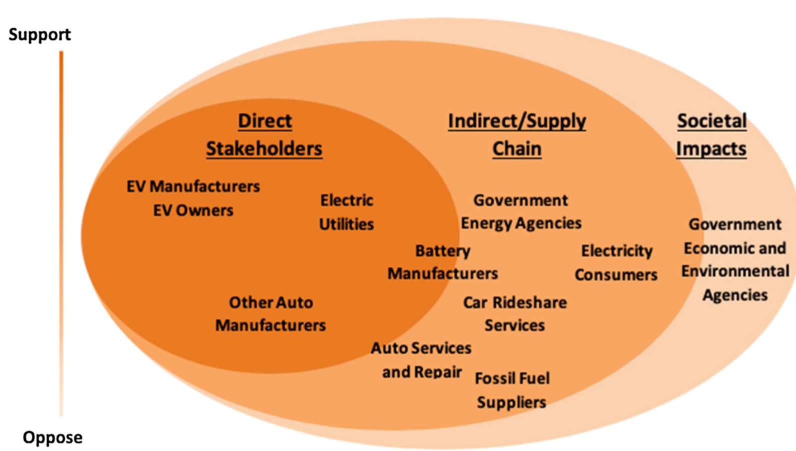


Fig. 1. Stakeholders Influenced by the Direct, Indirect, and Induced Impacts of Grid-Integrated Vehicles.
(Source: Authors)

Table 2
Stakeholder Analysis of Grid-Integrated EVs.

	Stakeholders	Interest and Objectives	Expected Position	Access to Resources	Strategies and Venues of Influence
Manufacturers	EV Manufacturers	Sales and profits	Would support the integration, if battery warranty can be addressed	Access to consumer data	Lobby for EV subsidies; influence standards and technology specifications
	ICE Auto Manufacturers	Sales and profits	Oppose	Significant financial resources; lobbyists	Lobby against EV subsidies
	Battery Manufacturers	Higher market penetration, reduced costs of battery technology	Mixed, due to perceived effects on battery life and quality	New manufacturing technology	Negotiate contractual obligations of EV owners and aggregators
	Solar Panel Manufacturers	Increase in solar installation	Likely to support	Increasing market share and assets	Lobby and partner with EV industry
Energy Suppliers	Fossil Fuel Suppliers	Maximize profits	Strongly oppose	Significant financial resources; lobbyists	Lobby against subsidies for EVs
	Electric Utilities	Electricity sales	Support	Significant financial resources; lobbyists	Operate according to FERC requirements; conduct market analysis; offer EV rebates and preferential rate designs
	RTOs/ISOs, Grid Operators	Maintaining reliability	Mixed	Limited financial resources	Operate according to FERC requirements; conduct market analysis
Incumbents	Auto Repair and Service Companies	Maintaining market share	Strongly oppose	Participate in legislation; influence consumer behavior	Lobby against subsidies for EVs; partner with ICE auto manufacturers
	Ride Share and Cab Services	Maximize miles of service	Likely to oppose	Limited financial resources	Influence consumer behavior
New Entrants	Third Party Aggregators, Fleet Operators, Charging, Solar Panel Installers	Acquiring new market share	Support	New business models	Participate in legislation; influence consumer behavior; partner with electric utilities
Government Agencies	U.S. Department of Energy and State Energy Agencies, City Sustainability/Resilience Offices, and Regulators	Grow economy, grid security, reliability, and consumer protection	Mixed	Political clout; conduct analysis; legislative and tax authority, rate oversight	Institute policies that foster clean energy, are fair and equitable, and prevent predatory practices
Consumers	EV Owners	Reduced costs of owning EVs, clean air	Support	Influence manufacturers by their buying behavior	Exert political will (as the electorate) and influence prices through fleet purchases
	Electricity Consumers - Residential	Lower rates; stable electricity supply protection of human health	Mixed	Limited; voting power	Elect candidates who will minimize rates and protect public health
	Electricity Consumers – Commercial and Industrial	Lower rates; stable electricity supply	Mixed	Significant financial resources and access to politicians	Lobby and leverage via access to politicians

Note: ICE = internal combustion engine; RTO = Regional Transmission Operator; ISO = Independent System Operator.

Table 3
Number of states with different EV support policies.
Source: Coded based on the maps by Hartman and Dowd [24]

Policy	Number of U.S. States
Fleet Requirements	28
Electric Vehicle Supply Equipment	27
Financial Incentives	23
Exemption from Emissions Testing	14
Utility Incentives	13
HOV Access	13
Reduced Licensing/ Registration/Road Charges	4

The two main groups of stakeholders who might oppose the transition towards grid-integrated EVs are the incumbents in both the traditional automotive and fossil energy sectors. Automakers who are not entering the EV manufacturing field will lose market share and therefore would likely oppose efforts to electrify transportation. Similarly, incumbent fuel suppliers – oil companies and gas station operators would likely oppose the move towards EVs as they would also lose market share. High levels of support can be expected from EV manufacturers, electric utilities and EV owners. The first two groups will gain more market and therefore revenues, and EV owners can benefit from an additional revenue streams created by integrated EV-electricity markets.

As new entrants in the market, such as owners of EV fleets and aggregators become more active, their orientation will depend on their evolution and the types of business models they deploy. Non-utility market aggregators have been involved in distributed solar and demand response for more than a decade. They are now also consolidating around mobile energy storage (i.e., EVs), stationary energy storage, micro grids, and other elements of the smart grid. In the solar market, consumers are becoming "prosumers"—both producing and consuming electricity, facilitated by the fall in the cost of solar panels. Grid-integrated vehicles are another form of "prosumership" where the vehicle owner can be a consumer as well as a producer of grid services [18].

3.3. Multi-scalar support for grid-integrated EVs

Several policies have been introduced at the federal, state and local levels to support the uptake of EVs and related technologies across the globe. The approach to policy design and implementation to mitigate climate change concerns in the energy and transportation sectors takes a multi-scalar and polycentric approach [19–21]. A wide range of support mechanisms have been adopted at different levels of government and include several stakeholders – both private and public. These policies and support mechanisms illustrate the multi-scalar approach to sustainability policy in the US. In addition to government agencies, electricity providers are also stepping in by providing EV charging rates and installing charging infrastructure for consumers who own EVs. The combination of policies affects the entire ecosystem of the electricity-transportation value chain. They address a wide range of factors that address consumer behavior and values, adopt behavioral approaches, and provide the requisite infrastructure, tasking building and construction and management sectors and electric utilities with the responsibility to make sure that cities are "EV ready."

In addition to policies that affect sales of EVs and related infrastructure, federal and state level governments have adopted policies that address storage technology. The policies will help create a market for storage services and technology and make storage available for grid services. The following subsections describe each level of policy making and provide examples of policies that address EV sales as well as storage capacity building.

3.3.1. Federal policies

The U.S. Government has adopted a combination of financial and non-financial policies that would, in the long term, support the growth of EVs and storage. Tax credits of $7500 are available for purchases of EVs with a cap of 200,000 plug-in electric vehicles for each manufacturer. In addition, funds disbursed by a settlement with Volkswagen are to be invested in improving the charging infrastructure for Zero Emission Vehicles; and the mitigation trust set up from the settlement will be used for investments in the clean transportation sector [22].

A recently issued order by the Federal Electricity Regulatory Commission (FERC Order 841) calls for creating a market for the services provided by energy storage, at large. While the order currently focuses on stationary storage, with the rising share of EVs, this could potentially be extended to the mobile storage provided by EVs. Estimates from the Brattle Group suggest that the storage market could offer up to 50 GW based on the falling cost of batteries [23].

3.3.2. State and local policies

Nearly all U.S. states have policies that encourage adoption of EVs. These can be in the form of state income tax credits, reduced registration fees for EVs, and access to parking and charging infrastructure. Table 3 provides a summary of the different support mechanisms across states. Several states have also reduced the registration requirements for EVs through simpler registration requirements, reduced licensing fees, or road used charges. Financial incentives include tax credits, special rebates, and vouchers. EV supply equipment policies typically include grants, rebates and financial support for charging equipment installed in homes as well as public places. States also have fleet requirements where both state and privately-owned fleets need to have a certain percentage of EVs. In some states, the utilities provide support mechanisms through reduced prices and better electricity rates. HOV access and free parking is also available for EV owners. Finally, states also provide exemption from emissions testing for EV owners.

While most of these state policies support the use of EVs, some states have introduced additional registration and road use charges for EVs, particularly in the last several years. This is primarily to make up for lower tax revenues and highway trust funds from the sale of petroleum products [25]. Financial incentives have played a large role in ensuring uptake of EVs in different states.

In the future, however, several of these incentives will reach their sunset dates or their maximum sales caps. Uncertainty regarding these incentives can adversely affect EV markets. The case of Georgia is illustrative: with the passing of its Transportation Funding Act (H.B. 170) in 2015, a popular $5000 state tax credit for EVs was repealed, and an EV registration fee was created. The repeal caused EVs sales in Georgia to plummet.

States have also introduced mechanisms to support expansion of storage either through incentives or through directives requiring utilities to increase storage. California and Massachusetts have directed their utilities to invest in storage capacities, while Nevada and Maryland have provided investment incentives [6]. Such policies have also encouraged further use of energy storage technologies for grid support and energy security. These programs are generally technology-neutral and will support the use of storage at the grid-level or behind the meter on the customer's premises. For example:

- California has directed its utilities to acquire 500 MW of energy storage by 2020;
- Massachusetts has ordered its utilities to procure 200 MW h of energy storage by the end of 2019;
- New York's legislators have proposed the creation of an Energy Storage Deployment Program, with a 2030 procurement target;
- Maryland has adopted at 30% income tax credit for storage facilities
- Nevada's legislature has passed storage incentives [6].

State and local building codes can require that new construction be PV-ready with sufficient recharging and other supporting equipment and facilities. At the state level also, policies to support EVs as well as storage are in place.

Finally, with the growing role of cities in defining future energy and transportation pathways, several cities are moving towards ensuring that adequate infrastructure is provided for EVs (see [26,27]). In Atlanta for example, the building codes require that new multi-family buildings be equipped with charging infrastructure [28].

3.3.3. Utility policies

In order to facilitate a transition towards adoption of distributed energy resources (DERs) for power generation, states have introduced alternative pricing policies and other supportive legislations. Some of these include net metering policies, real-time pricing, time variant pricing, and specialized power rates all of which can impact the cost of EV ownership.

Net metering allows distributed generation customers to benefit from the excess power they generate. These DER consumers are allowed to feed power back into the grid and receive credits for the excess power that they supply. Different forms of support for net metering exist across states. This includes explicit net metering policies, voluntary utility policies (TX and IO), and other compensation rules for DER (AZ, GA, IN, ME, MS, NV) [29]. The eligible renewable energy technologies, buy-back rates, and capacity limits vary across states [12].

Real-time pricing allows electricity rates to better reflect their marginal costs by changing dynamically in hourly or more frequent increments. With the pervasive presence of internet enabled electronic devices, the ability of consumers to respond to price changes in real time has been greatly enhanced. Real time pricing allows users to schedule their power usage in a way that they benefit from lower prices and spikes in demand can be reduced as well.

Some states, including Georgia, also offer alternative electricity rates to single-family dwelling EV owners, so that they can charge their EVs at highly discounted rates at night. Several states have also adopted advanced information and communication technology (ICT) policies that will be crucial for implementing the multiple modes of vehicle-grid integration. These include smart meters and rules and standards for interconnections [12]. Further, large scale adoption of the new interconnected systems will hinge in large part on data privacy and cyber security. Responding to this need, states have also introduced policies that protect consumer data, and limit the ability of power providers to share it (for example, California's Senate Bill 674).

4. Lessons from pilot projects and simulation studies

Pilot projects and simulation studies in the U.S. have been limited, reflecting the slow build-up of EVs in the marketplace. Nordic and other European programs that use EVs to provide grid services were spawned a decade ago and offer evidence that grid-connected EVs can operate beneficially [30–32]. This international experience base has also highlighted issues and difficulties associated with range anxiety, perceptions of EV safety, and concerns over environmental justice [33–36].

Simulation studies, and pilot projects have been conducted within and outside the U.S. to assess the revenue streams that could be generated by integrating EVs with the grid and managing charging and supply of power. In a simulation assessment, Kempton and Tomić [9] find that a battery vehicle could earn as much as $2554 in annual profits from providing regulation services. In another estimate by Shinzaki et al. [37], a vehicle could generate between $623 and $1014 in V2G service revenue streams. This could potentially reduce the up-front cost of purchasing an electric vehicle.

The Balls Gap Battery Pilot program led by the American Electric Power Company examined the role of installing a 2 MW battery to help reduce load on a substation transformer. This would be analogous to managing a fleet of EVs [38]. The battery output was successfully bid into the PJM market due to its reliable performance, analogous to how grid-integrated EVs could bid into wholesale markets.

In a vehicle-grid integration test bed project at the UC-Berkeley Global Campus in Richmond, California, Lipman [39] combined a Wi-Fi enabled charger with a power system control and visualization device. This test bed uses open source software to control the bidirectional charging of grid-integrated vehicles.

The BMW iChargeForward pilot study allows EV owners in California to "opt-in" for smart charging where the managed charging by BMW would provide demand response services to Pacific Gas & Electric (PG&E) [40]. In the second phase of the pilot study, participants receive a compensation of $600 in two installments in 2018 and 2019.[4] Others have estimated the monetary benefits of EV-provided demand response to be in the range of $100–$300 per year per participating vehicle [41]. This could potentially reduce the total cost of ownership of an EV [42].

Oak Ridge National Laboratory is partnering with UPS on a DOE-funded project focused on developing high-power, bidirectional wireless charging for electric delivery trucks. Technology will allow power to flow both ways, so vehicles can power the electric grid for the UPS facility in the event of an electricity outage. The goal is a V2G mode, with 6.6 kW wireless power transfer to building or grid loads providing grid support functions or ancillary services that can strengthen grid resilience. If charging of the vehicles plus all the operational energy usage at UPS sorting facilities causes a voltage drop, reactive power can be injected from vehicles for voltage regulation [43].

5. Survey findings

This survey aims to seek expert opinion on the role of EV integration as a provider of grid resilience services.

We used a Delphi[5] -type approach in designing our survey by consulting with the experts on the EAC Smart Grid sub-committee. The survey was conducted in three phases – first as a pilot with a limited number of experts from outside the committee, next with the members of the committee's Smart Grid Subcommittee, and then with the Electricity Advisory Committee. The survey was reviewed and revised based on the comments received from respondents prior to the full survey. The online survey link was then shared with all members of the EAC. Follow-up emails were sent to the committee members in order to ensure a high response rate. The committee in some ways represents the entire population, therefore the 10 responses reflect a wide spectrum of views including electric power companies, industry, consultants, and academics.

The questions explored the following questions:

1 Which mode of grid integration is likely to have the greatest impact on grid resilience?
2 What grid resilience services can each of these modes provide today and in the future?
3 Which models of non-utility participation would maximize grid resilience in terms of asset ownership, interactions with utilities, and the provision of mobility services?
4 What technological, socio-economic/financial, and regulatory challenges need to be overcome for a full deployment of G2V, V2B, and V2G?
5 Which stakeholders would support or oppose grid-integrated EVs?

At any point in time, the EAC typically has 20–25 members: 10 of them elected to complete our survey (See Appendix A). The following paragraphs summarize the survey findings for each of these five questions.

5.1. Modes of integration

Most respondents believe that G2V integration has the highest current and future potential impact (Fig. 2). This may reflect the

[4] https://www.bmwchargeforward.com/.

[5] For a history of Delphi method, please see: https://www.rand.org/topics/delphi-method.html.

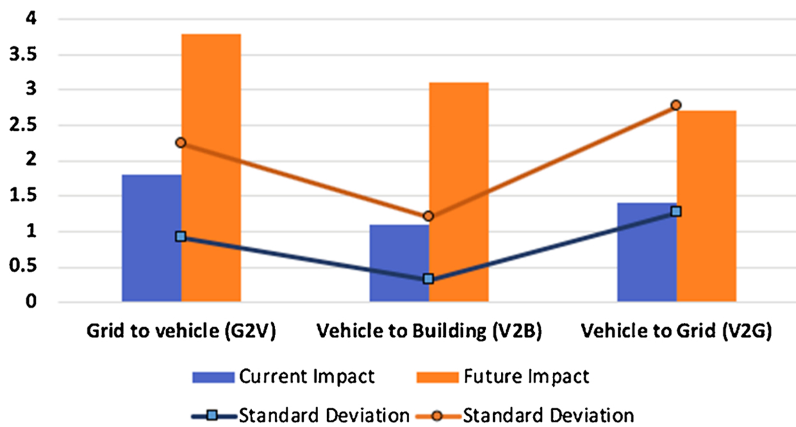


Fig. 2. Current and Futures Impact of Different Modes of Integration.
Survey questions: "On a scale of 1–5, how would you rate the current impact of G2V, V2B, and V2G in your region? Please also rate the potential impact of these modes in your region."
(Source: Authors)

additional technology and policy efforts needed to achieve V2G. Interestingly, both G2V and V2B are seen as having a large increase in potential future impacts compared to their impact currently. V2B increases by nearly 2 points on the 5-point scale) when comparing current and future potentials

5.2. Types of grid resilience services

The tradition of managing real-time demand with energy efficiency [44] can be expanded to consider the provision of grid resilience services with VGI. Based on Table 4, the respondents selected different resilience services they thought would be most beneficial for the different EV integration modes. These grid resilience services are closely aligned with each of the three modes of EV integration [12]. Some services are common to more than one mode of integration, such as frequency regulation which is common to both V2G and G2V and reserve provision which is common to V2B and V2G. Other services are unique to a particular mode, such as back-up generation, where EVs can be used to power homes, hospitals, and shelters, thereby reducing the casualties and economic cost of grid disruptions.

Fig. 3 lists the four types of services in rank order (from top to bottom) based on the potential for grid-integrated vehicles to provide grid resilience services, as evaluated by the EAC experts. Demand response was rated the most important G2V services, reflecting its ability via smart charging to avoid peak hours when generation margins are small and costs are high. This was followed by valley filling, reflecting the value of charging when there is ample spare capacity. Among the services offered by V2B integration, emergency back-up was judged to be the most beneficial. But demand charge reduction was also highly rated. By strategically discharging electricity, EVs could clip a facility's peak consumption, which would then reduce the consumer's monthly rates. Finally, in G2V integration, voltage control and frequency regulation services are seen as having the highest potential. By helping to balance the grid, these services could be particularly valuable with the expansion of solar and wind power generation.

5.3. Alternative business models

An array of different business models exist that could be used to deliver resilience and reliability services to markets. There is an emerging role of non-utility participants operating in the EV-grid marketplace. The evolving market structure is combining consumers with third-party producers and aggregators in a variety of novel ways, some of which are consistent with the sharing economy. A core concept of the sharing economy is the ability to capture and redistribute the idle capacity of existing assets [45]. By increasing the usage of products and assets, economic productivity is enhanced. In most advanced economies, owners drive their cars only a few hours each day, offices are often empty, large sections of homes are unoccupied much of the time, stores have peak- and off-peak shopping hours, and power plants have substantial unutilized capacity [46]. Collaborative consumption could potentially put this excess capacity to better use [47].

The EAC questionnaire asked respondents to consider alternative business models for grid-integrated vehicles (Table 5). "Aggregators contracting with fleet owners" was seen to be the most valuable approach for aggregators to deliver grid services. Warranty coverage by manufacturers and aggregators was viewed as the most helpful way to manage the impact of grid integration on the potential degradation of batteries. Professor Granger Morgan from Carnegie Mellon University stated "At the moment, if I use that [battery] to run my refrigerator and a few lights, I violate the warranty on my vehicle" [48].

5.4. Remaining challenges

Key challenges remain; they can be categorized as technological, socio-economic, and policy and regulatory (Table 6).

5.4.1. Technological challenges

Survey participants expressed strong concerns about the degradation of batteries and the voiding of battery warranties with bidirectional charging. Alternatively, some respondents suggested that the damage to

Table 4
Potential for Grid-Integrated Vehicles to Provide Grid Resilience Services[a].

G2V	Mean	Range	Std Dev	V2B	Mean	Range	Std Dev	V2G	Mean	Range	Std Dev
Demand Response	3.8	3	1.0	Demand Charge Reduction	2.8	4	1.4	Capacity Firming	2.2	3	1.2
Valley Filling	3.5	3	1.3	Reserve Provision	2.2	3	0.9	Voltage Control	2.9	4	1.5
Negative Demand Response	2.7	4	1.5	Negative Demand Response	1.9	2	0.7	Reserve Provision	2.3	3	1.2
Frequency Regulation	2.6	4	1.4	Emergency back-up	3.3	4	1.3	Frequency Regulation	2.8	4	1.5

[a] Survey question: "Please rate the potential for G2V/V2B/V2G to provide the following services in your region".

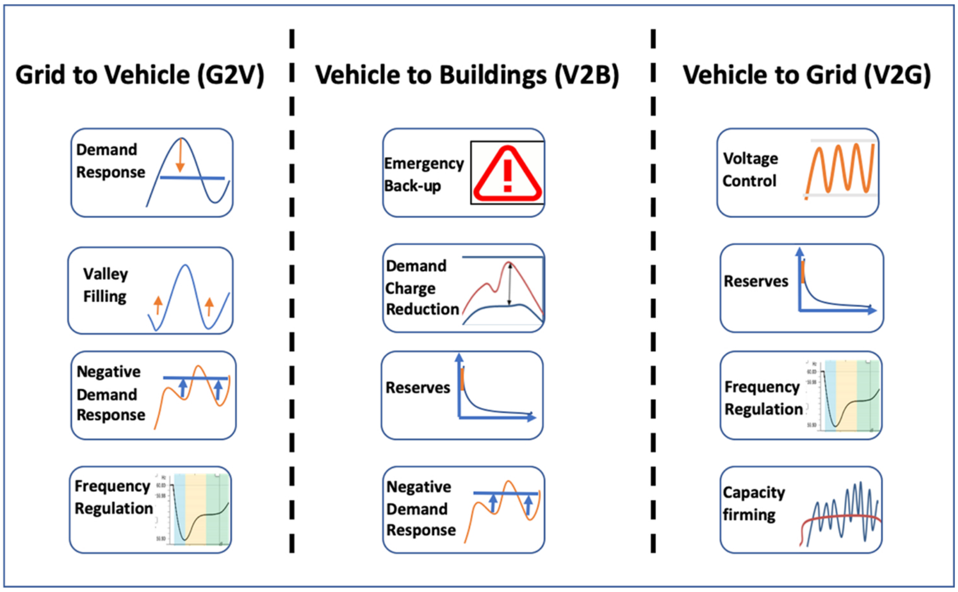


Fig. 3. Types of grid resilience services and the overall potential impact of various modes of EV integration.
Question: "Please rate the potential for G2V/V2B/V2G to provide the following services in your region."
(Source: Authors)

batteries could be reduced and battery quality could be maintained with proper monitoring: batteries that are "grid managed" can continue to deliver steady voltage supply and last longer than unmanaged batteries in EVs used just for mobility. The second most important technical challenge highlighted by the experts is standardizing the interface equipment and communication protocols. The current standards SAE J3072 and UL 1741 form the bridge to enable grid and vehicle integration. Utilities approve interconnection if electric vehicle supply equipment complies with UL 1741. The vehicle manufacturers will also need to certify their power converters for SAE J3072.

Finally, appropriate communications and technology platforms need to be developed. The communication protocols for different functions of grid-vehicle integration are being covered in IEEE 2030 for smart grid interoperability of energy and information technology. The communication channels need to be bi-directional and low latency for integrating DER/EV for ancillary grid functions. In addition, the growth of grid integration might get more complicated by the roll-out of DC fast charging. With more fast charging stations and a larger uptake of EVs, there are likely to be regional surges in demand over certain short periods of time. To prepare for this, scheduling demand and supply is important, along with stronger local infrastructure such as transformers and charging stations.

5.4.2. *Socio-economic and financial challenges*

The most critical socio-economic/financial challenge was found to be the voiding of warranties with bidirectional charging. This challenge is followed by range anxiety. The need for providing more charging network infrastructure is essential to reduce range anxiety [49–52] and enable more EV adoption. This finding aligns with the well-established theories of loss aversion in behavioral economics [53,54]. In addition, lifestyle choices [55] and socio-economic factors continue to affect the acceptance of EVs generally and a grid integrated model of EVs. The voiding of battery warranties remains a key concern according to the experts, followed by range anxiety of EV drivers and owners.

5.4.3. *Policy and regulatory challenges*

Policy design and regulation will need to evolve as technology and business innovations are introduced [56]. EVs can lead to surges in demand for charging power over space and time; thus, owners of DC fast charging stations have to pay for transformer upgrades as well as "demand charges". As a result, our expert respondents identified tariff design as the most important challenge, followed by the need to value these services. In areas where utilities are vertically integrated, providing dynamic valuation of services generation by EVs will be challenging since these values are currently implicitly determined and the services are not currently traded.

With the adoption of V2B and V2G, it will be necessary to ensure that sufficient range is still available to EV owners and drivers, as needed [57]. Since studies have shown that EV owners are interested in controlled charging patterns [55], leveraging this area to first develop the right rate design will be helpful over the long-term. Another key regulatory challenge will be ensuring that data privacy and cybersecurity rules intended to protect consumers are in sync with the changing industry and structure.

Table 5
Alternative Business Models.

Possible approach that aggregators could use to deliver grid services				Models might be most helpful to manage the impact on batteries			
	Mean	Range	Std Dev		Mean	Range	Std Dev
Leasing cars to customers	2.4	4	1.51	Battery Swapping	2.3	3	1.34
Providing subscription services for charging	2.9	2	0.88	Aggregator warranty/coverage	3.3	3	1.06
Contracting with fleet owners	4.3	3	1.06	Manufacturer warranty/coverage	3.5	3	1.08
Contracting with ride share services	3.3	4	1.25	Fleet owner warranty/coverage	2.9	3	0.99
Contracting with car rental services	3.1	4	1.29	Utility warranty/coverage	2.1	3	1.20

Question: "On a scale of 1–5, rate the value of each possible approach that aggregators could use to deliver grid services". "On a scale of 1–5, which of the following models might be most helpful to manage the impact on batteries".

Table 6
Remaining Challenges.

Technological Challenges	Mean Value	Range	Std Dev	Socio-economic/Financial Challenges	Mean Value	Range	Std Dev	Policy/Regulatory Challenges	Mean Value	Range	Std Dev
Degradation of batteries	3.9	4	1.4	Voiding of battery warranty with bidirectional charging	4.3	2	0.7	Tariff or rate design policies	3.5	4	1.2
Interoperability standards	3.6	4	1.3	Range anxiety	4.1	3	0.9	Valuing ancillary services in a vertically integrated market	3.3	4	1.3
Surge in demand for power with DC fast charging	3	4	1.5	Transaction costs with EV owners	4	4	1.2	Cybersecurity	3.3	3	1.1
Communication protocols	3	4	1.3	Payments to charging station owners and aggregators for ancillary services	3.7	3	1.2	Certification of charging infrastructure	3	4	1.2
Architecture issues	3	3	1.1	Least cost utility planning and financing	3.3	3	1.2	Open source architecture platform	2.8	3	1.1
Interconnections permits and fees	2.9	4	1.3	Access to charging infrastructure	3.2	3	1.1	Creating resilience service products in wholesale markets	2.8	4	1.4
Latency following signal inputs from aggregators	2.7	2	0.8								
DC compatibility with bidirectional flows	2.7	4	1.3								

Questions: "How much of a challenge do you think the following technological (or socio-economic/financial or policy regulatory) factors present to a full deployment of all modes - G2V, V2B, and V2G?

5.5. Stakeholders

As noted earlier, there are several players in EV grid integration markets who will support (or oppose) and influence the financial, technological and regulatory transition towards a grid-integrated transportation sector. On the one hand, our survey and research indicates that support and influence are highest among utilities and EV manufacturers as both these stakeholders stand to gain with higher EV and electricity sales. In contrast, other auto-manufacturers will face competition from EVs and are therefore unlikely to support integration. Battery manufacturers might also be opposed to support integration due to the uncertain impact on battery quality and warranty contracts. We use the support measurements from the survey and combine them with the level of influence each stakeholder would be expected to have in the adoption of policies to create an influence-support matrix (Fig. 4). Large players like utilities and electric grid operators appear to command high levels of support as well as influence. Consumers (commercial, industrial and residential) are concentrated in the middle; whereas battery manufacturers are seen as modestly influential and somewhat negative, while other automakers are on the bottom left of the scatter plot: highly influential and opposed to grid-integrated vehicles.

6. Envisioning EV grid integration in the future energy system

The pace and extent of EV-grid integration will depend on the structure of electricity and mobility markets. The other aspect of GIV business models is the evolving transportation market where the traditional approach to vehicle ownership is being replaced by provision of mobility services through rideshare and car rental options. In addition, the move towards autonomous or driverless vehicles is likely to affect the demand for personal vehicles. The common denominator of the sharing economy is accessibility to services and utilization of products, rather than ownership of assets (Fig. 5).

Social media forums encourage practices of sharing, because so much more consumer information is being exchanged and connections are being rapidly made. This process of information exchange, combined with ride and space sharing, advances a move towards potentially more efficient consumption of resources. From an economic perspective, a core concept of the sharing economy movement is the ability to capture and redistribute the idle capacity of existing assets [45]. By increasing the usage of products and assets, the sharing economy can help to ensure that excess capacity is put to better use [47].

In electricity markets, the rolling out of smart grids may make energy use and production data more readily available. A challenge identified in our survey of experts and literature review is the lack of valuation of and markets for ancillary services. This is especially characteristic of the vertically integrated electricity markets such as those in the Southeastern U.S. where markets for grid and ancillary services are thin or nonexistent. However, the integrated structure of these markets could make them more amenable to valuing their ancillary services. In the Southeast, for example, as the share of distributed energy resources rises, the demand for regulation services will increase, which could encourage the vertically integrated utilities to create new markets for such services.

Our research leads to the conclusion that integrating EVs into an increasingly green electricity market could produce resilience benefits. The resilience benefits of G2V were broadly recognized by our expert respondents, while for V2G, they were viewed with more skepticism. In contrast, a growing body of evidence of the resilience value of V2G is emerging in California, and markets for V2G ancillary services such as frequency regulation are expanding in New York. Pilot projects are already demonstrating that large gains can be made through G2V integration coupled with coordinated and smart charging. Studies of V2G integration in other regions also provide evidence of the benefits of considering this option. Nordic countries have one of the highest market shares of EVs and an expanding V2G system [58]. This has been

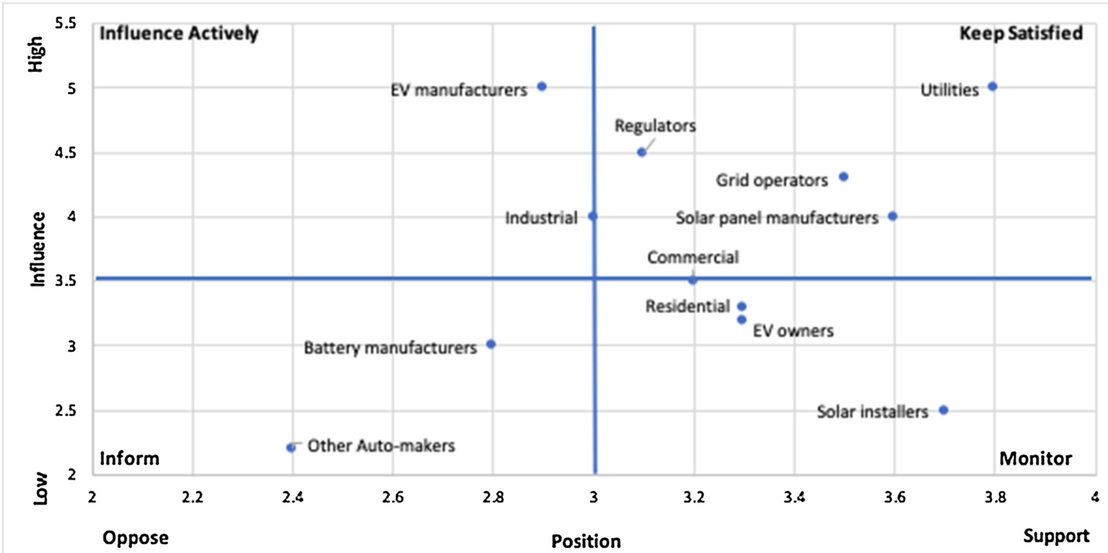


Fig. 4. "Influence-Support" Matrix of Stakeholders.
Question: "On a scale of 1–5, which stakeholders might oppose or support the present to a full deployment of all modes - G2V, V2B, and V2G?"
(Source: Authors)

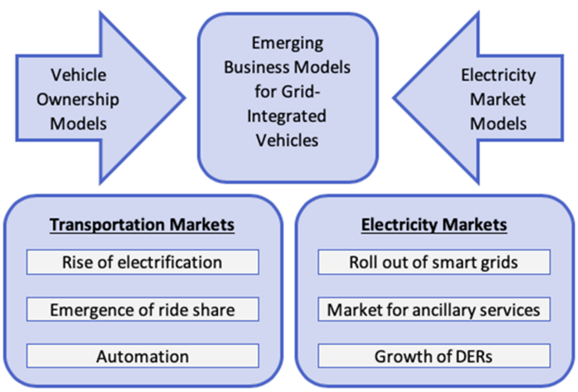


Fig. 5. Evolving transportation and electricity markets.
(Source: Authors)

facilitated by a supportive and stable policy environment that provides infrastructure for charging, benefits to EV buyers and economic incentives.

Car manufacturers, cities, and countries across the world have established targets to increase the share of EVs in their fleets, sales and on road vehicles. Almost all car manufacturers have an EV strategy in place. Companies like Volkswagen and BYD Auto have plans for rapidly ramping up their EV manufacturing and sales. Cities like London and Beijing have announced plans to have 100% electric transportation; countries in the Nordic region also have similar pathways defined. As such, the findings from this survey provide lessons for the trajectory the transportation and electricity sectors might take and the challenges they might face in the process. Business opportunities will likely emerge sooner in regions and countries with greater EV penetration as the benefits of grid integration could be realized more quickly.

Nevertheless, challenges remain, and the ultimate fate of grid-integrated EVs is unclear. Going forward, the magnitude of the benefits that could be delivered needs to be specified in terms of the values associated with each resilience service that GIVs can provide. The creation of load-management services delivered by energy-efficiency programs in the 1990s took more than a decade to materialize. This same expansion needs to occur for EVs. What are the costs and benefits of the full range of resilience services that EVs can offer, including spatially targeted demand response, valley filling and frequency regulation?

Our survey of experts suggests that the main barriers to grid-integrated EVs are operational and administrative in nature. With most respondents showing concern about the potential voiding of battery warranties, gains can be made by addressing this liability preemptively. If managed properly, it has been suggested that damage to batteries can be reduced and battery life can be extended [48]. Policies to support EV adoption do not exist in isolation but are, in fact, part of an entire power-transportation-ICT value chain. As such, coordinating policy design across these multiple infrastructures can leverage complementarities and strengthen the case for GIVs as a strong contributor to grid resilience.

Funding

Funding for this research was provided by the Energy Policy and Innovation Center at the Georgia Institute of Technology.

Acknowledgments

Members of the U.S. Department of Energy's Electricity Advisory Committee provided valuable input into the scope and design of the research described in this paper. Of particular note are John Adams (Electric Reliability Council of Texas), Laney Brown (Avangrid, Inc.), Gordon Feller (Cisco Systems), Sheri Givens (Givens Consulting, LLC), Michael Heyeck (The Grid Group, LLC), Mladen Kezunovic (Texas A&M University), Wanda Reder (Grid-X Partners), Heather Sanders (Southern California Edison), David Wade (Electric Power Board of Chattanooga), and Tom Weaver (American Electric Power Company, Inc.). Joshua Smith and Yilong (ICF) helped to format and administer the survey. Interviews with Joe Paladino and Lee Slezak at DOE provided valuable background on related laboratory research and technology demonstrations. This project benefited significantly from input and review provided by three colleagues at the Georgia Institute of Technology: Richard Simmons (Director of the Energy Policy and Innovation Center), Deepak Divan (Director of the Center for Distributed Energy), and Karthik Kandasamy (Postdoc at the Center for Distributed Energy). The assistance of all of these individuals is greatly appreciated. Any remaining errors are solely the responsibility of the authors.

Appendix A. Questionnaire for DOE/EAC Members

Enhancing Grid Resilience with Integrated Storage from Electric Vehicles

This survey explores the growing link between electric vehicles and grid resilience. How can access to mobile batteries enhance grid resilience? Responses to this questionnaire will help inform the EAC Smart Grid Subcommittee's current work product on EV integration. Fig. A1

Note: The questionnaire is structured to allow for skipping questions and returning to them later. Please try to answer all of the questions.

Since utility models vary across different regions of the United States, please respond to this questionnaire from the perspective of one or a few regions. The last question asks you to identify your region(s) (Fig. A1).

* Required

1. Name * ——————
2. Affiliation * ——————
3. Email Address * ——————

Section 1: Market Potential and Business Models

In this section, we look at the following three modes of EV integration:

> Grid to vehicle (G2V) - Refers to services based on unidirectional flow of power through smart and coordinated charging for dynamic balancing; the purpose is to make vehicle charging more efficient and ensure that EVs positively impact the grid.

> Vehicle to building (V2B) - Refers to the provision of building electricity management, back-up and emergency services to homes and businesses.

> Vehicle to grid (V2G) - Refers to EVs providing the grid with ancillary services for balancing the local distribution system; it requires a bi-directional flow of power between the grid and the vehicle to enable provision of advanced grid services (Fig. A2).

We also examine an array of grid services that each mode could provide:

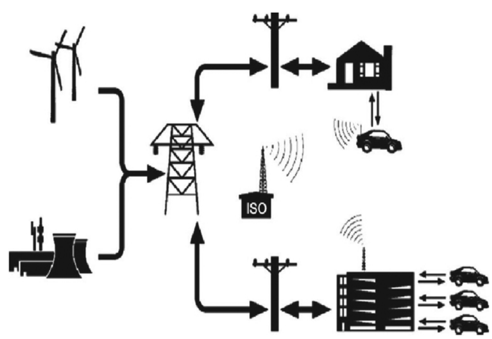


Fig. A1. Grid Integrated Vehicles.

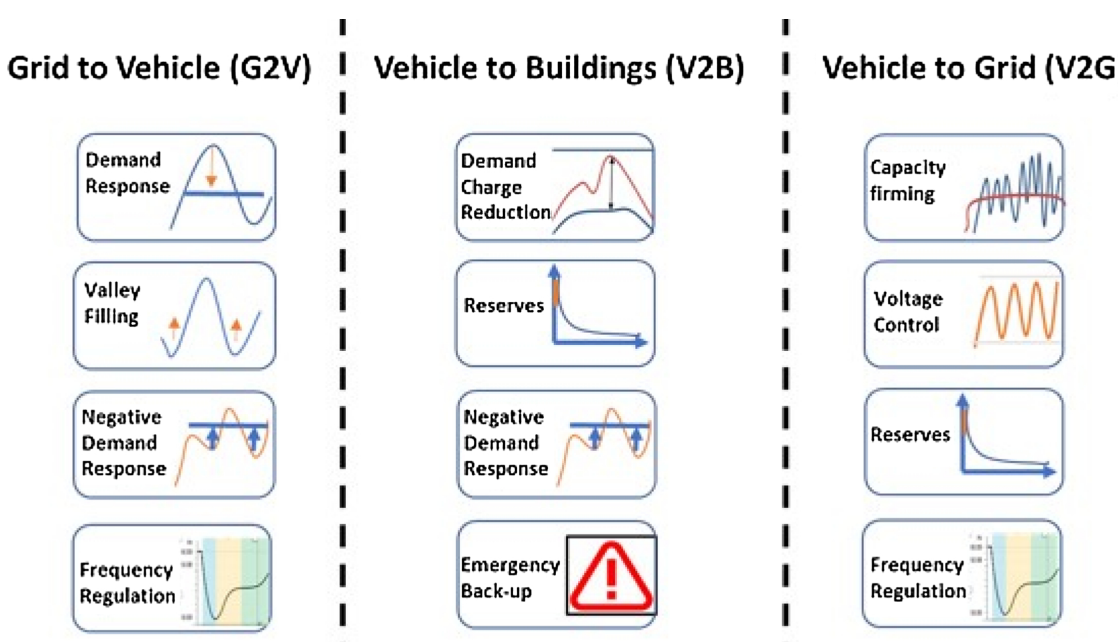


Fig. A2. Types of Grid Services.

4.1. a) On a scale of 1–5, how would you rate the current impact of G2V, V2B, and V2G in your region? Mark only one oval per row.

	1 - No impact	2	3	4	5 - Most impact
G2V					
V2B					
V2G					

5.1. b) Please also rate the potential impact of these modes in your region, by 2030. Mark only one oval per row.

	1 - Small	2	3 - Medium	4	5 - Large
G2V					
V2B					
V2G					

6.2. a) Please rate the potential for G2V to provide the following grid services in your region. Mark only one oval per row.

	1 - Least	2	3	4	5 - Most
Demand response					
Valley filling					
Negative demand response					
Frequency Regulation					
Other (please identify in the comment section below)					

7. Additional comments:

8.2. b) Please rate the potential for V2B to provide the following grid services in your region. Mark only one oval per row.

	1 - Least	2	3	4	5 - Most
Demand charge reduction					
Reserve provision					
Negative demand response					
Emergency back-up					
Other (please identify in the comment section below)					

9. Additional comments:

10.2. c) Please rate the potential for V2G to provide the following grid services in your region. Mark only one oval per row.

	1 - Least	2	3	4	5 - Most
Capacity firming					
Voltage control					
Reserve provision					
Frequency regulation					
Other (please identify in the comment section below)					

11. Additional comments:

12.2 d) Which of the grid services (listed above in a, b and c) could be provided as ancillary products in competitive wholesale markets?

13.2 e) Which of these grid services could be provided as products in vertically integrated markets?

14.3. On a scale of 1–5, rate the value of each possible approach that aggregators could use to deliver grid services Mark only one oval per row.

	1 - Least	2	3	4	5 - Most
Aggregators leasing cars to customers					
Aggregators providing subscription services for charging					
Aggregators contracting with fleet owners					
Aggregators contracting with ride share services					
Aggregators contracting with car rental services					

15.4. On a scale of 1–5, which of the following models might be most helpful to manage the impact on batteries Mark only one oval per row.

	1 - Least	2	3	4	5 - Most
Battery swapping					
Aggregator warranty/coverage					
Manufacturer warranty/coverage					
Fleet owner warranty/coverage					
Utility warranty/coverage					

16.5. Are there any innovative and effective cases of G2V, V2B, and V2G in your region? If yes, please describe these and provide any sources of information that you might be aware of and contact details if available.

Challenges and Solutions

17.6. a) How much of a challenge do you think the following technological factors present to a full deployment of all modes - G2V, V2B, and V2G? Mark only one oval per row.

	1 - Least challenging	2	3	4	5 - Most challenging
Degradation of batteries	◯	◯	◯	◯	◯
Surge in demand for power with DC fast charging	◯	◯	◯	◯	◯
DC Compatibility with bidirectional flows	◯	◯	◯	◯	◯
Latency following signal inputs from aggregators	◯	◯	◯	◯	◯
Communication protocols	◯	◯	◯	◯	◯
Interoperability standards	◯	◯	◯	◯	◯
Interconnection permits and fees	◯	◯	◯	◯	◯
Architecture issues	◯	◯	◯	◯	◯
Other (please identify in the comment section below)	◯	◯	◯	◯	◯

18. Additional comments:

19.6. b) How much of a challenge do you think the following socio-economic/financial factors present to a full deployment of all modes - G2V, V2B, and V2G? Mark only one oval per row.

	1 - Least challenging	2	3	4	5 - Most challenging
Transaction costs with EV owners	◯	◯	◯	◯	◯
Payments to charging station owners and aggregators for ancillary services	◯	◯	◯	◯	◯
Least cost utility planning and financing	◯	◯	◯	◯	◯
Range anxiety	◯	◯	◯	◯	◯
Access to charging infrastructure	◯	◯	◯	◯	◯
Voiding of battery warranty with bidirectional charging	◯	◯	◯	◯	◯
Other (please identify in the comment section below)	◯	◯	◯	◯	◯

20. Additional comments:

21.6. c) How much of a challenge do you think the following policy/regulatory factors present to a full deployment of all modes - G2V, V2B, and V2G? Mark only one oval per row.

	1 - Least challenging	2	3	4	5 - Most challenging
Tariff or rate design policies	◯	◯	◯	◯	◯
Valuing ancillary services in a vertically integrated market	◯	◯	◯	◯	◯
Open source architecture platform	◯	◯	◯	◯	◯
Creating resilience service products in wholesale markets	◯	◯	◯	◯	◯
Cybersecurity	◯	◯	◯	◯	◯
Certification of charging infrastructure	◯	◯	◯	◯	◯
Other (please identify in the comment section below)	◯	◯	◯	◯	◯

22 Additional comments:

23.7. On a scale of 1–5, which stakeholders might oppose or support the present to a full deployment of all modes - G2V, V2B, and V2G? Mark only one oval per row.

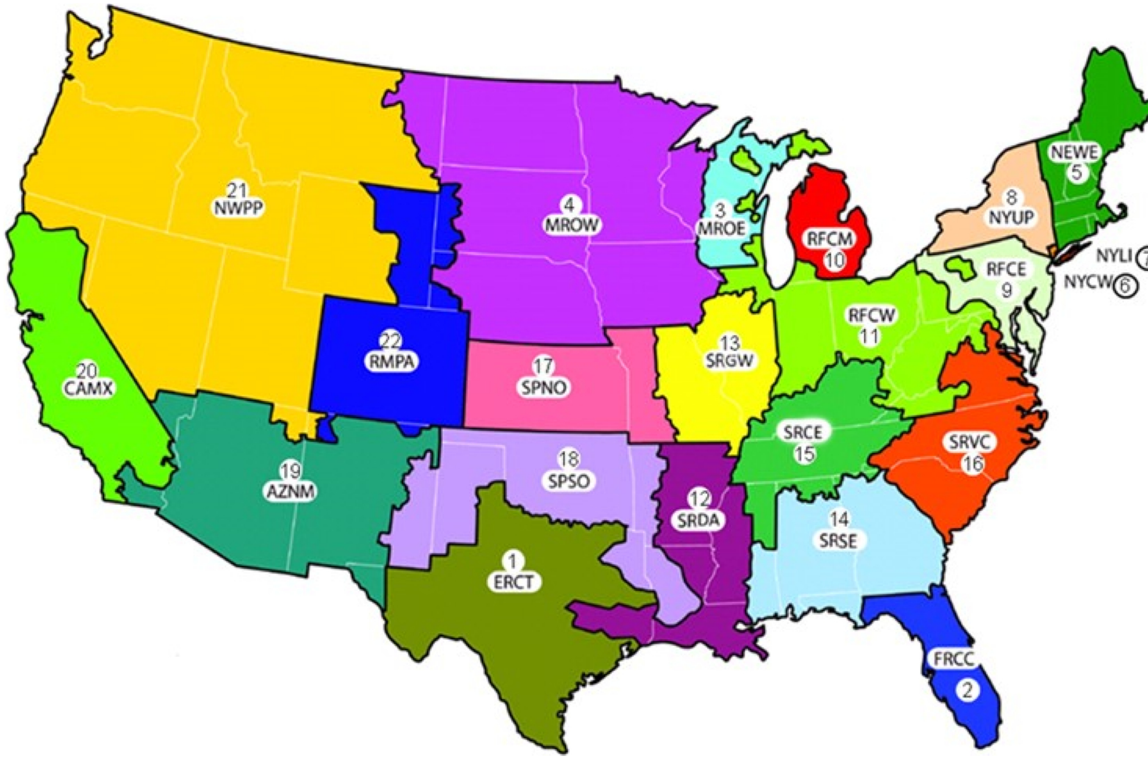
	1 - Strongly oppose	2	3 - Neutral	4	5 - Strongly support
Utilities					
Grid operators					
EV manufacturers					
Other automakers					
Battery manufacturers					
Solar installers					
Solar panel manufacturers					
Regulators					
Customers - residential					
Customers - industrial					
Customers - commercial					
EV owners					
Other (please identify in the comment section below)					

24.8. What policies or regulatory changes might enable EVs to contribute more to grid resilience? Please explain.

24.9. What types of technologies, communications or control systems might be needed to enable EVs to contribute more to grid resilience? Please explain.

26.10. How might grid resilience be impacted by integrating EVs with distributed solar and stationary storage?

NERC Region



27. Please select which NERC region(s) you were considering while responding to these questions. *
Check all that apply.

- ☐ ERCT - Texas Reliability Entity
- ☐ FRCC - Florida Reliability Council
- ☐ MORE - Midwest Reliability Organization - East
- ☐ MROW - Midwest Reliability Organization - West
- ☐ NEWE - Northeast Power Coordination Council/New England
- ☐ NYCW - Northeast Power Coordination Council/NYC-Westchester
- ☐ NYLI - Northeast Power Coordination Council/Long Island
- ☐ NYUP - Northeast Power Coordination Council/Upstate
- ☐ RFCE - ReliabilityFirst Corporation/East
- ☐ RFCM - ReliabilityFirst Corporation/Michigan
- ☐ RFCW - ReliabilityFirst Corporation/West
- ☐ SRDA - SERC Reliability Corporation/Delta
- ☐ SRGW - SERC Reliability Corporation/Gateway
- ☐ SRSE - SERC Reliability Corporation/Southeastern
- ☐ SRCE - SERC Reliability Corporation/Central
- ☐ SRVC - SERC Reliability Corporation/Virginia-Carolina
- ☐ SPNO - Southwest Power Pool Regional Entity/North

SPSO - Southwest Power Pool Regional Entity/South
AZNM - Western Electricity Coordinating Council/Southwest
CAMX - Western Electricity Coordinating Council/California
NWPP - Western Electricity Coordinating Council/Northwest Power Pool Area
RMPA - Western Electricity Coordinating Council/Rockies

References

[1] B. Hanrahan, Florida Public Service Commission Electric Vehicle Charging Roundtable, Florida Power and Light Company, 2017, https://www.floridapsc.com/Files/PDF/Utilities/Electricgas/ElectricVehicles/2017/presentations/FPL.pdf.
[2] EIA, Annual Energy Outlook 2018. Table: Electricity Supply, Disposition, Prices, and Emissions, Energy Information Administration, Department of Energy, 2018.
[3] BNEF, Executive summary, Electric Vehicle Outlook 2017, Bloomberg New Energy Finance, 2017.
[4] C. Curry, Lithium-Ion Battery Costs and Market, Bloomberg, 2017, https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf.
[5] A. Elgowainy, J. Han, J. Ward, F. Joseck, D. Gohike, A. Lindauer, T. Ramsden, M. Biddy, M. Alexander, S. Barnhart, I. Sutherland, L. Verduzco, T.J. Wallington, Current and future United States light-duty vehicle pathways: cradle-to-grave

lifecycle greenhouse gas emissions and economic assessment, Environ. Sci. Technol. 52 (4) (2018).

[6] DOE, Staff Report to the Secretary on Electricity Markets and Reliability, U.S. Department of Energy, 2017, https://www.energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf.

[7] National Academies of Sciences, E., & Medicine, Enhancing the Resilience of the Nation's Electricity System, The National Academies Press, Washington, DC, 2017https://www.nap.edu/read/24836/chapter/1.

[8] FERC, Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures, 08 January 2018.

[9] W. Kempton, J. Tomić, Vehicle-to-grid power fundamentals: calculating capacity and net revenue, J. Power Sources 144 (1) (2005) 268–279.

[10] B.K. Sovacool, J. Axsen, W. Kempton, The future promise of vehicle-to-grid (V2G) integration: a sociotechnical review and research agenda, Annu. Rev. Environ. Resour. 42 (2017) 377–406.

[11] J. Zhang, T. Markel, J. Jorgenson, Value to the grid from managed charging based on California's High Renewables Study, IEEE PES Transactions on Power Systems, (2018).

[12] M.A. Brown, S. Zhou, M. Ahmadi, Governance of the Smart Grid: an international review of evolving policy issues and innovations, Wiley Interdiscip. Rev. (WIREs): Energy Environ. (7(5)) (2018), https://doi.org/10.1002/wene.290.

[13] A.M. Smith, M. Brown, Policy considerations for adapting power systems to climate change, Electr. J. 27 (9) (2014) 112–125.

[14] B.K. Sovacool, M.A. Brown, S.V. Valentine, Fact and Fiction in Global Energy Policy: Fifteen Contentious Questions, JHU Press, 2016.

[15] D.J. Elgin, C.M. Weible, A stakeholder analysis of Colorado climate and energy issues using policy analytical capacity and the advocacy coalition framework, Rev. Policy Res. 30 (1) (2013) 114–133.

[16] C.M. Weible, An advocacy coalition framework approach to stakeholder analysis: understanding the political context of California marine protected area policy, J. Public Adm. Res. Theory 17 (1) (2006) 95–117.

[17] M.S. Reed, A. Graves, N. Dandy, H. Posthumus, K. Hubacek, J. Morris, L.C. Stringer, Who's in and why? A typology of stakeholder analysis methods for natural resource management, J. Environ. Manage. 90 (5) (2009) 1933–1949.

[18] S. Valentine, B.K. Sovacool, M.A. Brown, Empowering the Great Energy Transition: Policy for a Low-Carbon Future, Columbia University Press, 2019.

[19] E. Ostrom, Polycentric systems for coping with collective action and global environmental change, Glob. Environ. Change 20 (4) (2010) 550–557.

[20] M.A. Brown, B.K. Sovacool, Climate Change and Global Energy Security: Technology and Policy Options, MIT Press, 2011.

[21] A. Goldthau, Rethinking the governance of energy infrastructure: scale, decentralization and polycentrism, Energy Res. Soc. Sci. 1 (2014) 134–140.

[22] NASEO & NACAA, National Association of State Energy Officials National Association of Clean Air Agencies About the Settlement, VW Clearignhouse, 2019, https://vwclearinghouse.org/about-the-settlement/.

[23] R. Lueken, J. Chang, H. Pfeifenberger, P. Ruiz, H. Bishop, Getting to 50 GW? The Role of FERC Order 841, RTOs, States, and Utilities in Unlocking Storage's Potential, Brattle Group, 2018, https://brattlefiles.blob.core.windows.net/files/13428_13366_getting_to_50_gw_study_2_22_1811.pdf.

[24] K. Hartman, E. Dowd, State Efforts to Promote Hybrid and Electric Vehicle, National Council for State Legislatures, 2017, http://www.ncsl.org/research/energy/state-electric-vehicle-incentives-state-chart.aspx.

[25] K. Hardman, K. Pula, New fees on hybrid and electric vehicles, National Conference of State Legislatures, 2018. http://www.ncsl.org/research/energy/new-fees-on-hybrid-and-electric-vehicles.aspx. [accessed 07 July 2019].

[26] Ready Set Charge California, A Guide to EV-Ready Communities, n.d. https://www.prospectsv.org/wp-content/uploads/2016/12/Ready-Set-Charge-California-EV-Communities-Guide.pdf. [accessed 10 July 2019].

[27] AFDC, Local Laws and Incentives, Alternative Fuels Data Center. https://afdc.energy.gov/laws/local_examples#9. [accessed 10 July 2019].

[28] City of Atlanta, GA, City of Atlanta Passes "EV Ready" Ordinance into Law, News List, 2017. [Online]. https://www.atlantaga.gov/Home/Components/News/News/10258/1338?backlist=/. [accessed 07 July 2019].

[29] NCSL, State net metering policies, National Conference of State Legislatures, National Conference of State Legislatures, 2017, http://www.ncsl.org/research/energy/net-metering-policy-overview-and-state-legislative-updates.aspx#statenet.

[30] M. Marinelli, A. Thingvad, Influence of V2G frequency services and driving on electric vehicles battery degradation in the Nordic countries, 31st International Electric Vehicles Symposium & Exhibition & International Electric Vehicle Technology Conference, (2018).

[31] J. Kester, L. Noel, G.Z. de Rubens, B.K. Sovacool, Promoting Vehicle to Grid (V2G) in the Nordic region: expert advice on policy mechanisms for accelerated diffusion, Energy Policy 116 (2018) 422–432.

[32] S. Hashemi, N.B. Arias, P.B. Andersen, B. Christensen, C. Træholt, Frequency regulation provision using cross-brand bidirectional V2G-enabled electric vehicles, IEEE International Conference on Smart Energy Grid Engineering, 2018.

[33] L. Noel, G.Z. de Rubens, B.K. Sovacool, J. Kester, Fear and loathing of electric vehicles: the reactionary rhetoric of range anxiety, Energy Res. Soc. Sci. 48 (2019) 96–107.

[34] B.K. Sovacool, R.F. Hirsch, 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) (2009) 1095–1103.

[35] J. Kester, L. Noel, X. Lin, G.Z. de Rubens, B.K. Sovacool, The coproduction of electric mobility: selectivity, conformity and fragmentation in the sociotechnical acceptance of vehicle-to-grid (V2G) standards, J. Clean. Prod. 207 (2019) 400–410.

[36] B.K. Sovacool, J. Kester, L. Noel, G.Z. de Rubens, Energy injustice and Nordic electric mobility: inequality, elitism, and externalities in the electrification of vehicle-to-grid (V2G) transport, Ecol. Econ. 157 (2019) 205–217.

[37] S. Shinzaki, H. Sadano, Y. Maruyama, W. Kempton, Deployment of Vehicle-to-Grid Technology and Related Issues, (2015), pp. 0148–7191.

[38] T. Weaver, Applying DER for Resiliency on Distribution Circuits, (2017).

[39] T. Lipman, Open Source Platform for Plug-in Electric Vehicle Smart Charging in California, (2018).

[40] S. Kaluza, D. Almeida, P. Mullen, BMW iChargeForward: PG&E's Electric Vehicle Smart Charging Pilot, BMW & Pacific Gas and Electric Company, 2017, http://www.pgecurrents.com/wp-content/uploads/2017/06/PGE-BMW-iChargeForward-Final-Report.pdf.

[41] D.B. Richardson, Electric vehicles and the electric grid: a review of modeling approaches, Impacts, and renewable energy integration, Renew. Sustain. Energy Rev. 19 (2013) 247–254.

[42] D.-Y. Lee, V.M. Thomas, M.A. Brown, Electric urban delivery trucks: energy use, greenhouse gas emissions, and cost-effectiveness, Environ. Sci. Technol. 47 (14) (2013) 8022–8030.

[43] B. Ozpineci, Technology Development: Updates, Challenges and Opportunities, (2018).

[44] L. Gelazanskas, K. Gamage, Demand side management in smart grid: a review and proposals for future direction, Sustain. Cities Soc. 11 (1) (2014) 22–30.

[45] K. Finley, Trust in the Sharing Economy: An Exploratory Study, Centre for Cultural Policy Studies, University of Warwick, 2013, https://warwick.ac.uk/fac/arts/theatre_s/cp/research/publications/madiss/ccps_a4_ma_gmc_kf_3.pdf.

[46] B. Bhushan, S.K. Soonee, Utilisation of Idling Capacity of Captive Power Plants – A Viable Alternative. Annexure-B "Open Access" in the Indian Context.

[47] D. Demailly, A.S. Novel, The sharing economy: make it sustainable, Studies 3 (2014) 14.

[48] B. Sobczak, Car warranties pose unexpected hurdle for EV owners, EnergyWire 26 (June) (2018).

[49] S. Carley, R.M. Krause, B.W. Lane, J.D. Graham, Intent to purchase a plug-in electric vehicle: a survey of early impressions in large US cites, Transp. Res. D: Transp. Environ. 18 (2013) 39–45.

[50] T. Schneidereit, T. Franke, M. Guenther, J.F. Krems, Does range matter? Exploring perceptions of electric vehicles with and without a range extender among potential early adopters in Germany, Energy Res. Soc. Sci. 8 (2015) 198–206.

[51] B.W. Lane, J. Dumortier, S. Carley, S. Siddiki, K. Clark-Sutton, J.D. Graham, All plug-in electric vehicles are not the same: predictors of preference for a plug-in hybrid versus a battery-electric vehicle, Transp. Res. Part D: Transp. Environ. 65 (2018) 1–13.

[52] D. Lopez-Behar, M. Tran, T. Froese, J.R. Mayaud, O.E. Herrera, W. Merida, Charging infrastructure for electric vehicles in multi-unit residential buildings: mapping feedbacks and policy recommendations, Energy Policy 126 (2019) 444–451.

[53] D. Kahneman, A. Tversky, Prospect theory: an analysis of decision under risk, Econometrica 47 (1979) 263–291.

[54] M. Nicolson, G. Huebner, D. Shipworth, Are consumers willing to switch to smart time of use electricity tariffs? The importance of loss-aversion and electric vehicle ownership, Energy Res. Soc. Sci. 23 (2017) 82–96.

[55] J. Axsen, J. Cairns, N. Dusyk, S. Goldberg, What drives the Pioneers? Applying lifestyle theory to early electric vehicle buyers in Canada, Energy Res. Soc. Sci. 44 (2018) 17–30.

[56] F. Sprei, Disrupting mobility, Energy Res. Soc. Sci. 37 (2018) 238–242.

[57] A. Ensslen, P. Ringler, L. Doerr, P. Jochem, F. Zimmermann, W. Fichtner, Incentivizing smart charging: modeling charging tariffs for electric vehicles in German and French electricity markets, Energy Res. Soc. Sci. 42 (2018) 112–126.

[58] IEA, Nordic EV Outlook 2018: Insights from Leaders in Electric Mobility, International Energy Agency, France, 2018.