# Literature Review of U.S. Consumer Acceptance of New Personally Owned Light Duty Plug-in Electric Vehicles

EPA United States Environmental Protection Agency

BERKELEY LAB

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# 1 INTRODUCTION

## 1.1 Objectives, Scope, and Focus

The primary objective of this review is to provide a current and comprehensive summary of the scientific literature regarding consumer acceptance of light duty (LD) plug-in electric vehicles (PEVs) among private U.S. consumers.[1] The scope of this literature review includes retrospective, prospective, empirical, and theoretical studies.[2] However, we limit our scope to recent (i.e., primarily 2016 and later), peer-reviewed,[3] studies with relevance to the purchase decisions of private U.S. light duty vehicle (LDV) consumers and to nearer-term time frames (i.e., 2022 to 2035).[4] We focus on what constitutes PEV acceptance, namely how it is defined, elicited, observed, and/or measured; the multifaceted nature and current state of PEV acceptance in the United States among private LDV consumers; and the attributes of individuals, vehicles, and the systems (i.e., physical, social, and economic) that enable and stand in the way of PEV acceptance. Another important objective is to develop an organizing framework that supports actionable insights for a general audience.

In the course of this review, we considered more than 300 scientific studies within the transportation literature, including those we cite. We identified studies for consideration via search terms/key words (e.g., "battery," "plug-in", "electric", "vehicle", "car", "consumer", "acceptance", "awareness", "access", "adoption", "purchase", "preferences", "attitudes", "willingness-to-pay", "behavior", "policy", "incentive", "intervention") as well as variations and logical combinations thereof (e.g., "plug-in electric vehicle", "plug-in hybrid electric vehicle", "consumer acceptance", "policy interventions"). We also employed other conventional approaches such as forward- and backward-looking citation networks and consultation with colleagues and experts. Among those studies that served this part of our search are earlier works by these authors related to the plug-in electric vehicle purchase process, namely Taylor and Fujita (2018) and Fujita et al. (2022). Importantly, our search was extensive, but it was not intended to be exhaustive. Our intent was to capture a clear and comprehensive picture of the scientific literature within the scope described above (i.e., recent studies addressing U.S., private use, new vehicle consumer acceptance of PHEVs and BEVs), not summarize all of the literature. Thus, our substantial set of over 100 references reflects the scientific literature within the stated scope and supports the review that follows. It does not discuss every study considered or reviewed.

Furthermore, it is well-worth noting that much of the literature on PEV acceptance by U.S. consumers is limited in geographic scope—specific to a locality, state, or region—and therefore

[1] Battery electric vehicles (BEVs) always rely on electricity stored in a battery for fuel. Plug-in hybrid electric vehicles (PHEVs) can operate either on electricity stored in a battery or gasoline (U.S. Environmental Protection Agency 2021b).

[2] Though we touch on projections of future sales, fleet composition, and the like, we do not review fleet projection models. A review of such models would be a significant endeavor in addition to the task we undertake here. Several model reviews are available, including Yip et al. (2018), Muratori et al. (2020), and Taylor (2022).

[3] Some exceptions to peer-reviewed criteria, such as working papers and reports of high quality, are included in this review.

[4] This literature is based on large and small scale; local, regional, and national studies; and stated and revealed empirical data among other dichotomies. In the effort to preserve readability, this text does not detail the differences in scale, geography, method, etc. for all of the information presented. Rather, we provide information that is consistent across studies, therefore emphasizing where there appears to be consensus in the literature.

may not be generalizable. Tracking those limitations within the subsequent text may have made it more cumbersome than clear. Thus, we have sacrificed a full accounting of the time of data collection, geographic scope, location, and sample size of studies cited in favor of readability. Lastly, we engaged in a formal peer review process to ensure our objectives were met. The report can be found in the Environmental Protection Agency's (EPA's) Science Inventory Publication Number EPA-420-R-23-003.[5]

Regarding scope, we deemed some topics of considerable interest to be out of the scope of this report for several carefully considered reasons. Most importantly, we needed to manage the scale of this work. First, some topics are substantial in importance, content, or complexity that more than sufficiently justify reports of their own. For example, topics related to disparities, distribution of subsidies, and underserved populations touch on issues of equity, which given the scientific literature on this topic and its importance, is deserving of more complete and nuanced treatment than could be achieved in this literature review. Similarly, we acknowledge that the literature on the design and effectiveness of policy interventions is rich. We nevertheless chose to curtail the presentation of this literature since a comparative analysis of policy and policy design warrants a technical assessment of policy attributes not indicated in our stated objectives. This choice has the added benefit of a more expansive and perhaps more balanced presentation of acceptance enablers than drilling down into policy particulars would allow. Likewise, we acknowledge the importance of local level actions and dynamics as well as local level heterogeneity, but we do not delve into local level topics to manage the scale of the report. In the report, we do note the considerable efforts of other researchers in capturing local level considerations and refer readers to those studies and reviews. Second, for some topics, the literature was nascent, emerging, or relatively light. Current issues, such as supply constraints, used PEV markets, and PEV repurchase, are currently being analyzed by many researchers. Other issues of interest were absent or arguably received insufficient treatment in the literature. Because our intent was to comprehensively present current findings of the scientific literature regarding U.S. consumer acceptance of new light duty plug-in electric vehicles and to do so in a cohesive and understandable manner, we leave it to our readers and other researchers to identify gaps in the literature.

Thus, while important to the evolving understanding of the role of PEVs in transportation behavior, the following topics, most of which were also noted by our reviewers, are out of the scope of our current review with limited exceptions: (1) PEV acceptance studies related to non-U.S. consumers, with exceptions for foundational works or in cases where U.S.-specific information is limited; (2) publications before 2016 with the exception of foundational or unique earlier publications; (3) PEV use except to the extent that experience influences acceptance; (4) commercial purchase and use of PEVs, such as company fleets or transportation network company (TNC) drivers; (5) studies that project or forecast future PEV sales or market shares; (6) the used PEV market; (7) local level considerations, issues, complexity and/or heterogeneity; and (8) equity considerations.

[5] https://cfpub.epa.gov/si/

## 1.2 Background

To reduce air pollutant emissions and improve air quality, zero or near-zero tailpipe emissions can be achieved using current light duty vehicle technologies, which include plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and hydrogen fuel cell vehicles (HFCVs). In fact, zero tailpipe and upstream emissions from vehicle use can be achieved when electricity is generated via renewable or carbon-neutral sources. Among these three types of zero emission vehicle technologies (ZEVs), PHEVs and BEVs appear to have the greatest near-term potential for mass commercialization in LD markets.[6]

In the United States, annual sales of LD plug-in electric vehicles (PEVs), which includes PHEVs and BEVs, has been low and geographically uneven, but sales are growing and expanding geographically, despite pandemic-related shocks to the light duty vehicle market. New plug-in electric vehicle sales represented 2.2% (1.7% BEV and 0.5% PHEV) of new light duty vehicle sales in 2020 (Davis and Boundy 2021; U.S. Environmental Protection Agency 2021b). In 2020, PEVs were concentrated on the West Coast and in the Northeast, in so-called "ZEV States,"[7] and in urban areas (e.g., AFDC 2021a; Le and Lindhardt 2019; Brown et al. 2021; Bui, Slowik, and Lutsey 2020). PEV production in 2021 was projected to be 4% of new vehicles (U.S. Environmental Protection Agency 2021b). According to the Alliance for Automotive Innovation (2022) actual annual PEV market share in 2021 was 4.62% (3.38% for BEVs and 1.24% for PHEVs), and as of May 2022, actual PEV market share was 6.64% (5.21% for BEVs and 1.43% for PHEVs). These outcomes occurred under arguably unfavorable conditions—namely, relatively few PEV models were available, charging infrastructure was limited, and PEV purchase prices were relatively high, all concurrent with economic shocks related to the COVID-19 pandemic. Combined with recent announcements from vehicle manufacturers regarding substantial planned expansion of PEV models and production, there is reason to believe that PEV market share will continue to grow.

Nevertheless, there appears to be broad consensus in the scientific community that the proliferation of PEVs in the U.S. LDV fleet is subject to a number of uncertainties, including a combination of: advances in technology (e.g., vehicle range); production costs (e.g., battery costs); vehicle purchase prices (e.g., financial incentives, diversity of vehicle price points); further development of transportation infrastructure (e.g., charging infrastructure); vehicle model offerings (e.g., body styles); geographic availability; and consumer acceptance of PEVs.

Much of the scientific literature regarding consumer acceptance of LD PEVs describes the current state of consumer acceptance, the factors that influence consumer acceptance, and progression of acceptance over time (i.e., retrospective and empirical studies), all of which can translate into recommended interventions and likely outcomes as well as projections of PEV adoption and market share (i.e., prospective studies). The factors that influence consumer

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[6] We reiterate that our focus here in on individually owned vehicles. LD fuel cells may have more relevance in fleet applications because they can be paired with company-managed hydrogen fueling infrastructure.

[7] "So-called" ZEV states are states that have adopted California's zero-emission vehicle regulations under Section 177 of the Clean Air Act. As of March 17, 2022, ZEV states include Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont, and Washington; Colorado is expected to join in 2023; Minnesota, Nevada, and Virginia are expected to join in 2025; and Delaware is expected to join in 2027 (California Air Resources Board 2022).

acceptance are often framed as enablers and obstacles (sometimes referred to as "drivers" and "barriers," respectively). Enablers and obstacles can be monetary and/or financial (e.g., tax credit) or non-monetary and/or non-financial (e.g., high occupancy vehicle [HOV] lane access).[8] Enablers and obstacles also highlight the advantages and disadvantages of PEVs relative to conventional vehicles, as well as the imbalance in the knowledge and confidence of consumers in conventional vehicles relative to PEVs. Enablers and obstacles relate to consumer characteristics (e.g., knowledge, confidence, attitudes), vehicle attributes (e.g., safety, reliability) and features (e.g., range, purchase price, cost of ownership), and system factors (e.g., fueling and charging infrastructure, fuel and electricity prices, incentives and disincentives, social networks).

Despite the depth and breadth of this literature, consumer acceptance of LD PEVs has no generally accepted definition and is measured numerous ways. For example, consumer acceptance is demonstrated through the following:

- PEV sales and purchases (e.g., Jia and Chen 2021)
- PEV registrations (e.g., Kurani and Buch 2021)
- Stated and actual willingness to pay for PEVs (e.g., Nazari, Mohammadian, and Stephens 2019)
- Self-reported willingness to purchase or consider purchasing a PEV (e.g., Singer 2020)
- Availability of PEVs or of specific PEVs with desired attributes (e.g., Higgins, Mohamed, and Ferguson 2017)
- Knowledge of and accuracy of knowledge about PEVs (e.g., Kurani 2019)

Most consumer acceptance studies examine one or more of the many measures of acceptance, but not all. Most studies glean insights from an imperfect pool of research subjects who are either early PEV adopters or non-adopters, neither of which are representative of mainstream consumers who will make up the majority of PEV consumers under high levels of PEV adoption.[9] Definitions of consumer acceptance and of the many measures of acceptance vary across existing research. Organizing the complexity of the problem, as well as the myriad of results and recommendations, is a challenge in and of itself. Thus, we proceed by explicitly defining an organizing framework, which is beneficial in that it aids in the discussion of locating consumers along a continuum of acceptance and in the identification of key enablers and obstacles.

[8] While not explicitly monetary, the value to consumers of HOV access can be estimated (e.g., Shewmake and Jarvis 2014).

[9] Notably, we have employed the language of the Diffusion of Innovations Theory, in which Rogers (2003) outlines five different types of adopters. The first to adopt are innovators (first 2.5%), followed by early adopters (next 13.5%), early majority (next 34%), late majority (next 34%), and laggards (the last 16% to adopt). We discuss innovators and early adopters as one category that we call "early adopters." We also group the early and late majority into what we call the "mainstream." Furthermore, we focus on the first PEV purchase or lease, which we call "adoption." We call second and later PEV purchases, "re-purchase" or "re-adoption," which we do not emphasize in this review.

## 1.3 Defining a Framework for Consumer Acceptance of Light Duty Plug-In Electric Vehicles

In our review of the scientific literature regarding consumer acceptance of LD PEVs, we categorized topics into a framework of our own design consisting of four related components of *acceptance*—**awareness, access, approval**, and **adoption**. We discuss consumer acceptance of LD PEVs within this framework, which we refer to as "the 4-A framework" or "our framework."[10] Each component of the framework is formally defined below.

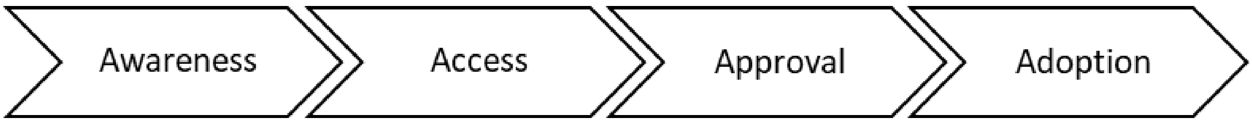


Figure 1. Stages of consumer acceptance.

**Awareness**, in short, is the knowledge of and the accuracy of knowledge of PEVs. It is not easily observable and therefore almost exclusively measured as reported by consumers. Enablers of awareness include education (e.g., Kurani 2019), advertising (e.g., Graham 2021b), social networks (e.g., Kurani 2018), and experience (Xu et al. 2020; e.g., Singer 2020), but not all consumers have the same exposure and receptivity. Awareness also emerges as a product of factors internal to consumers such as confidence, attention to information, and the ability to acquire, assimilate, and update information (Taylor and Fujita 2018; e.g., Jiang and Rosenbloom 2013; Punj and Staelin 1983). While we can ask the question, "Is a consumer aware of PEVs or not?," consumer awareness is clearly multidimensional. Awareness is knowing about and having a generally correct understanding of PEVs, including PEV technology, infrastructure, incentives, use, charging, servicing, and the signs and symbols associated with PEVs and PEV infrastructure. For example, someone could know about PEVs and have accurate knowledge of some attributes, such as range and driving performance, but also have incorrect or no knowledge of how to charge a PEV and the costs associated with charging. However, we will discuss it on a gradient of less and more aware, a practice we also adopt for access and approval.

**Access** means that a suitable PEV is, or is perceived to be, affordable, available, and convenient to purchase, use, charge, and service. Perhaps the simplest measure of access (i.e., most objective and easily observable) is the availability of vehicles and charging. Where are PEVs offered for sale; where is public, workplace, and commercial charging located; and who can get there? In general, more PEVs, more models of PEVs, and more charging sites have been available on the northeast and west coasts, ZEV states, and in urban areas (e.g., Alternative Fuels Data Center 2021; Brown et al. 2021; Bui et al. 2020; Le and Lindhardt 2019). It is a feasibility question in its simplest incarnation, but not perfectly objective. Access is more subjective and more difficult to measure when suitability, affordability, and convenience are considered. For example, even when a PEV is available for sale, it may not be appropriate for a particular person or household

[10] We note that there are several robust models developed and usefully applied to innovation and the adoption of new technologies and products. Among the most well known are Diffusion of Innovation Theory, Theory of Planned Behavior, Theory of Reasoned Action, and the Technology Acceptance Model. Lee at al. (2019) characterizes them well in the following: "Diffusion of innovations theory (Rogers 2003) outlines why people adopt innovations, who adopts them, and adoption rates over time… [including] information about the socio-demographic profile of early adopters. [Other] consumer innovation adoption models, for example the theory of planned behaviour (Ajzen 1991), theory of reasoned action (Fishbein and Ajzen 2009), or the technology acceptance model (Venkatesh and Davis 2000) … focus on motivational factors or behavioural issues."

(i.e., may not be suitable). For example, it may lack desired attributes such as body style, range, image, and color. Among those vehicle attributes is price. If PEV prices, relative to income and wealth, are high enough to effectively make PEVs unaffordable, PEVs cannot reasonably be considered in a purchase decision. Even if a suitable, affordable PEV is available, opportunities for purchasing, charging, or servicing may not be available in a location familiar to or frequented by a prospective buyer. Obstacles to access can relate to both feasibility and practicality. Of the four components of acceptance, access is the least well defined and least well understood.

**Approval** occurs when PEVs are perceived, at a minimum, as substitutes for other vehicles. It arises because of favorable attitudes, opinions, and emotions, and is achieved when a consumer seriously considers or intends to purchase a PEV. Consideration and intent, and therefore approval, precede and are distinct from the purchase itself. Nevertheless, as a continuum, approval is measured by the degree or level of positive views (e.g., attitudes, opinions, emotions), perceptions, and assessments of PEVs. It is often measured via stated preference, sometimes evidenced by inclusion of PEVs in consumers' consideration sets, and ultimately is revealed retroactively by PEV purchase. Whether binary or continuous, approval is, at best, difficult to observe directly prior to purchase. As a result, researchers often rely on surveys. For example, surveys question consumers' willingness to consider PEVs and how seriously they consider them (e.g., Carley, Siddiki, and Nicholson-Crotty 2019), willingness to pay for PEVs in terms of vehicle purchase price or total cost of ownership (e.g., White and Sintov 2017), assessment of PEVs relative to conventional vehicles (e.g., Singer 2017), and intent to purchase. Importantly, the distance between stated intent to purchase and actual purchase can be quite large. We include approval distinct from purchase in this organizing framework for exactly this reason. The internal and external processes that move a consumer to a high level of approval of PEVs are very likely to be different from those that bridge the gap between intent and actual purchase. One needs to be at the edge of the chasm to cross the bridge to the other side.

**Adoption** refers to the acquisition of a PEV via purchase or lease, specifically first purchase or lease. It is easily observable and measured via new vehicle purchases, sales, registrations, and production (e.g., U.S. Environmental Protection Agency 2021a; 2021b). However, it is difficult to discern what tips the scales in favor of PEV purchase once consumers seriously consider PEVs or intend to purchase a PEV (i.e., approval). As a consequence, the scientific literature offers limited insight into the drivers of adoption, separate from approval. However, there is consistent evidence that dealerships have influence on purchase decisions for many new vehicle consumers, such as through offering the opportunity to experience PEVs first-hand through test drives (Graham 2021b; Le and Lindhardt 2019; Lunetta and Coplon-Newfield 2017; Moon 2019c), though their role has declined over time (Dehdashti, Ratchford, and Namin 2018).[11]

The order in which we present these components is intentional. Viewed as a process, as in Figure 1 and Table 1, this stylized representation is useful organizationally, analytically, and for communication. We emphasize that the components are not mutually exclusive, and this is not a strictly ordered continuum. There are feedback loops. Nevertheless, awareness and adoption are the obvious beginning and end for a process that terminates with the acquisition of a new product. That said, one can easily imagine that ready access to PEVs and vehicle charging infrastructure might facilitate awareness. In other words, for some individuals, access may

[11] The decline in the role of dealerships in the new vehicle purchase decision may be bounded. In many states new vehicle purchases can only occur at a dealership, despite recent innovations in vehicle sales.

precede awareness. However, access is never a necessary condition for awareness—awareness can be achieved via other means—so we hold fast to intuition despite some exceptions and define awareness as the first stage in the process. Awareness, access, and approval all necessarily precede adoption. It is reasonable to assume that individuals will not purchase vehicles about which they are unaware, cannot obtain, and may not approve.

The somewhat trickier challenge is to determine if the most reasonable linear progression proceeds from access to approval or from approval to access. Some individuals might not seriously consider or intend to purchase a vehicle that is not already available to them with the attributes they desire. In that case, access precedes approval. In contrast, other individuals may specify in their minds or in a research study a vehicle with all the attributes they desire with intent to purchase, only to find that their criteria cannot be satisfied with current market offerings or in their local area. In this case, approval precedes access, and lack of access is the impediment to purchase. Thus, the process could reasonably go either way—from access to approval or from approval to access. We again invoke the notion of necessary conditions to resolve this. Specifically, approval is never a necessary condition for access. But access is sometimes a necessary condition for approval. Thus, we define this stylized continuum of four stages of consumer acceptance as proceeding from awareness to access, then approval and adoption.

| Component | Short Definition | Example Metrics |
|---|---|---|
| **Awareness** | Knowledge of and accuracy of knowledge of PEVs | Can recognize a PEV<br>Can correctly name a PEV model<br>Can describe or identify a charging site<br>Can accurately describe PEV range and/or charging time<br>Knows that a PEV is fueled with electricity |
| **Access** | Proximity to suitable, affordable, and convenient purchase, use, charging, and servicing | Number of PEV models<br>Availability of body styles<br>Geographic availability<br>Manufacturer's suggested retail price (MSRP)<br>Ownership cost<br>Charging location and density |
| **Approval** | View that PEVs are, at minimum, substitutes for conventional vehicles | "Consider" purchase<br>"Seriously consider" purchase<br>Intent to purchase (likelihood scale)<br>"At least as good as" ICEVs<br>Willingness to purchase exceeds purchase price or cost of ownership |
| **Adoption** | First purchase or lease | Sales and purchases<br>Registrations<br>Production |

Table 1. The four components constituting the organizing framework for consumer acceptance of LD PEVs.

### 1.4 Synthesis in Brief

The objective of this review is to provide a current, comprehensive, and accurate summary of the scientific literature regarding U.S. consumer acceptance of personal-use light-duty (LD) plug-in electric vehicles (PEVs). Another important objective is to develop an organizing framework that supports actionable insights for a general audience. The questions underlying this review are as follows:

- What is the current state of LD PEV acceptance in the United States among personal-use consumers at each stage of acceptance?
- How does a U.S. consumer, or community or the nation, move through the stages of PEV acceptance?
- What enables their progression at each stage of acceptance?
- What stands in their way at each stage of acceptance?

We ask these questions without value judgements, but with the presumption that we seek to understand how a broad range of actors and factors facilitate PEV acceptance, and how to overcome potential obstacles.

Because the literature is broad (i.e., multidisciplinary, multisector, geographically expansive, and diverse) as well as deep (e.g., geographically granular, scientifically rigorous), we define the stages of the acceptance process as awareness, access, approval, and adoption, intentionally choosing lay terms that speak to the state of mind of a consumer (or consumers) or the conditions under which they progress toward PEV adoption. We make consumers central to our presentation of the literature—that is, consumers in relationship with vehicles in the context of market, social, physical, and governmental systems (Figure 2). From that point of reference, we discuss the roles of other key actors and stakeholders (e.g., governments, vehicle manufacturers) and the factors within physical, social, economic, and governmental contexts that influence consumers.

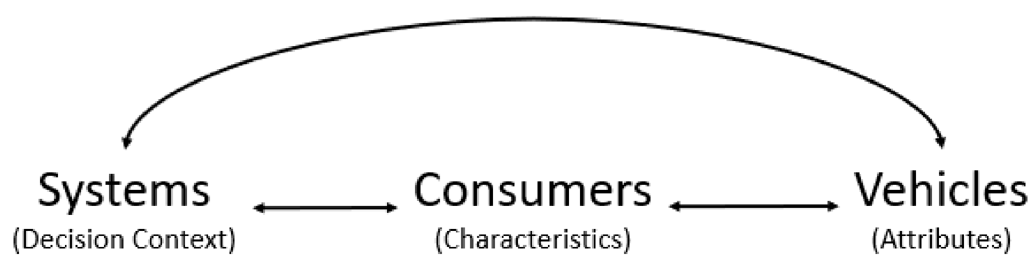


Figure 2. Interactions among consumers with diverse characteristics, vehicles with myriad attributes, and within a multitude of complex systems

Within this framework, we address the above questions via a summary and synthesis of the scientific literature. In the interest of scope and readability, we do not attempt to provide an exhaustive summary. Rather, we endeavor to be faithful to the literature as presented in the studies reviewed and have taken steps to ensure that critical literature is included. We also choose not to evaluate studies relative to each other. This choice should not be taken to mean that studies are equivalent via any metric of quality, merely that we do not offer an assessment of study quality with the exception of being of sufficiently high quality to be included in the review. In addition, we do not assess, evaluate, or critique the specific studies.[12] We do select what appears to reflect the variety of metrics, geographic diversity, sampling techniques, methods employed, and findings in the studies reviewed. We also note the amount of literature relevant to

[12] In Appendix A, we provide additional detail on the methods, scope, sample size, etc., of cited studies to allow readers of this report to better understand these sources, the specific populations to which they refer, and their potential limitations.

a stage or topic, the consistency of that literature, and the degree to which the literature conclusively supplies actionable recommendations for enabling PEV acceptance and for future research

Before proceeding with our summary (i.e., Sections 2 – 6) and synthesis (i.e., Section 7), we want to emphasize what we believe is implicit in the material that follows. With the exception of a likely small subset of consumers, we found that the enablers and obstacles of PEV acceptance are largely external to the consumer. In other words, we found no evidence in the reviewed literature to suggest anything immutable within consumers or inherent to PEVs that irremediably obstructs acceptance. Rather, under favorable conditions, including supporting the demonstrable plasticity of attitudes, emotions, and preferences, acceptance of PEVs is achievable among mainstream consumers. In addition, we note that awareness, access, and approval enable adoption. Thus, converting intent to adopt into actual purchase is critically important. There can be a strong focus on moving people from considering a PEV to actually buying one. While this is important, efforts to promote this shift in consumers should not replace efforts to improve awareness, access, and approval, which are all critical to adoption as well. Furthermore, we note the repeated appearance of enablers at multiple stages of acceptance. Specifically, favorable location, demographics, and attitudes correlate with awareness, access, approval, and adoption.[13] Direct and indirect experience with PEVs encourages awareness, approval, and adoption. Finally, the proliferation of charging availability facilitates each of the necessary conditions for adoption, albeit in different ways, namely via exposure, access, convenience, and cost.

Focusing first on awareness, a PEV-aware consumer recognizes a PEV when they see one and understands how PEVs and ICEVs differ. A consumer who is more aware of PEVs knows generally about available makes and models, has an accurate idea of the attributes and features available on PEV models, and understands that PEVs are charged with electricity rather than fueled with gasoline. Awareness also extends to recognition and understanding of charging infrastructure as well as knowledge of incentives associated with PEV adoption.

Measurements of various metrics of awareness among consumers vary, covering a wide range from the high teens to the low eighties in terms of percentages of individuals surveyed or interviewed. Generally, a higher percentage of consumers possess a general awareness of PEVs (e.g., they know that vehicles that use electricity rather than gasoline exist) as compared to consumers with more concrete awareness of PEVs (e.g., those who can name one or more PEV models available on the market). Synthesizing the information presented across studies, we conservatively estimate that approximately half of U.S. consumers have some basic awareness of PEVs. PEV awareness hinges on having information, specifically correct information delivered by a credible party to a receptive audience. With mixed results, friends, relatives, dealers, manufacturers, and governments are key enablers of awareness. Another key enabler of

[13] First, by "favorable locations", we mean places, for example, with charging infrastructures and PEV incentives and benefits. "Favorable demographics" refers to demographics currently correlated with PEV adoption such as high income and single-family housing. Similarly, "favorable attitudes" refers to attitudes associated with current PEV adopters like technology affinity, environmentalism, and particular awareness and/or sensitivity to vehicle operating costs. Second, growing acceptance in favorable locations and within favorable demographic group is, at minimum, a suboptimal strategy. Rather, high market penetration of PEVs requires the expansion of PEV acceptance to more locations and demographic groups. One can make a similar argument regarding individuals with favorable attitudes. In addition, attitudes are malleable and arguably ill-informed and under-stimulated by early PEV offerings, advertising, education, exposure, etc.

awareness is a consumer's local exposure to PEVs, PEV incentives, PEV policies, and PEV infrastructure. Furthermore, opportunities for direct experience with PEVs provide high quality information and positively affects not only PEV awareness, but also approval and adoption.

PEV access has physical and financial aspects, and its enablers and obstacles may relate to feasibility and practicality. Vehicles and charging infrastructure must be available in sufficient numbers and locations. Access requires that vehicles and charging are affordable, and with affordability in mind, the incentives must be available and easy to obtain. Access is difficult to characterize, let alone measure. However, it is clear that access varies geographically and socio-economically. Key enablers, therefore, are the continued expansion of charging infrastructure, implementation and expansion of PEV incentives and benefits, and the growth in availability of PEVs and PEV models at various price points.

PEV approval is the intent that precedes PEV purchase, and depending on the consumer, a rough equivalent for adoption or a far cry away. Though the literature on what we term approval is substantial, there is no shared metric across studies. A consumer who approves of PEVs views a PEV as a plausible substitute for an ICEV, expresses a positive assessment of PEVs, includes PEVs in their consideration set, and/or may express sufficient willingness to pay for a PEV. Key obstacles to approval likely echo awareness obstacles – namely a lack of knowledge or accurate knowledge of, exposure to, and experience with PEVs, PEV chargers, and PEV-related incentives – which undermine confidence and buoy uncertainty regarding PEV technology. As with access, lack of physical proximity to PEVs and charging and relative affordability of PEVs also inhibit consumers at the approval stage. However, surges in PEV sales and pre-orders in response to specific models (e.g., Tesla Model 3, Ford F150 Lightning) suggest there is growing demand for PEVs outside the original PEV markets, willingness to pay for PEVs appears to be increasing, and targeted education and advertising hold promise.

Finally, PEV adoption is on the rise. New PEV sales represented 2.2% of all new vehicles sales in 2020 and were estimated to have grown to 4%–5% in 2021. As with other stages of acceptance, adoption thus far has been geographically and socioeconomically uneven, has been more common among specific subgroups of consumers,[14] and has occurred more often in the presence of favorable PEV policies. PEV adoption among amenable subgroups and/or those able to benefit from favorable policies does not fully explain PEV adoption to date, nor is it likely to fully explain the mechanisms that lead to widespread adoption or the interventions that facilitate adoption among mainstream consumers. Enablers of adoption can also occur at the time of purchase. Test drives and sales practices can tip the scales; a positive dealer-purchaser interaction can be a key enabler of adoption.

### 1.5 Organization of the Review

Section 2 begins with a discussion of vehicle consumers and PEV consumers—who they are, their relationships with vehicles and the vehicle purchase process, and their relationships with contextual elements such as infrastructure, policy, and social and market forces. We proceed according to our 4-A framework. In Sections 3 and 4, we bring awareness and access to the fore

[14] E.g., high income buyers, single-family home-owners, technology forward, or environmentally oriented consumers

and disentangle approval and adoption in Sections 5 and 6. Our review does not include post-adoption PEV usage, though we acknowledge this is a rich area of research.

For each stage of the 4-A framework, we provide a summary of the relevant measures, metrics, and methods, followed by:

- the current state of acceptance at each stage,
- consumer characteristics that facilitate or inhibit the given stage of acceptance,
- vehicle attributes and features that positively and negatively influence the given stage of acceptance, and
- system factors that enhance or impede the given stage of acceptance.

We close in Section 7 with a synthesis of the literature. We additionally provide a descriptive table of cited studies in Appendix A, in which we note the analytical methods, scope, sample size, and other features of the works we cite throughout this report.

## 2 CONSUMERS

Many empirical studies provide insight into LD PEV acceptance among adopters of vehicle electrification (i.e., owners and lessees), while others examine the knowledge, opinions, attitudes, preferences, beliefs, and intent of non-PEV owners and lessees. In addition to the known limitations of both revealed preference and stated preference studies, PEV adopters and non-adopters observed to date almost certainly differ from the anticipated mainstream PEV adopters who would drive a large-scale PEV adoption scenario.

Acknowledging these limitations and contrasting PEV adopters and non-adopters, studies generally find that PEV adopters to date, on average, have higher incomes and more education than non-adopters. PEV adopters are also more likely to be male and to own their homes. In addition, current PEV adopters are more likely to self-identify with cutting edge technology, more likely to report environmental interests, and/or more likely to have interest in or knowledge of fuel prices. Finally, current PEV adopters tend to live in more urban locations, with more PEV registrations on the northeast and west coasts compared to other regions[15] (Jung 2019b; 2019c; e.g., AFDC 2021a; Kurani and Buch 2021; Bui, Slowik, and Lutsey 2020; Shin, Farkas, and Nickkar 2019; Degirmenci and Breitner 2017; DeShazo 2017; Soltani-Sobh et al. 2017; Morton, Anable, and Nelson 2016; Hardman and Tal 2016; Archsmith, Muehlegger, and Rapson 2021). In studying the characteristics of current PEV adopters and potential PEV adopters, and the characteristics of individuals associated with PEV adoption thus far, many researchers employ the language of technology diffusion. Like many of the studies reviewed, we also employ the categories of early adopters, and mainstream or majority (e.g., Rogers 2003).

Before turning our attention to a detailed examination of each stage of the 4-A Framework, we provide a background overview on several important topics surrounding consumer acceptance of PEVs. First, we discuss steps of the consumer purchase process, grounded in generalized consumer behavior research, and the ways in which consumer purchase behavior interact with and affect the 4-As. Building from the purchase process, we delve deeper into the criteria consumers use to select between available vehicles, including broad types of criteria and common decision rules. As decision criteria and ultimate vehicle choice are often observed to correlate with consumer characteristics, we also describe key consumer characteristics that relate to PEV acceptance, as well as ways characteristics are used to define segments of the population. Finally, we conclude the section with discussion of ways in which consumers interact with vehicles and systems (i.e., market, social, physical, policy).

### 2.1 Consumer purchase process

To provide context for the ways in which awareness, access, approval, and adoption of PEVs manifest, it is useful to consider the process through which consumers purchase vehicles. One such depiction is the five step consumer purchase process, which includes: (1) problem recognition, (2) search (internal and external), (3) alternative evaluation, (4) purchase, and (5) post-purchase experience (e.g., Taylor and Fujita 2018; Darley, Blankson, and Luethge 2010; Engel, Kollat, and Blackwell 1968). Throughout the purchase process, consumer awareness and

[15] Some studies (e.g., Jia & Chen 2021) note that PEV adopters are older, while others (e.g., Archsmith et al. 2021) describe PEV adopters as younger than the average car buyer. Some studies (e.g., Jia & Chen 2021) also show that younger consumers state more interest in PEVs than older consumers do.

approval of PEVs, as well as access to PEV models, will impact the likelihood of the consumer ultimately adopting a PEV.

In problem recognition, a consumer identifies the need or desire for a new vehicle; it often stems from the need to replace an existing vehicle, to meet a new need, or from the expectation of greater utility from a new vehicle. In all of these cases, awareness of PEVs comes into play. An aware consumer will be better able to recognize when a PEV may be well-suited to their lifestyle and travel patterns, while an unaware consumer is unlikely to identify a PEV as a potential solution to their recognized problem. Even if consumers are aware of PEVs, there is evidence that households seeking to replace a vehicle are less likely to be willing to consider PEVs (i.e., less likely to approve of PEVs) than those looking to purchase an additional vehicle (e.g., Higgins, Mohamed, and Ferguson 2017). Similarly, even when consumers are aware of and approve of PEVs (i.e. willing to consider PEV purchase), PEVs are still viewed more favorably as additional rather than replacement vehicles (e.g., Higgins, Mohamed, and Ferguson 2017; Karlsson 2017; Kurani, Turrentine, and Sperling 1996). It is not clear whether this tendency will persist in the coming years.

Awareness is also a major component of the next step—search—bounding not only what consumers know but also the new information they seek. During internal search, a consumer consults their existing store of knowledge to identify vehicles that could meet the need(s) or desire(s) identified in problem recognition (i.e., their consideration set). Internal search, and therefore awareness, also frames the types of information a consumer seeks out from external sources, such as expert reviews, manufacturer and dealer websites, or advice from family and friends. Thus, given the relationship between what we call *awareness* and what marketing calls *search,* the limits of a consumer's awareness of PEVs dictates what they already know about PEVs (i.e., internal search) and constrains what they are likely to learn from external sources (i.e., external search). By shaping internal and external search, awareness of PEVs is integral to inclusion of PEVs in a consumer's consideration set. In other words, if a consumer is not aware of PEVs, PEV attributes and features, PEV-related infrastructure, and PEV-related incentives and policies, PEVs will not enter into consideration. The constraining effect of low awareness on internal and external search, however, can be moderated by an individual's approach or circumstances.

Alternative evaluation involves the consumer assessing the objective and subjective attributes and features of the vehicles in their consideration set. To do this, the consumer applies a unique-to-the-individual set of decision rules that weigh vehicle attributes based on criteria derived from the consumer's needs and preferences, and the information gained during the search step. These decision rules are characterized as "compensatory" if they involve trade-offs between criteria, and "non-compensatory" if the consumer considers them to be non-negotiable. The outcomes of alternative evaluation are three sets of products: an evoked set (i.e., vehicles the consumer is willing to purchase), an inept set (i.e., vehicles the consumer is not willing to purchase), and an inert set (i.e., vehicles the consumer feels indifferent about).

The decision rules used to assess the suitability of vehicle models to a consumer's specific needs have implications for PEV acceptance. Common criteria considered under alternative evaluation include several relating to PEV access, including:

- vehicle and model availability at nearby dealerships (access in terms of geography);
- vehicle attribute availability (access to utility);
- purchase price, financing options, and financial incentives (access in terms of affordability);
- and availability of public charging and/or potential for home charging (access to infrastructure).

It almost goes without saying that without access to PEVs, the evoked set and associated willingness to purchase a PEV is trumped by practical limitations. Setting aside access challenges, assignment of PEV models to the evoked set hinges on consumer approval of PEVs. A lack of PEV approval relegates all PEV models to a consumer's inept set, even if attributes of PEV models do align with consumer criteria.

In the purchase step, a consumer makes the decision to buy (or not buy) a vehicle in their consideration set; possibly concluding with PEV adoption. While simple to state, the leap from approval to adoption may be a significant one. It can be facilitated and impeded by both tangible and intangible factors. These factors include the various types of access described above, the sales/buying experience, the alignment of compensatory and non-compensatory criteria and with vehicle attributes, and a host of psychological, emotional, and social factors.

The post-purchase experience of using a PEV and incorporating it into everyday travel patterns is another aspect of PEV adoption. Post-purchase experiences, and how they compare to a consumer's pre-purchase expectations, shape a consumer's likelihood of retaining a recently purchased PEV and of continuing to buy PEVs in the future. The post-purchase experience can also affect the awareness and approval of others that the PEV owner interacts with. Current owners of PEVs, particularly those with strong positive feelings about their post-purchase experience, can help to raise the awareness and approval of those who do not yet have direct experience with a PEV (Kurani et al. 2018; Kurani 2019).

## 2.2 Criteria: What Consumers Want from a Vehicle

Criteria are decision rules that consumers use to weigh different vehicle options as they evaluate alternatives in the course of the vehicle purchase process. Criteria define and prioritize what consumers want from a vehicle (e.g., Fujita et al. 2022). They may relate to specific vehicle features (e.g., number of passenger seats) or to the broader vehicle attributes that are outcomes of features sets (e.g., safety rating, which is a function of safety-related features such as airbags, blind-spot detection, etc.). The available vehicles that a consumer evaluates in the context of their criteria constitute their "consideration set." The vehicles within this set change over time as a consumer eliminates models from consideration or learns of new appealing options.

### *2.2.1 Compensatory and non-compensatory decision rules*

Consumer evaluation methodologies can be broadly classified into compensatory and non-compensatory decision rules. If a criterion is compensatory, a consumer is potentially willing to "trade off" one vehicle feature or attribute for another (e.g., low price may outweigh a color they do not particularly like). A non-compensatory decision rule addresses a non-negotiable aspect of a vehicle (e.g., number of seats, minimum cargo area, safety rating). For example, recent research suggests that vehicle body type may be non-compensatory for many consumers (e.g., Fujita et al. 2022; Archsmith, Muehlegger, and Rapson 2021; Higgins, Mohamed, and Ferguson 2017), with implications for PEV access, approval, and adoption, given that several types of vehicles (e.g., pickup trucks, minivans) have had very few, if any, PEV models available on the market. Another criterion that is often non-compensatory for consumers, across PEVs and ICEVs, is vehicle safety, in terms of either a test score metric or the presence of certain safety features (e.g., blind spot detection).

### *2.2.2 Objective and subjective criteria*

Criteria often relate to objective vehicle features and attributes or subjective attributes. Objective criteria relate to aspects of a vehicle that are tangible, observable, and/or measurable. For example, the amount of time required for a vehicle to accelerate from 0 to 60 miles per hour can be measured, and informs attribute-based criteria related to vehicle power and performance. Other objective criteria may relate to the volume of cargo space or number of passenger seats (two aspects noted as reasons for preferring ICE over PEV in a study by Higgins, Mohamed, and Ferguson 2017). Subjective criteria relate to vehicle attributes that are less tangible or more tacit, and more difficult to measure. For example, assessments of vehicle design and style, and the character or image of a vehicle are subjective attributes, which will differ widely across consumers.

### *2.2.3 Common consumer criteria for vehicle selection*

Some attribute-based criteria have been found to be important across numerous studies of consumer vehicle preferences, including safety, price or value, durability or reliability, and performance (e.g., Fujita et al. 2022). PEV approval and ultimate adoption will be affected by the degree to which consumers perceive accessible PEV models to meet these and other important criteria. To date, it is a common finding that the environmental performance of PEVs is a stronger predictor of positive consumer attitude toward PEVs (i.e., approval) than factors such as vehicle price and driving range confidence (Degirmenci and Breitner 2017).

Along with criteria common across all vehicle types, consumers often have a set of criteria specific to PEVs, such as range, charging/fueling speed, and charging/fueling opportunities. While these criteria have analogs in the context of ICEVs, the infrastructure to support ICEVs is so ubiquitous that these criteria enter into consideration differently for PEVs. For example, limited driving range on a charge has long been noted as a barrier to PEV adoption, with multiple studies finding that a majority of ICEV buyers indicate that they would not consider purchasing a PEV with less than 300 miles range (e.g., Singer 2016; Consumer Reports 2020). The ICEV analog is the distance that can be driven on a tank of gas. However, the widespread availability of gas stations largely diminishes the importance of this vehicle attribute. For PEV consumers, distance per charge may be a relevant concern depending on their access to charging. Similarly, the time required to recharge is a criterion unique to PEVs, as gas refueling times are generally negligible. Furthermore, PEVs also offer the unique ability to charge both at home and away from home. Notably, Level 2 home charging is a feature that appears to support the repeated purchase of PEVs (Hardman and Tal 2021). While we highlight PEV-specific criteria, keep in mind these criteria are still balanced against many other consumer considerations such as safety, durability, performance, power, environmental performance, value, design, image, and so on.

Each consumer uses a unique set of decision rules to assess the fit between their personal criteria and available vehicle models, though commonalities have been observed across groups of consumers. For example, Kurani & Buch (2021) noted that among PEV buyers, women were more apt to purchase based on environmental attributes, while men were more likely to cite the high tech aspect of PEVs as a factor in their purchase. These, and similar, observations provide evidence that vehicle selection criteria may differ based on consumer characteristics. Additionally, as Morton et al. (2016) note, it is important to understand the importance that consumers ascribe to vehicle attributes and purchase criteria, as well as the factors that underpin such evaluations.

## 2.3 Characteristics: Who Consumers Are

We use the umbrella term "characteristics" to describe aspects of consumers. These include socio-demographic characteristics of individuals, such as age, income, education, race, and gender, and of households, such as residence location, household size, and number of household vehicles. Socio-demographic characteristics tend to be observable and measurable.

Along with socio-demographics, other characteristics of consumers have relevance to their transportation behaviors and acceptance of PEVs. This class of characteristics is largely latent and unobservable (or difficult to observe). These characteristics are often gauged through consumers' statements describing psycho-social, political, or economic traits, such as attitudes, preferences, knowledge and perceptions, emotions, beliefs, status, identity and personality, lifestyle, and social connectedness. Like socio-demographics, latent and unobservable characteristics are associated with PEV acceptance.

Socio-demographic (i.e., observable) and latent or unobservable characteristics sometimes co-occur, though not always conclusively. For example, Morton et al. (2016) found higher educational attainment correlated with a reduced consideration of a car as an important possession, and an increased level of concern about environmental impacts. However, Fujita et al. (2022) found that low-income new vehicle buyers more heavily weighted environmental criteria in their vehicle purchase process than high-income new vehicle buyers.

### *2.3.1 High-level summary of known characteristics that contribute to PEV acceptance*

For some consumer characteristics, recent studies reinforce long-standing observations. A high level of education, high income, and strong environmental concern are factors that have long been identified as consumer characteristics with positive effects on PEV adoption (e.g., Hidrue et al. 2011) and continue to be called out in the literature today (e.g., Jia and Chen 2021; Hardman, Shiu, and Steinberger-Wilckens 2016; Hardman and Tal 2021; Brückmann, Willibald, and Blanco 2021). Specifically, Lee et al. (2019) found that "high income families" currently represent the largest share of the PEV market today, but also note that this segment represents a very small portion of total households. PEV adopters to date have also been predominately homeowners and/or occupants of single family homes. Pro-environmental attitudes, technology affinity, and concern for fuel efficiency are also well established factors that are supported by recent findings (e.g., Li et al. 2017; Axsen, Bailey, and Castro 2015; Kurani 2019; Moon 2019a; 2019b; 2019c). We refer to consumer characteristics often associated with PEV adopters as "favorable characteristics." However, PEV adopters are by no means a monolith and several studies have investigated the heterogeneity among the buyers of PEVs, particularly with attention to the buyers of PEVs at comparatively low and high price points (e.g., Hardman, Shiu, and Steinberger-Wilckens 2016). Specifically, Hardman et al. (2016) noted that buyers of high-end BEVs differed significantly from buyers of low-end BEVs in terms of gender, income, education, and age. High-end PEV buyers had higher incomes, were older, and had higher educational attainment. They were also more likely to be female than low-end adopters, but the representativeness of this finding is uncertain due to the overall very small number of women in the sample.

In early years of PEV sales, stated and revealed approval of PEVs was usually found to be higher among men than women. The gap in stated approval of PEVs between men and women has narrowed according to recent survey research (e.g., Kurani and Buch 2021), but revealed preferences studies continue to show that PEV buyers are predominantly male. Kurani (2019) found that a gender gap remains even after accounting for other socio-demographic characteristics; other preferences for environment, technology, and time; and specific knowledge of PEVs. Higher adoption rates among men than women continue to be identified in recent studies, such as Jia and Chen's (2021) finding of somewhat higher adoption of PHEVs and substantially higher adoption rates of BEVs among men.

PEV acceptance also varies across locations. Singer (2020) found differences in awareness and approval by comparing survey responses before and after PEV ride-and-drive events in the U.S. Pacific Northwest, Midwest, and Northeast, noting higher awareness and approval in the Pacific Northwest. Guerra and Daziano (2020) note that variation in acceptance also varies at a finer scale, pointing out that local features, such as the availability of parking and travel distances between destinations, vary across neighborhoods and likely have an influence on local PEV adoption rates.

While socio-demographic information tends to be easiest to collect, there is evidence that other characteristics, such as aspects of personality and psychographics, can be strongly correlated with PEV acceptance, in some cases more so than the commonly cited characteristics of gender, age, and income (e.g., Kurani 2019). Jia and Chen (2021) report that compared to ICEV owners, PEV owners in their sample were more likely to identify as "risk-taking," "environmentally conscientious," and "an early adopter [of] new technology." Similarly, Kurani (2019) found that those who express interest in PEVs are more motivated by future consequences.

Consumer perceptions of PEVs and their related infrastructure influence PEV acceptance. Kurani (2019) found that among non-PEV owners, survey respondents generally perceive an insufficiency of charging locations, charge times that are too long, and driving ranges between charge that are too short. Such perceptions, whether or not they accurately reflect the attributes of PEVs and related infrastructure, affect consumers' assessments and therefore approval of PEVs. Regarding other aspects of PEV performance and utility, Higgins et al. (2017) found evidence of low consumer knowledge, in terms of arguably inaccurate preconceptions of PEVs. Consumers in Higgins et al.'s (2017) sample described PEVs as small and under-performing as compared to ICEVs. Those interested in a minivan, pickup truck, or SUV stated that they preferred ICEVs because good performance was important to them. Those interested in a full-sized sedan or SUV stated that they preferred ICEVs because they required substantial passenger and/or cargo space that PEVs did not [yet] provide. As noted by Morton et al. (2016), it is necessary to consider consumer perceptions of PEV complexity, reliability, and safety alongside the more commonly studied aspects of range anxiety and response to purchase price premiums.

### 2.4 Consumer Segments

We use the term "consumer segment" to refer to a group of consumers who bear similarity to one another in terms of their observable and unobservable characteristics, which includes the attributes of vehicles of interest to them. Considering consumer segments can be important in the context of PEV acceptance when the defining aspects of the segment (e.g., gender or location) correlate with differences in interest in or availability of PEVs and PEV models, for example.[16] While there are many possible ways to define consumer segments, we focus primarily on just a few according to adopter status, and to body style or vehicle segment. The first aligns, arguably, with several useful frameworks such as the Diffusion of Innovation Theory (Rogers 2003) and Ajzen's Theory of Planned Behavior (1991). The second reflects the importance of body style in vehicle decision rules.

An informative way to segment potential vehicle buyers is to consider the differences between early adopters of PEVs as compared to those who have not yet adopted.[17] In addition to the characteristics PEV adopters noted in Section 2.3.1, Jung (2019b) finds parallels between typical early adopters and PEV adopters. Specifically, innovativeness is an early adopter tendency that "has significant influence on the determinants of [PEV] adoption," such as intent.

As noted in several recent studies, there is evidence that consumers tend to select from within broad vehicle categories,[18] that consumers of different vehicle categories differ from each other across demographics and other characteristics (e.g., Higgins, Mohamed, and Ferguson 2017; X. Wang, Shaw, and Mokhtarian 2022), and that PEV approval and retention likely differ across segments (e.g., Hardman, Shiu, and Steinberger-Wilckens 2016). Because vehicle body type appears to be a non-compensatory criterion for many consumers (e.g., Fujita et al. 2022), differentiating consumer segments by the body type of vehicle they are looking to purchase can reveal insights into heterogeneity in PEV acceptance. In addition to the examples provided by Higgins et al. (2017), Jia and Chen (2021) found that consumers interested in purchasing subcompact or compact cars were more interested in PEVs than those seeking to purchase larger vehicles like SUVs or vans. These findings may shift over time as manufacturers expand PEV model offerings (e.g., ACEEE 2021; 2022).

Important criteria appear to differ across consumer segments defined by vehicle body type, as noted by Higgins et al. (2017), who found that each segment defined by vehicle body style varied

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[16] One way in which to distinguish consumer segments is to consider separately those consumers who purchase new versus used vehicles, particularly as studies have noted higher likelihood of PEV approval among new vehicle purchasers (e.g., Singer 2016). Because used car sales account for more than 70 percent of total light duty vehicle sales in the U.S. in 2020, the used car market is a critical element to achieve mass adoption of PEVs. Further acknowledging that growing a used PEV market can encourage the purchase of new PEVs by increasing certainty surrounding resale value and improve a potential buyer's evaluation of PEV value (Zou, Khaloei, and Mackenzie 2020), we restate as noted previously that this review focuses on the new car market.

[17] Those who have not adopted PEVs are also sometimes called also "prospective adopters," "non-adopters," or "mainstream," "majority," "average," or "conventional" buyers.

[18] Several common ways in which vehicle types are categorized in data collection, modeling, and analysis include: body style (e.g., minivan, SUV, hatchback, pickup truck), size (e.g., compact, midsize, large), and segment (e.g., economy, luxury).

in social demographics and preferred vehicle-related attributes. Specifically, they found that respondents in the survey sample who were interested in a luxury vehicle were as likely to purchase a hybrid electric vehicle (HEV) or PHEV as an ICE vehicle, and those who were interested in a minivan were as likely to choose an HEV as an ICE vehicle.[19] Luxury and SUV customers were the least concerned about the possible disadvantages of BEVs as compared to the conventional ICE vehicles. The pickup segment showed a lower likelihood of considering PHEV and BEV. There is consumer recognition of this type of segmentation as well, as demonstrated by a Consumer Reports finding that a majority of survey respondents agreed that automakers should make PEV technology available for a variety of vehicle types (Consumer Reports 2020).[20] A variety of PEV models are increasingly becoming available, offering different size, range, performance, etc., at different price points.

## 2.5 How Do Consumers Interact with Vehicles?

To further facilitate discussion of consumer interaction with vehicles, we define the relevant aspects of vehicles for our discussion: features and attributes. Features are physical components of vehicles, such as side curtain airbags or blindspot-sensing systems; they are concrete, tangible, and can in general be measured or visually identified. Attributes derive from features and encompass broader concepts such as "safety" or "environmental performance." During the purchase process, consumer perceptions of attributes ultimately drive decisions.

PEV approval and adoption are affected by the combination of attributes and features included in marketed PEV models as they relate to the sets of attributes and features valued by consumers. Vehicle attributes and consumers' preferences for them have been the topic of a variety of studies in the U.S. and around the world. While the exact set of attributes relevant to specific consumers varies, along with the relative importance they ascribe to each (i.e., their purchase criteria and decision rules), there are a number of attributes that have been commonly identified as relevant to vehicle purchase decisions in general. These include, for example, design, performance, power, durability, safety, value, comfort, image, environment, and fuel economy (Fujita et al. 2022).[21]

Here we describe some of the key attributes relevant to vehicle purchase decisions and the vehicle features and metrics that relate to them. The attribute of affordability, sometimes referred to as "value" or "economic aspects" in previous studies (e.g., Raut, Bhasin, and Kamble 2011), is

[19] Note that this review focuses on BEVs and PHEVs. However, many studies include HEVs. To be faithful to the research, we include Higgins et al.'s (2017) HEV results here.
[20] Interestingly, when asked to design a plausible next new vehicle, 38% of California respondents designed a PHEV (21%), BEV (11%), or FCEV (6%) in a design world with electric vehicles incentives but without all-electric drive in full-size vehicles (Kurani, Caperello, and TyreeHageman 2016). Noting the differences between California (e.g., Kurani, Caperello, and TyreeHageman 2016), Canadian (e.g., Higgins, Mohamed, and Ferguson 2017), and American (e.g., Consumer Reports 2020) respondents and the timing of this study, Kurani's (2016) results are only arguably in contrast to Higgins et al. (2017) and Consumer Reports (2020) regarding body style. Instead, this may be an artifact of survey methodologies, an illustration of regional heterogeneity, evolution of preferences over time, or possibly an indication that the divide between intent and purchase (i.e., approval and adoption) is significant and perhaps under-studied.
[21] Recent reviews of attributes relevant to PEV purchase include Liao et al. (2017) and Coffman et al. (2017). Liao et al. (2017) consider attributes grouped into "financial," "technical," "infrastructure," and "policy" categories, while Coffman et al. (2017) highlight several specific "internal factors" of EVs: "vehicle ownership costs, driving range, and charging time."

an outcome of vehicle price, which is influenced by location, dealership, form of payment, government incentives, etc., and the cost of ownership; the affordability attribute is of particular importance to consumers in the context of available income and access to incentives. The attribute of safety is an outcome of such features as collision warning, automatic braking, blind spot detection and other advanced driver-assistance systems (ADAS) technologies. The attribute of performance can encompass aspects including acceleration and handling. Acceleration is itself an outcome of electric motor, engine, and related vehicle systems. Handling also derives from physical vehicle components. Of import for many current PEV adopters is a vehicle's "environmental performance," which incorporates such aspects as fuel economy, fuel type, and emissions, as well as the environmental impacts of the vehicle production (e.g., the energy and materials used to construct the vehicle). Fuel economy and range per charge are commonly discussed attributes of PEVs, with salience to environmental performance, affordability, and the ease of owning and driving a PEV.

When purchasing a vehicle, consumers engage in a complex process beginning with the recognition that they want or need a vehicle, culminating in a purchase that could result in short term or long post-purchase experience with that vehicle. The 4-A framework defined in Section 1.3 and the purchase process described in Section 2.1 consider approval, search, and alternative evaluation, where the task of matching shopping criteria to vehicle attributes and features is most salient. This effort brings together both pragmatic and intangible aspects of consumers' relationships with vehicles.

Among the more (but not perfectly) practical considerations are the tangible aspects of vehicles that have taken the form of advantages and disadvantages in the press and scientific literature. According to Graham (2021a), commonly accepted advantages of PEVs are:

- Driving performance (e.g., sporty, instantaneous torque)
- Environmental performance (or environmental potential)[22]
- Lower operating costs (i.e., energy costs)
- Lower maintenance and repair costs
- Home, workplace, and public charging (i.e., convenience in daily use)
- Less noise

Commonly noted PEV disadvantages include:

- Higher purchase cost
- Range
- Charging time
- Uncertain battery life
- Resale value

Many of these advantages and disadvantages are arguable, perceived, and acted upon differently by different consumers, or are more or less salient depending on context or circumstances (Graham 2021a). Along with the actual features and attributes of PEVs, consumer perceptions of these vehicle aspects influence PEV acceptance. For example, Morton et al. (2016) found that

[22] Graham (2021a) does not explicitly include environmental performance among advantages, though environmental performance is clearly a vehicle attribute valued by many current PEV adopters. Thus, we include it among advantages.

consumers who were concerned with the practicality of personal vehicles as a means of travel were less likely to positively view the performance, reliability, and safety of PEVs. The consumer tendency to create cognitive associations with brands (e.g., brand perceptions, brand loyalty) also has implications for several aspects of PEV acceptance. For example, consumers loyal to a particular make were more likely to know about, approve of, and purchase a PEV if their preferred manufacturer produces and markets PEVs (Morton, Anable, and Nelson 2016).

In addition to the practical considerations of selecting a vehicle, consumers place symbolic, emotive, and instrumental meanings on vehicle ownership (Morton et al. 2016). Many individuals consider what the vehicle represents within the context of their identity and the emotions elicited by driving the vehicle and envisioning themself in it, which is clearly evidenced by the general nature of vehicle advertising. This evidence extends to the scientific literature on PEV acceptance (Moon 2019b; 2019c; Kurani et al. 2018; Tal et al. 2020). For example, White and Sintov (2017) showed that certain aspects of self-identity, such as identifying as an "environmentalist" or a "social innovator," are positively correlated with intent to adopt a PEV and willingness to pay more for a PEV, controlling for other variables including vehicle-related attributes and demographics. It almost goes without saying that consumers also consider such factors as their lifestyle, social norms, and perceptions of peers. All of these factors enter into the ways in which consumers interact with vehicles in general, including PEVs.

## 2.6 How Do Consumers Interact with Systems?

Consumer acceptance of PEVs does not occur in a vacuum, but rather within the context of a number of overlapping systems, all of which have the potential to influence PEV awareness, access, approval, and adoption. In particular, we consider four types of systems: market systems, social systems, physical systems, and government systems.

### *2.6.1 Market systems*

Market systems encompass the broader economic background in which vehicle purchase decisions take place, as well as the specific markets for vehicles and vehicle fuels.

Many factors influence the ability of consumers to pay for the upfront and operating costs of vehicles, and therefore, will affect their decisions regarding whether and when to purchase a vehicle, and which to select. Especially important are macroeconomic conditions (e.g., inflation, interest rates, unemployment, wage growth or stagnation), a consumer's personal wealth and income, availability and access to credit (e.g., immediate/near-term access to capital), and the ability to recover expenses through a tax credit. In the absence of favorable macroeconomic or personal circumstances, access to vehicle purchase and approval will be constrained, especially for PEVs as long as the average purchase price of PEVs exceeds that of conventional vehicles. The lower cost of ownership achievable for many PEV consumers may make PEVs more accessible and increases PEV approval rates for some. However, the degree to which a mainstream consumer will incorporate ownership costs into their purchase decision is unknown.[23]

[23] It seems reasonable to assume that total cost of ownership will prove no more important or clear a predictor of PEV purchase than it is for ICEVs. In the context of EVs, Dumortier et al. (2015) found that the manner in which

Additionally, vehicle fuel prices respond to broader market conditions and vary geographically. Gasoline prices vary geographically and are subject to changes in global oil production and pricing. Electricity prices and charging costs also vary geographically. Rate structures are complex within and across regions, and the source of electricity generation varies geographically and by time of day. Furthermore, beyond the local retail price of electricity, PEV charging prices can be highly variable and may or may not be subsidized by the charger provider. For example, per unit electricity charging costs can be substantially higher at public charging stations compared to retail electricity costs at homes. This difference is especially notable for some consumers, such as apartment dwellers, who cannot install charging at home and could face these higher charging costs. Many PEV consumers are motivated by the environmental performance of PEVs, and others report greater interest in PEVs when electricity generation is sourced from renewable. However, the variability and complexity of electricity generation and distribution—as well as charging locations, fees, and subsidies on the whole—may create hesitancy and act as a counterweight to the reduced operating costs that many consumers could achieve through a PEV purchase.

Finally, access to and approval of PEVs for some consumers may also be constrained by the strategic decisions of manufacturers and dealers. Manufacturers sell vehicles in an industry in which the choices of incumbents are subject to the influence of new entrants, existing competitors, suppliers, and customers (Porter 1979). They undertake marketing activities to influence consumer decisions, to increase their brand's market share, or to support the sales of specific vehicle models. Strategic decisions that affect awareness, access, approval, and ultimately adoption must also be made at the dealership level, including the geographic distribution of vehicle models, dealership-specific promotions, sales targets, and sales practices.

*2.6.2 Social systems*

Consumers make vehicle purchase decisions within the context of the social systems around them. Social systems include networks of face-to-face relationships (e.g., friends and family, coworkers, and neighbors) as well as interactions through various forms of social media and indirect communication (e.g., social networking sites, common informational sources).[24] Social systems influence consumer vehicle purchase decisions through social exposure, social norms, concern for reputation, and expressed, perceived, or expected attitudes of peers. In other words, vehicles have long been a means to express one's identity, project an image, or achieve status. As noted, PEVs appear to serve the same role with regard to projecting one's environmental ethos and affinity for technology. Vehicles have also served to help consumers gain social acceptance and express conformity to group norms (e.g., Cherchi 2017).

An emerging area of inquiry delves into the power of social connectedness to enhance PEV acceptance. Via conversations between PEV and ICEV owners in California, PEV owners effectively teach non-adopters a "new symbol system" that enables non-adopters to give their attention to PEVs (i.e., see, hear, and interpret the sign of PEVs), often resulting in more

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the total cost of ownership was presented to potential buyers had implications for their interest in an EV, so consumer responsiveness to cost information is likely to vary.

[24] Consider, e.g., Adepetu et al.'s (2016) inclusion of several parameters describing social network size and influence in an agent-based model of the PEV ecosystem in San Francisco, CA.

favorable evaluations of PEVs among non-adopters (Kurani et al. 2018). In another California study focused on consumer engagement (Meckler-Pacheco and Hardman 2022), two-thirds of more than 5,000 Californians who purchased PEVs between 2017 and 2020 reported speaking to family and friends prior to purchase. In the same study, 87% of PEV buyers who recalled engaging in in-person conversations with a PEV owner prior to purchase (e.g., with friends, family, colleagues, strangers, dealers) reported that those conversations led to more favorable PEV attitudes.

*2.6.3 Physical systems*

Consumers use PEVs within the context of physical systems. These include charging infrastructure and other Electric Vehicle Supply Equipment (EVSE), such as software, communications protocols, and electrical conductors, as well as other aspects of the built environment, such as roads, sidewalks, curbs, and parking facilities. Aspects of infrastructure can be altered to facilitate PEV use, and policies relating to infrastructure have implications for PEV acceptance.

There are multiple aspects of charging infrastructure that are relevant to every stage of consumer acceptance. These include the location, (e.g., public, workplace, home, travel routes), quantity, density, and visibility of charging infrastructure, as well as factors such as accessibility, convenience, level of charging, and prices. At the national and regional level, we can easily observe that adoption and public charging co-occur (Figure 3). Whether public charging access precedes sales or sales precede charging infrastructure installations is nuanced. For example, Zambrano-Gutierrez et al. (2018) report evidence that support for charging infrastructure is an important mediating variable for PEV purchase tax incentive effectiveness. With consumer acceptance as the goal, we tend toward discussing the effect of infrastructure on consumers, rather than the other way around.

The relationship between charging infrastructure and PEV acceptance likely varies by location, possibly down to the neighborhood level. The effect also varies depending on the charging speed, the distance between the charging stations and home or work locations, and whether the consumers purchase a new or used EV (Zou, Khaloei, and Mackenzie 2020). For example, in a study of PEV adoption across counties in Virginia, availability of DC fast charging stations was found to be positively associated with PEV adoption, particularly for BEVs (Jia and Chen 2021). Extending beyond first adoption to repurchase, Tal et al. (2020) found that access to Level 2 charging at home increased the likelihood of a current PEV owner purchasing a PEV again.

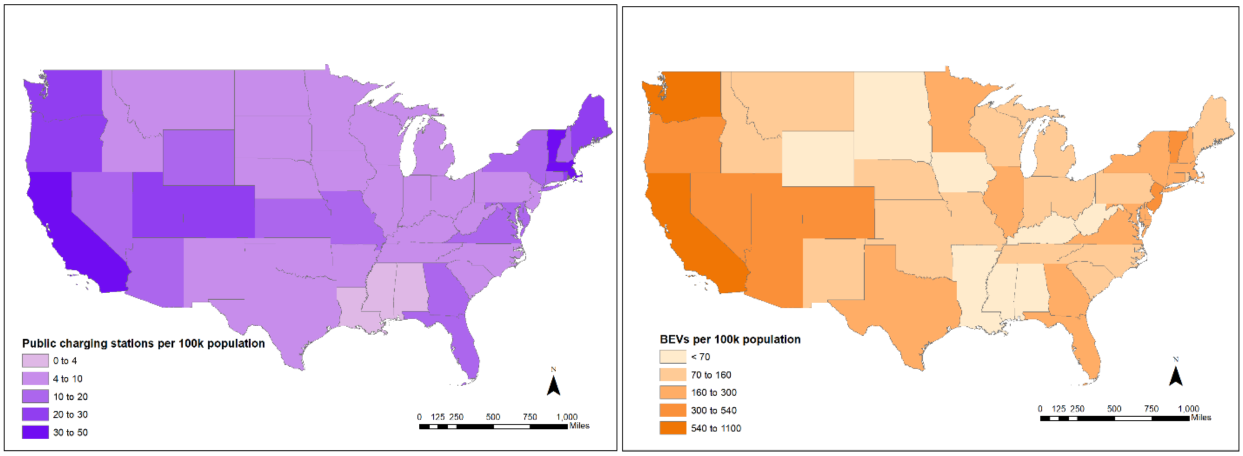


Figure 3. Public charging and BEVs per 100,000 residents in the United States
Source: (https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC), accessed 3/8/2022

Lastly, we highlight a challenge for PEV acceptance that combines aspects of the physical system (primarily charging infrastructure) and consumer characteristics. Consumers' default experience with vehicle fueling is at gas stations, so PEV charging infrastructure is often evaluated relative to this reference point.[25] For example, even in the presence of convenient, accessible charging stations and ports, consumers may nevertheless be unaware of charging infrastructure. They simply are not seeing it, they do not know what they are seeing, or they incorrectly (consciously or unconsciously) mistake charging infrastructure for something else. Such lack of awareness can cascade to deficits in perceived access and therefore to approval and adoption. Another possible implication of using gas stations as a reference point for charging behavior is the carryover of expectations regarding the frequency, duration, location, and level of engagement in fueling. These long-lived fueling habits can obscure some of the advantages of PEVs and charging, thus inhibiting approval and adoption. For example, charging can occur frequently, for long or short periods of time, and at various locations (e.g., home, work, grocery store) without anyone actually attending to the charging process, with the exception of plugging in.

*2.6.4 Government systems*

Government systems refer to the policies that affect consumers' purchase and use of vehicles, and the groups of decision-makers who set these policies. Another way to frame government systems is that the array of interventions represent ways in which governments can reduce obstacles and enhance enablers for each of the aspects of PEV acceptance. Such government interventions may occur at the federal, state, and local levels. There are a number of dimensions across which potential interventions may be broken down: timing (one time versus recurring), impact (increase or decrease PEVs' attractiveness to consumers), form (financial versus non-financial, targeted attribute (price-related versus other), and complementarity (which system[s] does the intervention interact with: market, social, or physical?).

In terms of intervention impact, many PEV-related policies aim to increase the value prospect of PEV to consumers, either by reducing the upfront cost or enhancing other aspects of PEV use.

[25] See, e.g., Zou et al. (2020), where consumer preferences for EV charging times, availability, and distances from home are evaluated in a context where a "gasoline car option is the reference alternative."

However, there exist interventions that act as disincentives to PEV purchase as well. For example, in a number of U.S. states, PEV owners must pay an additional annual fee for PEV operation, above and beyond any annual vehicle registration and use fees applied to ICEVs. A 2020 study indicated that at that time, 18 states implemented annual fees for EV registration intended to address the loss of gasoline tax revenue from PEVs, and an additional 10 states proposed such fees. In 11 cases, existing and proposed EV fees were greater than the average annual gas tax for a new vehicle based on estimated MY2025 fuel economy (Harto and Baker-Branstetter 2019).

Financial interventions can be one-time or recurring and can be offered across different levels of government.[26] Common one-time financial interventions include rebates and tax credits, which act to reduce the purchase price differential between a PEV and a similar ICEV model. Recurring financial interventions can take the form of waived fees for parking or toll road access. Non-financial interventions affect the potential value of PEVs to consumers across other vehicle or system aspects. Common examples include access to high-occupancy vehicle (HOV) lanes or special PEV parking.

Interventions generally target one or more of the previously mentioned systems (i.e., market, social, physical). Market systems can be influenced by any of the financial interventions discussed above, as well as any policies or choices that reduce manufacturer barriers to producing PEVs. Similarly, interventions that affect fuel prices (both gasoline and electricity) will affect the value proposition of PEVs. Interventions complementing physical systems include policies that encourage installation of public charging and support free or reduced cost charging or free and/or conveniently located parking for PEVs. Interventions complementing social systems often focus on the ways in which information on PEVs is disseminated and the accuracy and interpretations of this information. Examples include the provision of cost calculators to help consumers determine if a PEV is likely to be cost effective for their specific travel patterns and needs (e.g., Sanguinetti, Alston-Stepnitz, and Cimene 2020) or showcase events to allow for firsthand experience with PEVs (e.g., Singer 2020).

The remainder of this report iterates through the 4-A's—awareness, access, approval, and adoption—delving into the measures and metrics associated with each aspect, the state and dynamics of these measures, consumer proclivities, challenges and opportunities, and enablers and obstacles.

## 3. AWARENESS

PEV awareness encompasses consumer recognition of and knowledge regarding PEVs. A PEV-aware consumer recognizes a PEV when they see one and/or has a general understanding of the difference between PEVs and ICEVs. A consumer who is aware of PEVs generally knows about available makes and models, has a somewhat accurate idea of the attributes and features available on PEV models (e.g., reasonable expectation of range), and understands that the fueling of PEVs is different from that of ICEVs. PEV awareness exists along a continuum from the

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[26] We demonstrate through the scientific literature that financial incentives do influence acceptance positively. We also note that the literature explores financial incentives in detail including magnitude of behavioral effects, appropriate size of financial incentives, cost effectiveness, emissions outcomes, etc. We deemed these specific topics to be out scope as they speak more directly to policy design questions and/or environmental impacts.

broad and general (e.g., PEVs are powered by electricity rather than gas, recognition of the most common models) to the highly nuanced (e.g., accurate knowledge of range, charge time, purchase cost, and available incentives). Awareness also extends to recognition and understanding of charging infrastructure.

### 3.1 Measures & Metrics

Awareness or knowledge about PEVs is not easily observable and therefore almost exclusively measured as reported by consumers. Most studies address this topic by asking questions related to familiarity with PEVs and PEV models, PEV technology, PEV incentives, and PEV fueling and operating costs. Common framings of PEV consumer awareness include:

- Belief they have been in close proximity to a PEV (i.e., they can recognize one when they see it)
- Belief they have seen PEV chargers in the course of their regular travel activities
- Ability to name specific PEV makes and models
- Understanding of the differences between how BEV, PHEV, HEV, and ICEV are fueled
- Accurate assessment of the range and recharging time of PEVs available on the market
- Knowing someone in their social circle who owns a PEV
- Having firsthand experience with a PEV (i.e., has been the driver or passenger in one)

These measures and metrics are generally reported in terms of percentage of a survey sample or projected percentage of a population (e.g., percent of respondents who can correctly name a PEV model currently available on the market). In some cases, accuracy of knowledge of PEV metrics is reported, such as the difference between respondent's reported estimate of PEV range or charging time and the actual measures based on vehicle statistics.

### 3.2 State of Awareness

PEV awareness ranges from abstract and low to concrete and high. Considering the most basic forms of awareness, studies have tracked consumer-reported sightings of PEVs and EVSE over the course of their regular travel. Singer (2016) found that across a representative survey sample of the U.S. population, 49% of respondents reported having seen PEVs in parking lots through the course of their regular travel activities; a similar percentage was found in the 2017 update of the work as well (Singer 2017). Respondents were less likely to have reported having been in proximity to EVSE, with 18% reporting that they were aware of charging infrastructure on their regularly driven routes (Singer 2016). Reporting on pre-event awareness among participants in a series of PEV ride-and-drive events across the U.S., Singer (2020) found a similar level of recognition of PEVs over the course of everyday activities (44%). The 2020 study also reported on consumer exposure to PEVs through advertisements (36% of respondents) and basic knowledge of tax incentives for PEV purchases (34% of respondents). In 2022, Meckler and Hardman report that 50% of survey respondents in California reported awareness of PEV advertisements.

Considering a somewhat more specified level of PEV awareness and knowledge of vehicle attributes, Singer (2016) reported that 48% of respondents could name a specific PEV make/model then available on the market.[27] However, this moderate level of awareness has not been universally found across surveys; a survey conducted in California (Kurani 2019) found that three-quarters of prospective vehicle buyers could not correctly name a BEV model, and for those who could, name recognition was limited to a few makes and models (e.g., Teslas, Nissan Leaf). In the 2021 Cox Automotive Path to EV Adoption Study, "83% of respondents were aware that Tesla sells EVs; just 44% were aware that Ford does … 37% of survey respondents knew the Leaf existed, …69% of current EV shoppers were unsure if Chevrolet even makes an EV" despite the Bolt being the "third-best-selling EV in America" (Cox Automotive 2021). Respondents demonstrated a similar lack of knowledge of available PHEV models. In addition, Consumer Reports (2020) found that even though almost all respondents across a 2020 U.S. survey of knowledge about and interest in PEVs stated that they had heard of PEVs, 68% of them stated that they "don't know much" about PEVs. Furthermore, when asked why they have not yet adopted a PEV, 30% of respondents stated that they "don't know enough about EVs to buy one."

Direct experience with PEVs remains fairly uncommon as compared to more generalized and less tangible forms of awareness. In Kurani's (2019) California survey, only 2.5% of respondents expressed a self-reported "high level of familiarity" with PEVs. Respondents similarly lacked awareness about available incentives that could partially offset PEV prices (Kurani 2019). Singer (2020) reported that 26% of respondents at PEV ride-and-drive events held in 2016 had previously sat in a PEV, while 22% had a neighbor with a PEV, and only 9% currently or previously owned a PEV. These ride-and-drive events took place in three cities across the U.S. (Pacific Northwest, Midwest, Northeast); online surveys were conducted before and after the events. It should be noted that these values are likely to be higher than for the general U.S. population, as this survey sample self-selected into the events, demonstrating a base level of awareness and interest in PEVs. Across some metrics of awareness, increases have been observed over recent years. For example, based on multi-year national surveys conducted by NREL about consumer experiences and acceptance of PEVs between 2015 and 2020, the fraction of respondents who reported having sat in, having driven, or having a neighbor with a PEV has grown significantly (Singer 2020; 2016; 2017). This is salient to further stages of PEV acceptance as well, as respondents with firsthand exposure to PEVs also express higher interest in considering a PEV in their next vehicle purchase.

### 3.3 Enablers of Awareness

Consumers can gain awareness of PEVs through exposure to and interaction with the vehicles, PEV adopters, and charging infrastructure; such exposure can come from casual contact with PEVs and their infrastructure or through more deliberate interventions, such as outreach and tools. Exposure to PEVs contributes to awareness and serves to motivate later stages of acceptance. For any new technology, exposure helps to legitimize and normalize the technology in consumers' minds, and may lead to, for example, a reduction in perceived risk and uncertainty surrounding the new technology. An increase in awareness of PEV technology is positively correlated with the likelihood that a consumer will consider a PEV as an option for future purchase (e.g., Kurani, Caperello, and TyreeHageman 2016; Turrentine, Hardman, and Garas 2018).

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[27] In the 2017 update to this report, Singer found that 46% of respondents could name a specific PEV model.

Enhancing consumer exposure to PEVs often requires some proximity to the technology (physical exposure) and/or interactions with people who use the technology (social exposure). These different types of public visibility are also referred to as "peer effect" or "network effect," and studying their impact at both home and work locations is thought to be critical in estimating the spatial distribution of PEV exposure and uptake (Chakraborty, Buch, and Tal 2021). Exposure to PEVs can also occur through media (e.g., advertising, information campaigns, social media); while these avenues do not allow for tangible experience with the vehicles and their attributes, they do reinforce PEV normalization. Seeing public chargers in regularly visited locations also can raise awareness of PEVs and contribute to the normalization of PEVs and electric charging.

Exposure to PEVs varies dramatically across geographies, at both the state level and more granularly. Across regions of the United States, Singer (2020) identified higher awareness of PEVs (e.g., seeing them in parking lots, having a neighbor who owns one, firsthand experience with one) in the Pacific Northwest as compared to the Northeast and Midwest. For example, within California, DeShazo (2017) found that neighborhoods in the top quartile of income had more than 10 times the number of PEVs as neighborhoods in the bottom quartile. Within the same study, the share of single-family homes in an area was also found to correlate with the adoption of PEVs, and thus exposure of residents to PEVs on a regular basis. Another study focused on PEV adoption in California showed that one additional BEV or PHEV within a one-mile radius of a Census block group is associated with an increase in BEV sales by 0.2 percent in the block group (Chakraborty et al. 2022), reinforcing the finding that exposure is linked to PEV awareness and subsequent stages of acceptance. Proximity to PEVs in one's own neighborhood heightens a consumer's awareness of the technology, which ultimately helps lead to adoption.

More intentionally, a number of interventions provide information that can help to raise levels of PEV awareness—among those with some positive knowledge of PEVs and with consumers with little or incorrect knowledge about them. Such interventions can take the form of intentional exposure, education, and/or marketing. As discussed above, additional exposure to PEV can help to normalize the technologies for consumers, such that they will view them as viable purchase options. Education focuses on increasing and improving the accuracy of consumer knowledge regarding PEVs and EVSE. While marketing from PEV manufacturers can raise awareness of PEVs generally and the marketed models in particular, marketing focuses on brand and model differentiation, rather than helping consumers to understand differences and similarities between PEVs and ICEVs in general.

Outreach events—which provide drivers a chance to closely examine PEVs, interact with people familiar with the technology, and often take test drives—provide tangible exposure to PEVs. These events do yield positive pre- versus post-event changes in consumer attitudes toward PEV, but they also generally attract people with at least some level of knowledge about and interest in PEVs already (Singer 2020). Thus, these events are less likely to draw the attention of and engage individuals with little or no awareness of PEVs.

On the other hand, approaches such as online calculators can be used to enable greater consumer awareness of PEVs among those new to or misinformed about them. By enabling users to incorporate details about their personal driving habits and preferences, these tools give them greater insight into the ways PEVs can benefit them. They help to overcome low consumer awareness generally and low accuracy of PEV-related knowledge (e.g., battery range, cost to charge, types and functions of charging infrastructure) in particular. Even the act of using the calculator can increases awareness of PEV performance (e.g., Sanguinetti, Alston-Stepnitz, and Cimene 2020).

General marketing campaigns familiarize consumers with the range of PEV vehicles available on the market and convey basic information about their attributes. While such campaigns primarily aim to differentiate and encourage purchase of a manufacturer's models, they do increase PEV exposure of those consumers who engage with the campaign. In a survey of recent Californian PEV adopters, Meckler-Pacheco and Hardman (2022) examined common outreach methods used by PEV manufacturers to engage with potential buyers. They found that television, printed media, and social media ads were the most common advertisement methods respondents recalled seeing. They also identified differences across manufacturers in terms of consumer engagement strategies employed. For example, Tesla owners had significantly lower awareness of advertisements of electric vehicles than owners of vehicles from other manufacturing groups, and Tesla owners also reported seeking information from social media and YouTube at a significantly higher rate than non-Tesla PEV owners. These results are notable but unsurprising since Tesla does not advertise via traditional media.

Education about PEV attributes and potential consumer benefits is a public good, and thus likely to be under-provided by the market. Each PEV manufacturer has incentive to promote their own vehicle models, but not to do additional work to promote PEVs generally, which could benefit their competitors. Moving toward a scenario of greater consumer awareness of PEVs can be enabled through additional intentional PEV exposure and general education regarding PEV attributes and options available on the market, and the ways in which they compare to ICEVs.

### 3.4 Obstacles to Awareness

Obstacles are often, but not always, the flip side of enablers. In terms of PEV awareness, obstacles can stem from a range of factors: the consumer's proximity to the vehicles and their EVSE, how distinguishable the PEVs around them are from ICEVs, or how easily and quickly a consumer can obtain and assimilate new information.

For many consumers, awareness of PEVs begins with recognition of the vehicles, which leads to the question: are PEVs easy to visually identify? Various survey and interview studies ask respondents if they recall seeing or being near a PEV in the course of their regular activities. Given the current number of PEVs sold each year, it is likely that the majority of respondents have in fact been near one, but depending on the vehicle's styling and the persons' level of knowledge, they may not have distinguished it from other vehicles. While a PEV that closely resembles an ICEV may be appealing to many consumers (i.e., enable PEV approval), it may present an obstacle to PEV awareness thus inhibiting acceptance generally and the establishment of new social norms specifically. As new norms emerge regarding PEVs, average buyers are more likely to think of PEVs as normal and uncontroversial.

Across manufacturers and models, PEVs differ greatly in how they are visually distinguishable from conventional vehicles. Some are highly stylized and clearly marked with "EV" or "PHEV" labels, incorporate an "e" prefix or suffix into the model name, or otherwise highlight the electric aspect of the vehicle through a model name relating to electricity or iconography hinting at electricity.[28] Others look virtually identical to their ICEV counterparts and are only revealed to be PEVs after careful inspection. Even in cases where PEVs have some visual differentiation and signage, it is important to consider that understanding of PEVs requires knowledge and interpretation of a specific set of signs and symbols (Kurani et al. 2018). Knowledge of PEVs underpins the symbolic and emotive meanings that consumers associate with PEVs, which have been found to influence their approval and adoption (e.g., Morton, Anable, and Nelson 2016), whereby obstacles to PEV awareness may influence further stages of PEV acceptance as well.

Consumer awareness of PEVs will be affected by common cognitive factors such as attention to information, receptivity or susceptibility to information sources, and information processing ability. A lack of specific knowledge about PEVs increases the likelihood that a consumer will act on other information and impulses; under such circumstances, the opposition between vehicle shapes that look "environmentally friendly" and those that look "safe" observed by Bi et al. (2017) is likely to steer consumers away from PEVs.

## 4. ACCESS

We define PEV access as the affordable, proximal, clear, and convenient purchase and use of vehicles, charging, and PEV- and EVSE-related incentives. Access to PEVs encapsulates both physical availability and affordability of PEVs and EVSE. For an individual consumer, there are multiple dimensions to physical availability of PEVs. First, there is the issue of distance from their residence and regularly traveled routes to vehicle dealerships, as well as the variety and density of vehicle dealerships within close proximity.[29] Second, the stock of specific vehicle models, including the number and variety of PEVs, can vary substantially across dealerships. For potential buyers in areas devoid of PEVs, there is not only an absence of exposure to PEVs but also no or very few opportunities for firsthand experience with them. Third, the potential for a long waiting period before receiving a vehicle also makes PEVs less appealing to some consumers, especially if the need to acquire a new vehicle is urgent. Access to PEV infrastructure includes the presence of charging equipment at homes, workplaces, and along commonly used routes of travel, along with the affordability of charging. The affordability aspect of PEV access manifests across consumers, vehicles, and systems, and oftentimes they interplay with each other, encompassing PEV MSRPs, available incentives,[30] future savings discounting, volatility in electricity prices, charging tariffs, and PEV use fees.

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[28] We note, however, that many of these vehicle labels and iconography are not standardized and may be confusing to consumers, particularly in the case of abbreviations that could imply the use of electricity.

[29] Currently, the vast majority of new vehicle sales occur at dealerships, and pre-purchase test drives are common, particularly when a consumer is considering a vehicle with which they are unfamiliar. These tendencies may change over time, making the consumer-dealership interaction and its importance to the purchase process continuing topics of interest.

[30] Available incentives at the access stage is distinct from the awareness of incentives discussed at the awareness stage. Here access to incentives refers to eligibility for incentives and the feasibility of obtaining them. For example, the Federal tax credit only applies for those for whom their tax liability exceeds the tax credit. Some incentives require substantial and complex paperwork that some consumers may find insurmountable. Furthermore, some PEV incentives and benefits, such as HOV lane access and free parking, are irrelevant to some consumers.

## 4.1 Measures & Metrics

We categorize PEV access in terms of physical access and affordability of PEVs and EVSE. Physical access is often measured in terms of:

- counts per region (e.g., number of public charging stations or number of car dealerships in a county or state);
- distances (e.g., miles between charging stations, miles to the nearest car dealership);
- counts normalized by population (e.g., charging stations per 100,000 residents); or
- percentages of the population (e.g., percent of population with parking access near an electrical outlet at their residence).
- PEV affordability can be measured in terms of:
- dollars a consumer is willing to pay (e.g., maximum price premium above comparable ICEV, maximum willingness to pay in terms of PEV purchase price)
- price ranges for PEVs, or
- price differentials between PEVs and similar ICEV models.

Affordability can also be characterized in terms of purchase price with, for example, the vehicles below a specified price point comprising an "affordable" segment. Availability, eligibility, and sufficiency of PEV purchase incentives as well as ease of obtaining incentives also enter into the definition of access. They are measured in terms of dollar value, "yes/no" indicators, comparison against PEV prices, or incentive use rates.

## 4.2 State of Access

We consider both physical access and affordability to suitable PEVs (i.e., with attributes a consumer wants or requires, such as a particular body style, cargo space, number of seats, towing capability, etc.) and convenient EVSE (i.e., at home or work, along regular travel routes, etc.). In terms of physical availability, expanding from a handful of models in the early 2010s, Consumer Reports stated that there will be approximately 100 BEV models available on the U.S. market by model year 2025, alongside expanding options for PHEVs as well (Preston and Bartlett 2021). This upcoming cohort of PEVs includes models in vehicle body types not previously available or with few options, including pickup trucks (e.g., Ford F-150 Lightning, GMC Sierra EV), midsize to large SUVs (e.g., GMC Hummer EV, Mazda MX-30), and vans (e.g., Ford e-Transit) (Preston and Bartlett 2021).

### 4.2.1 Vehicle Availability

The number of PEVs sold has increased dramatically over the same time period, growing from under 10,000 vehicles annually in 2011 to approximately 300,000 in 2020 (Bureau of Transportation Statistics 2021). While growing, the number of PEVs sold and available for sale still represents a small share of the total U.S. LDV market: approximately 1.7% for model year 2019 and 2.2% for model year 2020. Physical access to PEVs varies geographically, with the highest number of PEVs available and sold along the West Coast (e.g., PEVs made up over 7% of LDV sales in California in 2019) ranging to under 0.5% of LDV sales in parts of the Midwest and South (e.g., 0.3% of LDV sales in Oklahoma) (evadoption 2019).[31] While metrics on vehicle sales do not perfectly reflect the availability of PEV models at dealerships, they provide a reasonable estimate that also reflects regional variability in PEV availability.

4.2.2 Infrastructure

For PEVs to be truly practical, and even convenient, consumers must have access to EVSE, either at their residence, at places of work, or at accessible public locations (e.g., shopping center or transit hub parking lots or garages). Reporting on a study of PEV use and charging habits, an Idaho National Laboratory report found that study participants used home charging for their vehicles more than 80% of the time, with the remainder coming from public or workplace charging stations (Smart and Salisbury 2015). Similarly, Tal et al. (2020) report that nearly 80% of charging occurred at home for a sample of nearly 8,000 BEV and PHEV drivers in California. Chakraborty et al. (2022) reported that about one-quarter of BEV and PHEV drivers surveyed in California had access to free workplace charging. Of note, the choice of level 1 versus level 2 charging was found to differ substantially between BEV and PHEV drivers, with BEV drivers using level 2 home charging at approximately twice the rate of PHEV drivers (Tal et al. 2020).[32] These were average findings across the whole sample. When focusing on PEV owners living in multifamily housing, use of non-home charging locations was significantly more common (Tal et al. 2020). These findings gain salience when paired with the finding of Singer (2016) that only 57% of U.S. consumers state they could park their vehicle(s) near an electric outlet at home. In a survey of residential parking and electrical access, Ge et al. (2021) found that 33% of consumers currently park near electrical access, and predicted that up to 75% of consumers could gain access to home charging through home electrical upgrades and modification to parking behaviors. Home charging alone is unlikely to meet all the needs of every consumer. Public or workplace charging also has a role to play and may be a necessity for some.[33] Charging away from home is likely to be desirable for many people, even among those who primarily charge at home. Households that are unable to access electricity near their available parking areas must charge away from home.[34]

As with the vehicles themselves, the current distribution of public charging stations across the U.S. is highly uneven, in terms of both charging stations per capita and total charging stations by state, as shown in Figure 3.[35] Charging networks have expanded over time in concert with PEV adoption, with an approximately 3.3% increase in availability nationally in the third quarter of 2021 (Brown et al. 2021); this study also noted regional variability in network expansion, with the highest observed in the Northeast at 4.9%. However, charging infrastructure remains sparse across much of the landmass of the U.S. (e.g., Idaho, Montana, Alaska, and a number of other states have fewer than 10 chargers per 100,000 residents).

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[31] Adoption in California exceeded 8% in 2020 (Kane 2021).

[32] Retention and repurchase of PEVs was also supported by installation of level 2 home charging.

[33] Building out public charging infrastructure is an objective of recent and proposed legislation, and there is research underway to estimate public infrastructure needs. Discussion of this legislation and infrastructure projections is out of the scope of this review.

[34] Currently, charging at multi-unit housing tends to be more challenging than charging at single unit, detached housing. How home charging can occur at multi-unit housing is often noted as an important area for innovation.

[35] Bellon and Lienert (2021) also provide state-level analysis of charger densities.

4.2.3 Affordability

Considered from a financial perspective, access hinges on the affordability of PEVs as compared to consumers' other transportation options, with key purchase and ownership metrics being the pricing of PEVs compared to consumers' willingness to pay for PEVs; the degree to which common interventions, such as tax credits and rebates, increase the affordability of PEVs; and operating and maintenance costs. Regarding PEV pricing, previous and current PEV models have not been readily available in very-low-price categories; prices range from $30,000 and up.[36] PEV models currently on the market and planned for release in near-term model years vary substantially in price, with the highest-priced BEV models from luxury brands over $100,000 and a few models somewhat under $30,000; many models of PEV fall into the price range of $40,000 to $60,000 depending on the brand and vehicle body type. In a study of 7,000 BEV and 6,000 PHEV owners in California, Chakraborty et al. (2022) found that respondents paid approximately $80,000 for BEVs and $40,000 for PHEVs, on average. Expectations of near-term PEV prices vary, with some predictions of price decreases, such as Jia and Chen (2021)**,** which assumes that in 2024, the average price for a new BEV sedan will be $40,000, while ICEVs and HEVs will average $22,500 and $27,500, respectively.

Regarding willingness to pay, Singer (2017) found that consumer willingness to pay for PEVs above similar ICEVs is not straightforward. The study identified a trimodal distribution with 17% of respondents willing to pay a premium for PEV over $9,000, another approximately 10% willing to pay a premium of $4,000–$5,000, and 20% unwilling to pay any premium for a PEV.[37] There was some willingness to pay between $0 and $4,000, but to a lesser extent than the highlighted price points. Within the same study, Singer (2017) found the mean willingness to pay for the next vehicle purchase to be $27,000, which is less than average PEV MSRPs, but compatible with post-incentive costs for some of the lower-priced PEV models. Importantly, the dollar figures reported in Singer (2017) very likely combine the willingness to pay estimates of new and used vehicle buyers. Willingness to pay is probably higher among consumers whose next purchase is expected to be a new vehicle.[38] We note that willingness to pay can vary across consumer groups, such as the geographical differences in PEV willingness to pay between several U.S. states and Japan explored by Tanaka et al. (2014). We also note that while willingness to pay measures are relevant to affordability and access to PEVs, willingness to pay measures also relate to PEV approval, which we discuss in Section 5.

Financial incentives intended to increase the affordability of PEVs include a federal tax credit and various state and local incentives. The vast majority of states offer some form of PEV, or EVSE incentives, in the forms of, for example, fee reductions, price rebates, tax credits, and non-financial benefits (Figure 4) (AFDC 2022b; 2022a). The value of monetary incentives varies

[36] According to Kelly Blue Book, the average price of a new car in January 2022 topped $47,000 (Tucker 2022). Kelly Blue Book also reports that the average price of an electric vehicle in October 2021 was over $56,000 compared to the average price of a vehicle which topped $46,000 (Tucker 2021).

[37] An earlier version of the study identified a similar distribution with 14% of respondents willing to pay a premium for PEV over $9,000, another approximately 15% willing to pay a premium of $4,000–$5,000, and 26% unwilling to pay any premium for a PEV (Singer 2016).

[38] For reference, the average price of a new car in 2016 was approximately $34,000 (Rosenholtz 2016). The MSRP of the 2016 Nissan Leaf S was approximately $29,000 before the Federal tax credit of up to $7,500 (Nissan Motor Corporation 2015). Also in 2016, the Tesla Model 3 was introduced with a base price of approximately $36,000 before applying the Federal tax credit (Nishimoto 2019).

substantially by state, and states also differ in whether they offer incentives in the form of a rebate or tax credit. For example, in 2021, PEV buyers in Colorado were eligible for a $4,000 state tax credit, and qualifying PEVs in Connecticut were eligible for a rebate of $5,000 (Hartman and Shields 2021). In addition, many municipalities are incentivizing PEV acceptance as are a number of utilities that generally offer small rebates, in the range of several hundred dollars, for the purchase of qualified BEVs or PHEVs.[39] Several studies demonstrate that financial incentives increase PEV sales. For example, PEV incentives (reaching a combined value of $10,000) may have increased PEV purchases by approximately 30% in California, suggesting that incentives improved PEV affordability for a number of consumers (e.g., Jenn, Springel, and Gopal 2018b). We further discuss financial incentives as an enabler of access in section 4.3 and also note that for some vehicle consumers, financial incentives are more relevant to approval than to affordability.

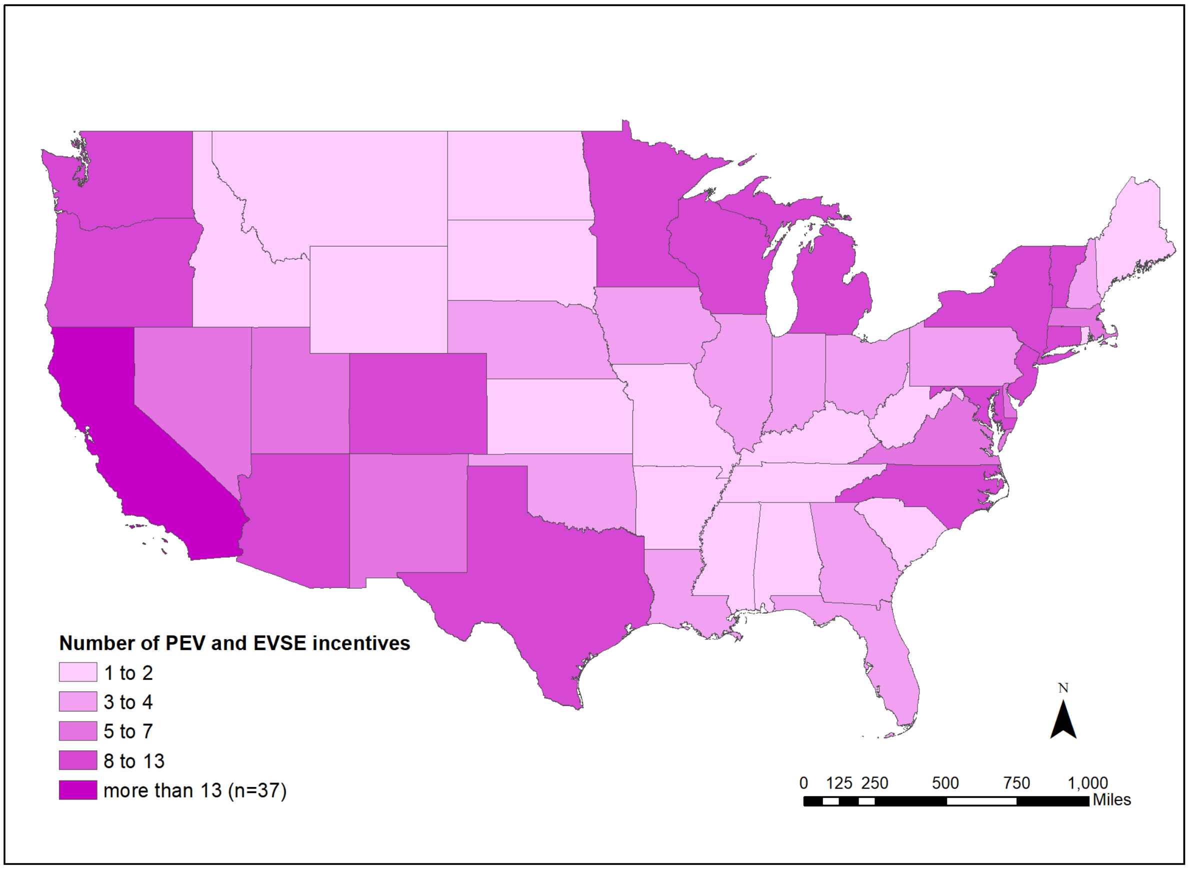


Figure 4. PEV and EVSE incentives by state.

Source: Alternative Fuels Data Center: https://afdc.energy.gov/laws.

[39] A detailed summary of state and local programs is beyond the scope of this review. However, both Bui et al. (2020) and Greschak et al. (2022) delve into PEV acceptance programs at the local level. The Alternative Fuels Data Center provides state-level information on clean transportation laws, regulations, and funding opportunities (AFDC 2022b).

### 4.3 Enablers of Access

The enablers of access to take the general form of "more of," "targeted," "tailored", and "easy." For example, more PEVs, in more body styles (e.g., hatchback, pickup truck, sedan, SUV, compact), with more utility and options (e.g., towing, cargo space, seating), in more locations, and at a variety of price points (i.e., particularly lower price points) can address the vast heterogeneity of mainstream consumers. In other words, an expansion in PEV numbers, attributes, features, and prices means increases the opportunity that a "suitable" PEV is available for a particular individual or household, which address access as we have defined it as well as approval. Greater numbers of public charging stations and ports that are visible, conveniently located, reliable, easy to use, and affordable enables access, especially among consumers who do not have electrical access where they park at home. Visible, convenient, affordable, and easy to use charging also enables awareness (e.g., "I see it"), approval (e.g., "Charging is easy"), and adoption (e.g., "I feel confident that I can charge when and where I need"). For those who can park their vehicle(s) near electrical access, a process of electrical upgrades and charging installation that is transparent, fairly priced, and easy to obtain enables access to home charging as well as the considerable convenience of charging at home.

Given the overlap among vehicle attributes and features that enable access and approval, we focus here on PEV price and two paths to greater affordability of PEVs, namely production costs and financial incentives. Advancement in battery technologies can reduce production costs, which can lead to lower PEV prices and improved affordability. Battery-related PEV costs have long been noted as an obstacle in reducing the cost of PEVs, and in turn as an obstacle for mass market PEV purchases.[40, 41] While battery costs have decreased over the past decade, they remain a concern (e.g., Hidrue et al. 2011; Adepetu and Keshav 2017).

As for incentives, while PEVs currently have a price premium relative to ICEV "equivalents," clear, timely, and easy to obtain incentives can make PEV purchase more accessible to individuals who would not have purchased a PEV otherwise. Currently, government rebates and tax credits have been the main measure to bring PEV prices more in line with ICEV alternatives, but the effectiveness of those incentives is not uniform between different consumer segments, and the amount of rebate or tax credit offered may not offset the full price premium of a PEV.[42] Even with tax credits, it is still likely that PEV purchasers must support a higher initial MSRP, a particular concern for lower-income consumers. Tax credits are of greater utility to higher-income consumers, as their tax liability generally allows them to take full advantage of the tax credit (e.g., Jia and Chen 2021). Other factors such as the knowledge of incentives can contribute to the heterogeneity in response to PEV incentive programs (Jenn, Springel, and Gopal 2018b). The cost-effectiveness of government subsidies can be improved significantly when tailored to different consumer characteristics and driving behaviors (Sheldon and Dua 2019); for example,

[40] Forbes estimated that in 2015, 29% of the cost of a Tesla was due to battery cost. Though the cost has fallen, as of 2020, they estimated that 14% of the cost of a Tesla was still due to battery cost (Forbes 2021).

[41] There are other relevant aspects of PEV battery production as well that affect PEV access, such as availability of rare earth minerals required for battery production, compatibility (or lack thereof) of batteries across vehicle manufacturers, and options for battery reuse, recycling, and replacement.

[42] Sheldon et al. (2017) report that current PHEV subsidies are approximately in line with the difference between consumer willingness to pay for PHEVs and the price gap between PHEVs and comparable ICEVs, but BEV subsidies are an order of magnitude smaller than the difference between willingness to pay and the BEV to ICEV price gap.

by setting an upper bound for rebate eligibility on vehicle price and/or household income (e.g., DeShazo, Sheldon, and Carson 2017).

For PEV technology to reach the mass market, in particular to those who do not regularly encounter it, dealerships and their marketing strategies play an important role (e.g., Yavorsky, Honka, and Chen 2020).[43] It is common for a consumer's initial firsthand experience of PEV technology to occur at a car dealership (Zarazua de Rubens, Noel, and Sovacool 2018). Findings from Matthews et al. (2017b) suggest that a salesperson's positive attitude and the availability of PEV models at the dealerships are the main success factors in increasing the likelihood of a consumer considering a PEV purchase. In short, access and enthusiasm at the point of sale are critically important to PEV acceptance and ultimately adoption. Matthews et al. (2017b) further suggest that the importance of dealerships in promoting PEV adoption could be usefully considered in policy formation.

Among the key enablers of consumer's ability to charge at home can be an attractive feature of a PEV, but whether it is or not depends on the consumer's ability (or perceived ability) to do so. If a consumer's home can support PEV charging, being able to charge a vehicle rather than having to visit a gas station is a positive feature. However, the consumer must know it is possible, be motivated to adapt their space and behavior to make it happen, and be able to arrange and afford electrical upgrades and charger installation. This can be facilitated by normalizing and simplifying the charger installation process.

However, in a future where PEVs make up a large fraction of the vehicle fleet, a smaller percentage of PEV owners would have consistent residential charging access; therefore, more high-speed public charging infrastructure is needed to complement the private charging infrastructure (Ge et al. 2021). Many direct and indirect factors influence the economics of public charging infrastructures, and they can interact with each other. For example, the deployment of public charging infrastructure goes hand in hand with battery technology advancement, as high capacity batteries at a reasonable price may reduce the need for a high density of charging infrastructure. The type of charging infrastructure influences the charging time, which in turn affects PEV consumers' driving behavior in terms of lengths of trips they choose to embark on (Zhang et al. 2018). Government support can play a critical role in promoting the development of public charging infrastructure. The recently passed Bipartisan Infrastructure Law includes up to $7.5 billion to expand infrastructure for vehicle charging and alternative fuels, with a target of 500,000 chargers by 2030, including $2.4 billion designated for infrastructure support in underserved areas, such as rural and economically disadvantaged communities (U.S. Department of Energy 2022; White House Briefing 2021).

### 4.4 Obstacles to Access

As suggested by the previous section, the two greatest obstacles to access are the physical availability of PEVs and EVSE and PEV affordability. This section details these and other obstacles more fully.

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[43] Yavorsky et al. (2020) noted that while the average number of consumer dealership visits has decreased from approximately 4.6 in 1986 to 1.3 in 2016, they find that the benefits of dealership visits are substantial.

For an individual consumer, there are multiple dimensions to physical availability of PEVs. First, there is the issue of distance from their residence and regularly traveled routes to vehicle dealerships, as well as the variety and density of vehicle dealerships within close proximity. Second, the stock of specific vehicle models, including the number and variety of PEVs, can vary substantially across the dealerships selling different manufacturers' vehicles. For potential buyers in areas devoid of PEVs, there is a barrier to firsthand experience with the vehicles, which impedes approval and adoption as well. At this time, a relatively long waiting period between ordering and receiving new vehicles, including PEVs and particularly new or popular models, is another factor that inhibits access to PEVs for some consumers (Matthews et al. 2017b). This delay in access, at least in the short term, could play out in the approval and adoption stages, making a PEV less appealing to some consumers or acting as a barrier to purchase since some consumers cannot or will not wait. Third and as mentioned earlier, the historical and arguably current lack of PEV model options in certain vehicle body types may present an obstacle to access for certain groups of consumers. Wang et al. (2022), Spurlock et al. (2019), and Fujita et al. (2022) noted that consumer groups with differing characteristics (e.g., gender, income, family structure) exhibited differences in their propensities to prefer particular vehicle body types and fuel types. Higgins et al. (2017) found differences in PEV interest across consumers who were considering different vehicle types.

Physical proximity to PEV chargers is also a key aspect of access. Several papers provide statistics regarding the importance of additional chargers or include survey questions measuring agreement with statements that there are "too few chargers" (e.g., Jia and Chen 2021). While most new PEV buyers prefer private charging units at their home, the expansion of public charging infrastructure is critical for spurring PEV adoption, by helping owners overcome concerns about range and improving access to charging stations at a large scale (Zou, Khaloei, and Mackenzie 2020). The disproportionate distribution of residential charging in single-family homes also highlights an equity issue of access. Currently the majority of PEVs are owned by residents of single-family homes, and access to residential charging remains challenging for multi-family dwelling residents and renters (Ge et al. 2021).

Regarding the affordability of PEV access, consumers tend to discount (in some cases quite highly) future value streams, including energy cost savings associated with PEVs, and this presents a challenge. A consumer may be likely to receive a net benefit from switching from an ICEV to a PEV, but if they make their purchase decision while strongly discounting future savings they may not perceive a PEV to be affordable, which will reduce their approval of PEVs (Morton, Anable, and Nelson 2016). A factor in consumer perception of the potential future savings of a PEV is the consumer's anticipated electricity prices. In a dynamic choice model that incorporates the evolution of fuel prices, Liu and Cirillo (2017) found that changes in electricity prices have a significant impact on the purchase of electric vehicles. Affordability also encompasses the challenges associated with consumers who cannot meet the PEV purchase price. High purchase price is ranked among the top barriers for PEV adoption. Adepetu and Keshav (2017) suggest that improving PEV affordability is more important than increasing battery performance. Despite advances in battery technology and reduction in battery cost, the price of PEVs is still higher than similar ICE models. Affordability in terms of the cost of charging, and differential pricing between private and public charging stations places a higher financial burden on EV owners who rely on public charging (i.e., those who do not own a house or have access to garage, driveway, or curbside parking). These affordability issues further hinder PEV access, and therefore adoption, among those groups of consumers.

Relatedly, incentives can reduce total price by many thousands of dollars and enable access. However, perceptions of incentives can inhibit the effectiveness of financial incentives. First, consumers do not necessarily view a tax credit or rebate in the same way, nor do they all equally value post-purchase price reductions (e.g., tax credit or rebate) and upfront price reduction as (e.g., Higgins et al. 2017). Additionally, Jia and Chen (2021) noted that while lower-income households can benefit from financial incentives, they may not be able to fully utilize a PEV-related tax credit given their level of tax liability. They also note that lower-income households tend to be more sensitive to purchase price than incentive amount. Furthermore, the factors used to determine a federal tax credit can be complex. This potentially contributes to uncertainty rather than confidence for a consumer trying to determine the affordability of a given PEV. For example, prior to the signing of the Inflation Reduction Act (IRA) in October 2022, the federal tax credit for a MY2022 Prius Prime PHEV was $4,502, while the credit for a MY2022 RAV4 Prime PHEV was $7,500 (Internal Revenue Service 2022). Further, the federal PEV tax credit had phased out for manufacturers whose sales had surpassed 200,000 PEVs, meaning that consumers also had to know the status of a given manufacturer relative to the threshold. The new provisions of the IRA remove the manufacturer sales threshold, but add additional requirements pertaining to the battery content, place of manufacture, household income, and MSRP. Thus, consumers must also determine the status of a given vehicle relative to these requirements, as well as know the amount and availability of the credit, assuming they know about the tax credit at all. Lastly, a patchwork of state and local financial incentives adds yet another layer of information that could leave some consumers uncertain about the ultimate amount the vehicle will cost them.

Another potential obstacle to PEV access, especially in the near term, are special EV operation fees that have emerged in some states. As of 2020, 18 states had existing annual fees for EV operation and 10 had proposed them (Harto and Baker-Branstetter 2019). These fees are intended to make up for a reduction in gas tax revenues. However, in 11 cases, existing and proposed EV fees are greater than the average annual gas tax for a new ICEV, based on MY2025 fuel economy assumption. Several states recently increased EV fees, and proposed fees are more likely than existing fees to be greater than the expected gas tax burden, leading to an increasing trend in this obstacle (Harto and Baker-Branstetter 2019). EV fees higher than expected gas tax burdens present an additional obstacle to consumers considering a PEV purchase. Plus, substantial geographic variations in EV fees, ranging from 0% to over 300% of the expected gas tax revenue of an ICEV, may reinforce existing geographic variation in PEV acceptance. The general pattern appears to be that states with high PEV adoption to date are also those with no or low EV fees either existing or proposed as of 2020.

## 5. APPROVAL

Approval occurs when PEVs are perceived, at minimum, as substitutes for other vehicles. A consumer who approves of PEVs expresses a positive assessment of PEVs, considers purchasing a PEV, reports intent to purchase a PEV, and or expresses a willingness to pay for PEVs or PEV benefits. Though clearly related, stated approval of PEVs does not automatically translate to adoption Jia and Chen (2021). Generally, it is well-known that intention and action are different and can be very far apart indeed (e.g., Ajzen 1991). Thus, it is unsurprising that approval is generally observed at substantially higher rates than PEV adoption. This suggests that approval is not only distinct from adoption, but obstacles and enablers differ as well.

## 5.1 Measures & Metrics

PEV approval is elicited primarily through surveys and interviews, often taking the form of "yes/no" answers or agreement scales regarding measures including:

- stated willingness to consider a PEV in the next vehicle purchase (e.g., Singer 2017; Consumer Reports 2020; Degirmenci and Breitner 2017 [in the context of Germany]),
- plan to purchase a PEV as their next vehicle (e.g., Carley, Siddiki, and Nicholson-Crotty 2019), or
- agreement with statements such as "PEVs are as good as gasoline fueled vehicles" (e.g, Singer 2017). The format often takes the form of "yes/no" or agreement scales.
-

Another metric of PEV approval is consumer willingness to pay (e.g., Egbue, Long, and Samaranayake 2017; Nazari, Mohammadian, and Stephens 2019; Greene et al. 2020; Sheldon, DeShazo, and Carson 2017), measured in terms of:

- the monetary amount an individual says they are willing to pay for a PEV,
- the additional amount a consumer is willing to pay for a PEV relative to a similar alternative vehicle,
- the amount they are willing to pay for PEV-associated benefits or specific attributes,
- willingness to pay for their next vehicle in general (as compared to PEV market prices), or
- willingness to pay for public PEV charging infrastructure.

## 5.2 State of Approval

Regardless of the metrics described above and the range of estimates that we discuss below, approval appears to be strong, increasing, and spreading. In a national survey conducted between 2015 and 2017, nearly half of respondents stated both PHEV and BEVs were just "as good as" or "better than" traditional gasoline vehicles. Between 2015 and 2017, Singer (2017) also found that a stable fraction of respondents stated they would consider PHEVs for their next vehicle purchase (24%). In addition, the percentage of respondents stating that BEVs are "not as good as" gas vehicles decreased over the study period, suggesting that the approval for PEVs increased (Singer 2017). Another study based on two national surveys of potential vehicle consumers in the 21 largest American cities found that the intent to purchase a PEV increased markedly between 2011 and 2017 (Carley, Siddiki, and Nicholson-Crotty 2019).[44,45]

Survey-based assessment of approval varies substantially across consumer characteristics. When investigating the variations in PEV perception by respondent segments, Singer (2017) found that

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[44] Examining intent to purchase along a 10 point scale (1 - not likely to purchase PEV to 10 - very likely to purchase PEV), Carley et al. (2019) observed an average increase in this metric of between 0.5 and 1.5. Given that 2011 values for this metric were in the range of 2 to 3, this represents a substantial increase.

[45] Though these studies are within the scope of our specified publication range, we acknowledge that the data are somewhat dated. However, there appears to be no reason to believe that approval has decline since these data were collected. Rather, with the introduction of longer range vehicles and more body styles, for example, approval has likely grown.

single-vehicle households and new vehicle purchasers have a higher likelihood of considering PEVs “as good as” or “better than” ICEVs. Singer (2017) also found that those who were aware of nearby charging stations and of PEV tax incentives were more likely to report PEV being “as good as” or “better than” traditional gasoline vehicles. Those individuals were also more likely to state that they would consider a future PEV purchase. In addition, approval of PEVs was highest among respondents younger than 35 years old and with high educational attainment (i.e., college degree). In combination with adoption statistics, the interests and actions of younger and older new vehicle consumer illustrate a notable difference between approval and adoption. Specifically, interest in and approval of PEVs tends to be higher among young respondents in stated preference studies, but current adoptions to date have concentrated in higher-income, middle-aged consumers (e.g., Jia and Chen 2021). Furthermore, respondents making less than $50,000 a year show higher approval of PHEVs when compared to other income groups, a finding that does not align with the demographics of current PEV adopters (Singer 2017). These findings suggest that interest and approval do not necessarily align with ability to pay.

Stated willingness to pay for PEVs also varies considerably. For example, willingness to pay for a PEV ranges from $0 to over $10,000 above the price of a comparable ICEV (e.g., Singer 2016), with common values between $1000 and $5000.[46] As with non-monetary expressions of approval, there are notable relationships between the characteristics of prospective buyers and the expressed willingness to pay. For example, gender, education level, ethnicity, household size, and income level were found to be influential factors for willingness to pay and BEV adoption (e.g., Nazari, Mohammadian, and Stephens 2019).[47] In a comparative study across four U.S. states (i.e., California, Texas, Michigan, and New York), Tanaka et al. (2014) found that willingness to pay for fuel cost reduction, range, emissions reductions, alternative fuel station availability, and home charging installation varied considerably across states. For example, Californians were willing to pay substantially more for fuel cost reductions than respondents from the other 3 states. Compared to the other three states, Michigan respondents were willing to pay markedly more for additional range and for emissions reductions, but Michigan respondents had notably lower willingness to pay for the availability of alternative fuel stations than respondents from other states.[48]

### 5.3 Enablers of Approval

As with awareness and access, enablers of PEV approval rely upon the characteristics of consumers, the attributes and features of vehicles, and the context in which consumers form assessments of PEVs relative to their purchase criteria. To date, PEV approval appears to have been enabled largely by strong associations between pre-existing consumer characteristics and PEV attributes such as environmental ethos and environmental performance; technology acuity and vehicle innovation; high income and high purchase price; sensitivity to operating costs and lower cost of ownership; single unit housing and home charging; multi-vehicle household and

[46] In a 2011 study, Hidrue et al. (2011) estimated that the acceptable price premium for electric vehicles ranged from $6,000 to $16,000 above gasoline vehicles. These values relative to more recent findings highlight the dynamic and diverse contexts in which these WTP values are estimated and the difficulty in comparing these quantities within and over timeframes.

[47] Nazari et al. (2019) estimated the endogenous effect of willingness to pay on BEV adoption using the 2016 California Vehicle Survey. Results showed that having higher willingness to pay for the next vehicle is positively correlated with the likelihood of adopting a BEV, with all else equal

[48] Tanaka et al. (2014) also compared U.S. and Japanese consumers.

range or charging concerns; and so on (e.g., Axsen, Bailey, and Castro 2015; Kurani 2019; Raut, Bhasin, and Kamble 2011).[49] As noted in Section 5.2, PEV approval is also enabled by the availability of incentives and charging infrastructure as well as exposure to and experience with PEVs (Singer 2017).[50] More generally, individuals with higher levels of awareness of and greater levels of access to PEVs, PEV infrastructure, and pro-PEV policies also have higher levels of PEV approval. In other words, awareness and access enable approval. Thus, the enablers of awareness and access indirectly enable approval; awareness and access are intermediaries. This appears in the scientific literature via studies where the outcome of interest is an approval variable (e.g., willingness to pay), factors related to awareness and access are measured, and the intermediaries of awareness and access are not measured. Though not parsed in the scientific literature, it seems reasonable that some enablers of awareness and access may also directly influence approval.

Importantly, PEV approval is not limited to individuals with characteristics currently correlated with PEV ownership, who have accurate information, and/or reside in locations with supportive conditions. And many consumers who possess accurate knowledge of PEVs, have characteristics common to current PEV owners, and live in locations that with supportive conditions may nevertheless have no intention to purchase a PEV.

### *5.3.1 Alignment between Attributes and Criteria*

Critical among enablers at the approval stage is the quality of PEV-related knowledge generated through exposure, advertising, and education. This knowledge, especially of the advantages and disadvantages of PEVs, underpins consumers' attitudes toward PEVs and their ultimately their purchase decisions. PEV advantages discussed in Section 2.5 include environmental performance, driving performance, ownership costs, and charging convenience. Disadvantages include vehicle purchase price, range and charging concerns, and uncertainty related to the battery.

While these are generally accepted pros and cons, how the advantages and disadvantages of PEVs manifest for individual consumers is what really matters to individual consumers. For example, consumers are often concerned with the image their vehicle projects. A vehicle that personifies concern for the environment may be desirable, as demonstrated by the environmental ethos expressed by a subset of PEV adopters and arguably projected by some PEVs (e.g., Nissan Leaf). For other PEV adopters, concrete environmental impacts may be important, but a vehicle that projects "environmental friendliness" may be undesirable. Among U.S. consumers between 2011 and 2017, Carley et al. (2019) observed, a decrease in the importance ascribed to the appearance of acting in an environmentally friendly way, along with an increase in the importance of reducing negative impact on the environment. The motivations around these aspects of PEV environmental attributes differ (e.g., environmental image and environmental performance), and the precise framing of "environment" has implications for approval among diverse consumers (Degirmenci and Breitner 2017). Similarly, depending on the consumer, PEV charging can be an extraordinary convenience or extremely inconvenient. For example, owners

[49] Previously, we have described consumer traits often associated with PEV acceptance as "favorable characteristics."
[50] Previously, we have described circumstances under which we observe higher levels of PEV acceptance as "favorable conditions." We have also described the locations where PEV adoption, charging, and pro-PEV policies co-occur as "favorable locations."

of detached home, with ready access to off street parking, who can plug in their vehicles close to where they already regularly park would likely find home charging to be an outsized benefit of PEVs relative to ICEV alternatives (Ge et al. 2021). Should any of those conditions not hold, such as regularly parking in a spot that does not have immediate access to an electrical outlet, the benefit of home charging could be masked by the efforts necessary to plug in. And clearly, if consumers have no regular, off-street parking location at their homes (e.g., many multi-unit dwellings), home charging may be infeasible.

How consumers interact with vehicles and how consumers match their vehicle criteria to vehicle attributes (discussed in depth in Section 2.5) greatly influence how PEV attributes can lead to or inhibit PEV approval. Some consumer criteria, like image, can be quite nebulous; thus, how vehicle attributes correspond to consumer criteria can be unclear. For other PEV attributes, the correspondence between PEV attributes and consumer criteria is relatively straightforward. For example, most consumers strongly weigh driving performance, value, safety, and durability in their vehicle purchase decision (Fujita et al. 2022). PEVs are known to deliver the first two of these important shopping criteria; driving performance (e.g., instantaneous torque, quiet ride) and value (e.g., lower operating costs) are well-documented enablers of PEV approval. Direct experience with PEVs and interactions with PEV adopters helps to bring the advantages of PEVs to the fore and often leads to more positive assessments of PEVs (Singer 2016; 2017; Kurani et al. 2018).

Another example of how consumers align vehicle criteria to vehicle attributes relates to body style. Many consumers fix on a body style early in their vehicle purchase decision process (Fujita et al. 2022). Early PEV models were primarily compact to midsize-sedans, which presented an obstacle to consumers who preferred different vehicle types (e.g., X. Wang, Shaw, and Mokhtarian 2022; Higgins, Mohamed, and Ferguson 2017). Consumer response to the recent increase in model variety suggests that the wider range of vehicle body styles better satisfies the criteria of a wider range of consumers (Figure 5).

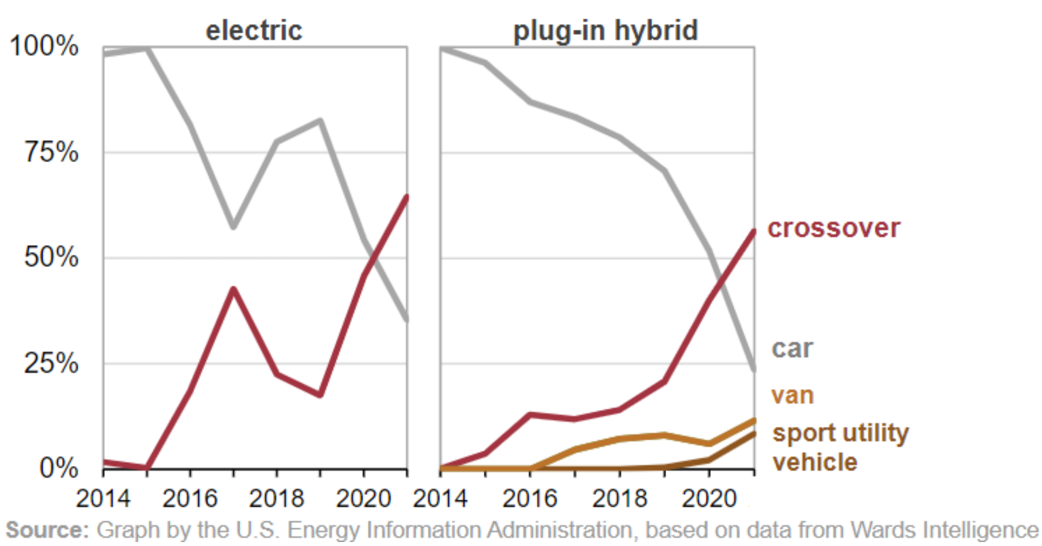


Figure 5. Sales of electrified light-duty vehicles by powertrain (2014–2021)

Source: EIA. 2022. https://www.eia.gov/todayinenergy/detail.php?id=51218

As PEVs diversify, consumers will have a better chance of identifying a PEV that fits their criteria. Increasing variety across PEV attributes (e.g., body style, range, price, towing capability) is likely to enable approval for more consumer segments. For example, BEV range has often been cited as an obstacle to PEV approval and adoption. However, the range of BEVs has grown substantially in recent years, making range less of an obstacle.[51] Manufacturers have also begun to offer different ranges as an option for a given model. Assuming these trends continue, consumers will be able to choose from many, varied PEV models that cover a rich spectrum of attributes, features, and electric driving range.

*5.3.2 Normalization of PEVs*

Other enablers of approval derive from the context (i.e., physical, economic, social, and government systems) in which consumers' attitudes toward PEV emerge and evolve. As with awareness and access, the presence of charging infrastructure and PEV-supporting policies is associated with higher levels of PEV approval(e.g., Jenn, Springel, and Gopal 2018b; N. Wang, Tang, and Pan 2019 [international comparison]).[52] Stated preference survey data in the U.S. have shown that having a denser distribution of fast charging stations in a town is correlated with higher preference for BEVs among new car buyers (Zou, Khaloei, and Mackenzie 2020), though results differ for PHEVs and BEV. When differentiating between PHEVs and BEVs, Nazari et al. (2019) found that the presence of more charging stations has a significant positive effect on the preference for PHEVs but not for BEVs. Free and low-cost charging also contribute to the intent to adopt a PEV as well as on sales (Maness and Lin 2019). In addition, the presence of discounted, free, and/or designated PEV parking spaces has also been found to increase the intent to adopt a PEV, as do non-financial interventions, such as HOV lane access.[53, 54] However, there is variability across studies in terms of the strength of these effects, with the most notable influence in urban areas where parking tends to be more expensive and scarce (Hardman 2019) and traffic congestion is more common.

Similarly, social exposure, advertising, and education shape attitudes and normalize PEVs as well as inform. However, the demands on information at the approval stage are more specific and individualized. Information provision aimed at approval, such as online cost calculators, can enable PEV approval by giving potential PEV purchasers a more accurate picture of how a PEV could fit their travel habits and into their lives than they would otherwise be able to do given their own knowledge, resources, and biases (e.g., present bias). Sanguinetti et al. (2020) reviewed the features of online cost calculators through a multipronged process, including survey of users and focus groups with potential buyers. They found that key features of effective cost calculators include minimal inputs, optional specificity to a prospective buyer's location and

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[51] In 2016 the median of a BEVs was 83.5 miles (Vehicle Technologies Office 2016). Currently, electric vehicles travel about 250 miles on a charge (U.C. Davis, n.d.); the typical driving range of a BEV ranges from 150 to 300 miles (Alternative Fuels Data Center, n.d.).

[52] In other terms, approval derives in part from what we have described as favorable conditions and favorable locations. Thus, we can expect that PEV approval will increase with an expansion of conditions and locations that support PEVs acceptance.

[53] In the context of Scandinavia, Langbroek et al. (2016) note high valuation of free parking and access to otherwise restricted traffic lanes in a stated choice experiment investigating PEV policy effectiveness.

[54] Financial and non-financial incentives are not limited to government actors. Some manufacturers have offered free DC fast charging to PEV buyers. For example, Nissan offered two years of unlimited use of DC fast charging for new Leaf buyers through 2019 and now offers a modified version of this incentive with a limit on the total cost and number of DC charger uses (EVgo Fast Charging 2022).

lifestyle, separately presenting operating cost and purchase price differences between models, and purchase price differences with and without rebate or tax credit incentives. The credibility of PEV information and its source also influences approval. Studies have identified firsthand experience with a PEV as an important factor in approval, in terms of attitude toward PEV and stated intention to purchase (Degirmenci and Breitner 2017) Interactions with PEV adopters, especially friends and family, also lends credibility PEV information (Kurani et al. 2018).

### 5.4 Obstacles to Approval

Most obstacles to PEV approval are counterpoints to the enablers discussed above. Nevertheless, some challenges for PEV adoption warrant emphasis as obstacle as well. Key obstacles to PEV approval relate to consumers' perceptions, attitudes, reference points, uncertainties, and anxieties. Key obstacles to PEV approval also relate to more pragmatic concerns, such as affordability, durability, range, and infrastructure. To illustrate, we offer several examples.

Regarding perceptions, vehicle ownership and the specifics of a personal vehicle can be tied up in a person's perception of self, status, and identity (e.g., Morton, Anable, and Nelson 2016), which may or may not serve PEV approval.[55] There is also evidence that how a consumer perceives vehicle features may contrast with its actual functionality, thus undermining PEV approval. Specifically, some consumers view certain vehicle designs as "safer" (e.g., those with long, boxy front ends) and others as "more environmentally friendly" (e.g., smooth, aerodynamic-looking designs) (Bi et al. 2017), possibly setting up a false dichotomy. Such perceptions can give some consumers a false sense that a vehicle is not safe or is not environmentally friendly based on its appearance or that a vehicle cannot be both safe and environmentally superior. Regarding attitudes, individuals can reasonably hold positive and negative assessments of PEVs simultaneously. For example, when comparing PEVs and ICEVs, the same individual could value the time, effort, and monetary savings associated with home charging while also doubting PEV safety and reliability (Morton, Anable, and Nelson 2016). Whether and why the benefits of home charging outweigh concerns about reliability and safety differ from one consumer to the next. This could make a messaging campaign, for example, effective for one group and counterproductive for another. Regarding uncertainty, some PEV attributes, such as range, charging practices, maintenance, and operating costs are unfamiliar to prospective adopters by virtue of the dominance, maturity, and inertia of ICEV markets and fueling infrastructure, but these PEV attributes are ultimately knowable in the short term. Other uncertainties, such as battery life and infrastructure availability, are unknown in the short term and may remain so for some time. Uncertainties, especially those related to range, infrastructure availability, and unfamiliar practices (e.g., charging rather than fueling) precipitate anxiety.[56]

A few of the often-cited obstacles to approval could persist. For example, range expectations could be especially sticky given human tendencies to evaluate new information or outcomes relative to established information or reference points and to prefer known or existing

[55] Morton et al. (2016) provide evidence that the more a consumer holds emotive and symbolic feelings relating vehicles to status and identity, the less likely they are to approve of PEVs. However, we note that at the time this study was conducted, only a handful of PEV models existed. The subsequent increase in the number of PEV models across all LDV classes may lead to different results.

[56] Consumer assessment of PEV attributes will be subject to such influences as incomplete information, internal and external uncertainty, and decision-making under risk, which are discussed broadly in the field of study of consumer behavior(e.g., Davies 2017; Kahneman and Tversky 1979).

circumstances and practices over something new. Currently, median ICEV range per tank of fuel is approximately 400 miles. This value serves as a natural point of comparison for BEV range when fully charged (Vehicle Technologies Office 2016). For example, in one study, 57% of respondents said they would consider purchasing a BEV with a range of 400 miles or less (Singer 2017). At the same time, most consumers' daily driving needs are far lower than this. A BEV with a shorter range would be unlikely to pose most consumers with a range limitation in the course of regular driving. Nevertheless, consumer expectations about vehicle driving range may persist.

Similarly, since their introduction and continuing to the present day, the purchase price of PEVs has exceeded the price of similar ICEVs. This so-called purchase price premium will likely remain a challenge in the short term and may be exacerbated if average prices for personal light duty vehicles continue to increase. However, the price premium is expected to diminish over time and effectively vanish, assuming battery costs continue to decline and as production volumes increase. In addition, PEVs have significant potential for much lower operating costs compared to ICEVs, given present and projected gasoline and electricity prices. Nevertheless, the purchase price premium may continue to inhibit PEV approval, at least in the short term.[57] Relatedly, the arguably premature implementation of PEV fees to make up for lost gas tax revenues (e.g., fees explored by Harto and Baker-Branstetter 2019), stands as potential obstacle to greater PEV approval.

[57] Morton et al. (2016) noted that early studies predicting PEV demand suggest that if parity in terms of technical performance and costs can be achieved, there may exist a substantial market for PEVs. However, we emphasize that definitions of "cost parity" vary, parity in terms of technical performance is somewhat ambiguous and/or subjective, and numerous other versions of parity may be also be of interest (e.g., parity in purchase price, production costs, consumers' total cost of ownership).

## 6. ADOPTION

We define adoption as the personal acquisition of a PEV via purchase or lease. It is the final stage of PEV acceptance. Within adoption, we consider the purchase of a PEV and factors that may impact future adoption decisions among potential consumers. Adoption is relatively simple to observe and measure but distinguishing approval and adoption is not. Thus, to distinguish approval from adoption we focus on the following question: If a PEV is included in a consumer's consideration set, what factors tip the balance in favor of a PEV at the time of the purchase decision? Importantly, within the scope of this report, we do not attempt to dive into the nuances of post-adoption PEV usage as compared to pre-purchase expectations or ICEV usage. We do, however, acknowledge that these behaviors represent a rich and important area of research.

### 6.1 Measures & Metrics

Unlike the previously discussed stages of PEV acceptance, adoption is relatively easy to define, observe, and measure; it is often measured in terms of counts, percentages or rates, including:

- Number of vehicles purchased or leased,
- Number of vehicle registrations,
- Number of vehicles produced,
- Percentage of new vehicle sales,
- Percentage of households with PEVs, or
- Rate of PEV sales change over time.

### 6.2 State of Adoption

The *2021 EPA Automotive Trends Report* states that 2.2 percent of model year 2020 light duty vehicles produced and offered for sale in the United States were PHEV, BEV, and fuel cell vehicles (FCVs). This was an increase from 1.7 percent in model year 2019 (U.S. Environmental Protection Agency 2021a) and projected to be 4 percent in model year 2021 (U.S. Environmental Protection Agency 2021b).[58] These production data correspond to sales and registration data cited elsewhere (e.g., Davis and Boundy 2021). Importantly, both 2020 model year production statistics and calendar year sales statistics demonstrate growth in the PEV market that occurred despite the sharp decline in conventional new light duty vehicle sales, from 15.3 million in 2019 to 12.7 million in 2020 (Figure 6). In addition, actual annual PEV market share in 2021 exceeded EPA's production estimates. PEVs actually represented 4.62% (3.38% for BEVs and 1.24% for PHEVs) of annual market share in 2021, and as of May 2022, actual PEV market share was 6.64% (5.21% for BEVs and 1.43% for PHEVs) (Alliance for Automotive Innovation 2022).

Geographic distribution of PEV sales and registrations is uneven, concentrated on the coasts and in urban areas (evadoption 2019). This is shown in Figure 7, which illustrates the density of BEV and PHEV vehicles by county across the U.S. (panel A and panel B, respectively). There is substantial variation in BEV and PHEV density across the United States and even within states with the highest rates of adoption.

[58] FCVs make up a very small portion of the market. Only 0.04 percent of all light duty AFV registrations in the United States in 2020 were hydrogen fuel cell vehicles (AFDC 2021b).

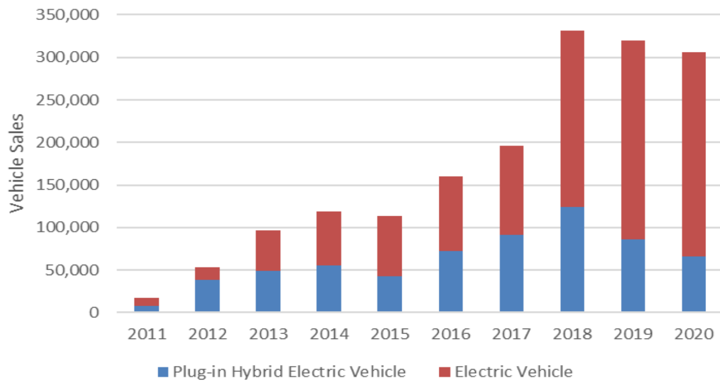

Figure 6. Light-duty vehicles sold by fuel type, PHEV and EV.

Source: U.S. Department of Energy, Energy Vehicle Technologies Office Oak Ridge National Laboratory. Transportation Energy Data Book, Edition 39, table 6.2 Available at https://tedb.ornl.gov/data/ as of May 19, 2021.

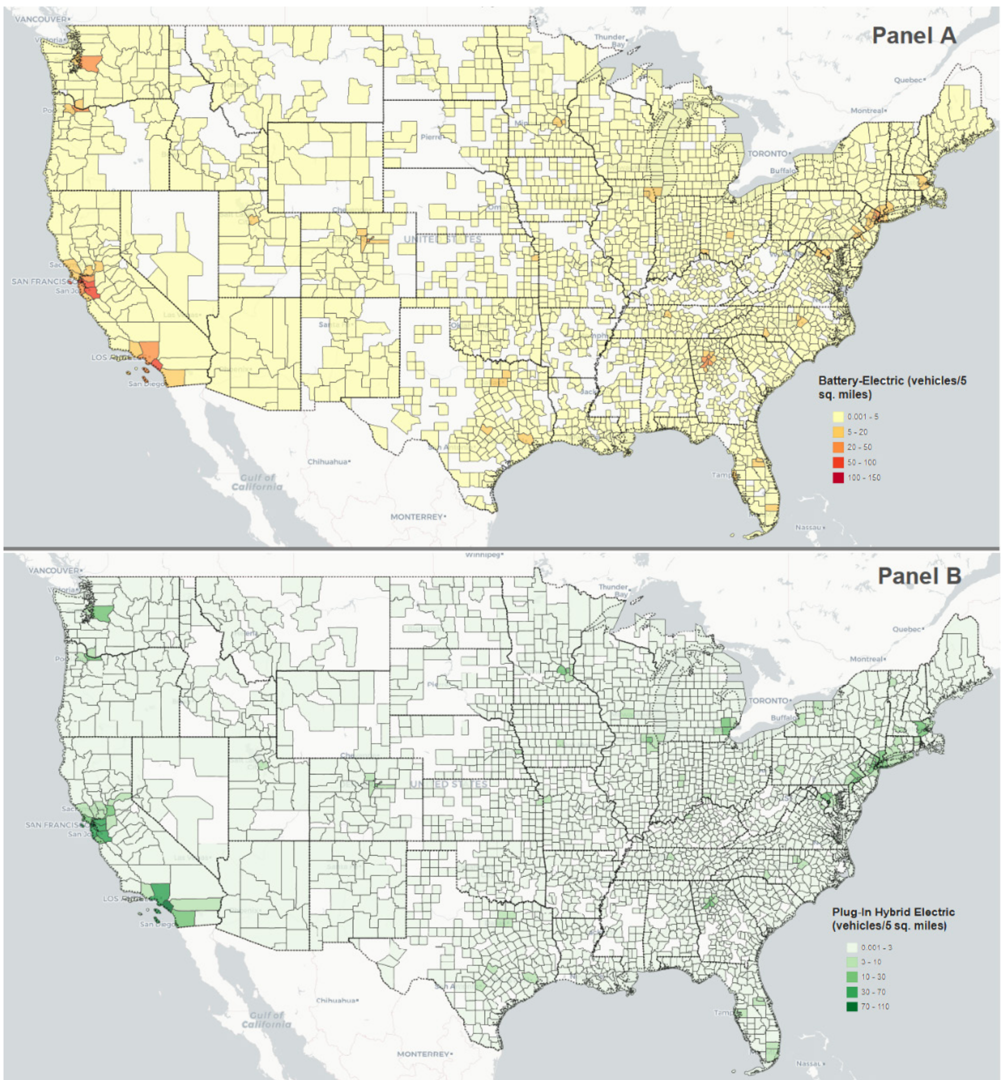

Figure 7. BEV and PHEV vehicle density by county (Source: https://maps.nrel.gov/transatlas)

## 6.3 Enablers of Adoption

Because the underlying motivation for approval and adoption overlaps and varies from one person to the next, it is impossible to fully separate adoption enablers from approval enablers. Nevertheless, it is clear that awareness of PEVs, access to PEVs, and the intent to purchase a PEV are associated with PEV adoption, and thus, enablers at every stage of the 4-A framework can influence adoption. With that in mind, here we highlight the enablers that relate specifically to PEV adoption after inclusion in the consideration set has been achieved. Keeping in mind that purchase decisions can happen anytime and anywhere, especially as the new vehicle search process becomes more and more fragmented, key enablers of adoption include financial and nonfinancial purchase incentives; PEV experience, such as test drives; effective sales practices, both in-person and online; high fuel prices and low electricity prices; and PEV vehicles with attributes and features that satisfy the consumer criteria (e.g., Fujita et al. 2022; Hardman 2019; Carley, Siddiki, and Nicholson-Crotty 2019; Narassimhan and Johnson 2018; Hardman and Tal 2016; Jenn, Springel, and Gopal 2018).

Findings suggest that incentives for PEV purchases have a generally positive effect on PEV adoption (e.g., as reviewed in Carley, Siddiki, and Nicholson-Crotty 2019). Purchase interventions may take on many forms, ranging from one-time financial incentives, such as tax credits or rebates, to recurring daily use benefits, such as access to HOV lanes, reductions or waiving of tolls, and specialized parking opportunities. [59] These enabling effects, though notable, are neither unequivocal nor uniform.

While generally regarded as enablers of acceptance, the design of a purchase incentive influences its effect on adoption rates. For example, rebates and tax credits have been found to bring PEV purchase costs more in line with consumer willingness to pay and the cost of comparable ICEVs. However, when one-time financial incentives take effect after purchase, consumers temporarily bear the full purchase price of the PEV, either in the form of a single payment or financed monthly payments. Additionally, the process of obtaining rebates and tax credits can be opaque or confusing. Furthermore, some PEV incentives may accrue to consumers already likely to purchase PEVs without an intervention. [60] Thus, financial incentives at the time of purchase may increase adoption rates while design elements simultaneously influence, and possibly diminish, their enabling effect.

Regarding recurring incentives, Hardman et al. (2019) found a range of effectiveness across U.S. studies. For example, Jenn et al. (2018) found that HOV lane access could increase PEV sales by approximately 50% while Narassimhan & Johnson (2018) found no significant relationship between HOV access and PEV sales. [61, 62] In addition, though not always or explicitly a purchase

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[59] High occupancy vehicle (HOV) lanes are generally reserved for vehicles with multiple occupants, but many states offer HOV lane access for PEVs regardless of the number of vehicle occupants. Such incentives may be available for all PEVs or for a set number of early adopters.

[60] For example, PEV buyers have tended to have higher incomes. Some studies suggest that caps on vehicle price and/or on buyer income can increase the likelihood that the recipient of a purchase incentive would not have purchased a PEV otherwise, improving the equity of PEV incentives (Linn 2022).

[61] Note that these studies each used state-level variables, covering similar time frames.

[62] We locate this discussion here because PEV sales are an “adoption” metric, but we recognize that the mechanism through which HOV lane access increases sales is likely via increased approval tied to this additional benefit of PEV ownership and use.

incentive, access to charging enables adoption. Jia and Chen (2021) found that availability of DC fast charging stations in Virginia was positively associated with PEV adoption, particularly for BEVs. Indeed, expanding charging networks and increasing charging access[63] – achieved, for example, through more public charging stations and ports, lower cost or free charging, and subsidized home charger installations – are associated with higher PEV adoption rates and greater effectiveness of tax incentives (e.g., Zou, Khaloei, and Mackenzie 2020; Zambrano-Gutiérrez et al. 2018; Neaimeh et al. 2017).

Experience with PEVs and EVSE also appear to enable PEV adoption, especially when it reveals to the consumer attributes of PEVs that they want in their new vehicle. Experience includes driving a PEV via test drives at dealerships and events as well as opportunities that emerge through social networks or at the purchase location such as driving, riding in, or charging PEVs and speaking with PEV owners. While experience is varied, we note that the majority of new vehicle consumers rely on dealerships at some point in the purchase process, and very often are at the dealership at the instance when the purchase decision occurs.[64,65]

From the PEV owner assessments conducted in Hardman et al. (2016), there is evidence that experience driving a PEV can reveal potential positive aspects of performance and lifestyle fit. In Hardman & Tal (2016), high-end BEV buyers note "high performance" and the vehicle being "fun to drive" as reasons for adoption. Retroactively, consumer experience with PEVs informs their intention to retain their vehicle and possibly purchase additional PEVs in the future, as well as creating the basis from which they share their PEV ownership experiences to others. For example, Meckler-Pacheco and Hardman (2022) found that recent PEV owners often share information with potential adopters, with 90% of their sample of California PEV owners reporting that they spoke to non-PEV owners about their vehicles. A similar percentage of respondents also reported speaking to PEV owners before deciding to adopt a PEV.

Relatedly, experience with EVSE is a key factor influencing PEV ownership, which we distinguish from initial adoption but nevertheless deem relevant. Hardman & Tal (2021) found PEV discontinuance (i.e., choosing to replace a PEV with an ICEV) was related to dissatisfaction with the convenience of charging, specifically not having level 2 charging at home. Higher rates of level 2 home charging supported intended PEV continuance. Thus, it seems likely that PEV retention is associated with the convenient and lower cost charging that level 2 home charging provides and that association may logically extend to PEV adoption among prospective PEV consumers.[66]

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[63] Access to fast charging, specifically, also increases PEV usage among PEV adopters (Neaimeh et al. 2017).
[64] Consumer dealership visits assessed through author calculations using Strategic Vision's New Vehicle Experience Survey data for calendar years 2014, 2015, and 2016.
[65] Almost 30% of new car sales were completed online in 2020, though only 2% were online before the COVID pandemic (Korn 2021). However, a portion of consumers who purchased online may have visited a dealership to view or test drive a vehicle before completing a purchase online.
[66] Hardman and Tal (2021) also found that those with fewer household vehicles were more likely to discontinue PEV ownership. Hardman et al. (2016) found that high-end PEV buyers expressed greater satisfaction across many aspects of their post-purchase experience and also expressed greater likelihood of PEV ownership continuance; of note, satisfaction was found to be generally high for PEVs of all price points.

## 6.4 Obstacles to Adoption

As with other stages of acceptance, obstacles to adoption are largely the logical inverse of enablers. Throughout this report, we have taken care to characterize factors as enablers or obstacles when they are generally presented as such in the scientific literature. While relevant to the entire report, our attention to perspective is especially important here. Our review is bounded by what researchers have studied, how they have chosen to present their findings, and where their research lies within the structure of the 4-A framework. The consequence is that the discussion that follows may appear to be unbalanced. Specifically, awareness, access, and approval of PEVs are key enablers of adoption. Thus, their absence or insufficiency can be critical obstacles to adoption. For example, limited advertising, charging deserts, confusing eligibility requirements, no PEVs available for sale locally, high PEV purchase prices, etc. are all associated with lower PEV adoption rates. However, those topics appear in Sections 3, 4, and 5, not here. In addition, the experiences of some consumers at dealerships have received a lot of attention without 1) separating the effects of awareness, access, and approval from the sales experiences and 2) acknowledging the evolution from awareness through approval likely underway among sales staff. Thus, in this section we proceed from acknowledging the importance of awareness, access, and approval to adoption (above), we address the dealership experience which has historically and primarily been presented in the literature as an obstacle, and we note what is likely a significant degree of variability in obstacles faced by U.S. consumers.

For many consumers, a dealership is the location where they first physically interact with PEVs. Thus, dealerships play a key role in adoption; a positive experience can increase adoption, while a negative or lackluster experience can hinder or stop the purchase process.[67] While the effect of dealership experience in PEV adoption has not been studied extensively, some research has identified several issues at the point of sale that can be barriers to adoption(e.g., Lunetta and Coplon-Newfield 2017; Le and Lindhardt 2019). First, salespeople may not be well-equipped with accurate information about the technology, and so are unable to communicate PEV benefits to consumers at the point of sale (e.g., Matthews et al. 2017; Le and Lindhardt 2019). This lack of knowledge extends to familiarity with relevant tax credits, rebates, or other incentive programs that could weight a consumer's decision in favor of a PEV. It has been noted that dealership staff can undergo specialized training regarding ways to address consumer hesitancy about purchasing PEVs (e.g., Carley, Siddiki, and Nicholson-Crotty 2019). Second, a "one size fits all" marketing approach ignores the heterogeneity in consumer preferences, and may lead to missed opportunities for adoption when the "full suite of consumer motivations and their different combinations" are not considered (Axsen, Bailey, and Castro 2015). Third, Cahill et al. (2014) noted that some dealers may be demotivated to sell PEVs if they are associated with lower profit margins and lower revenue streams from less service and maintenance requirements after the purchase. Fourth, as recently as 2019, it was found that a majority of dealerships across the U.S. had no PEV models available for sale, though availability in ZEV-mandate states, and California in particular, is substantially higher (Le and Lindhardt 2019). However, it is important to note that recent expansion of PEV model offerings and signaling from manufacturers and

[67] We note that while Tesla has not followed the traditional dealership model, other manufacturers, who have represented approximately half of PEV sales in recent years, do sell PEVs through dealerships alongside ICEV models (Alternative Fuels Data Center 2020).

dealers  suggest that practices may now be shifting in ways that would reduce this potential obstacle (e.g., Stanton 2021; Lowell and Huntingtion 2019).

## 7. SYNTHESIS

The objective of this review is to provide insight into PEV acceptance and how acceptance may be achieved. To that end, we define the 4-A framework for consumer acceptance, which consists of 4 components – awareness, access, approval, and adoption – intentionally choosing lay terms that speak to the state of mind of consumers and the conditions under which they progress toward PEV adoption. In short, awareness is the knowledge of and the accuracy of knowledge of PEVs. Access means that a suitable PEV is affordable, available, and convenient to purchase, use, charge, and service. Approval occurs when PEVs are perceived, at minimum, as substitutes for other vehicles. Adoption refers to the acquisition of a PEV via purchase or lease. Though not all consumers proceed through these stages in this order, awareness of, access to, and approval of PEVs are certainly preconditions for adoption, and in this order, reflect a reasonable progression from one stage to the next.

We focus on consumers as they proceed through the stages of acceptance toward their first PEV purchase, with particular emphasis on mainstream LDV consumers who comprise the majority of prospective PEV buyers. From this perspective, consumers are the foremost stakeholders and decision-makers. They are more than economic actors. Consumers' purchase decisions take place in the contexts of complex social, economic, physical, and governmental systems. Consumers influence and are influenced by the institutions, actors, and factors that comprise those systems. As such, understanding consumer acceptance necessarily requires examination of the dynamic contexts in which they acquire and assimilate information, examine their circumstances, form opinions, and ultimately make decisions

With this consumer-centered structure in mind, we address the following questions according the 4-A framework:

- What is the current state of LD PEV acceptance in the United States among personal-use consumers at each stage of acceptance?
- How do U.S. consumers move through the stages of PEV acceptance?
- What enables their progression at each stage of acceptance?
- What stands in their way at each stage of acceptance?

While PEV adoption can easily be measured via purchases, sales, and registrations, there are no generally accepted metrics for awareness, access, and approval. In addition, empirical evidence is frequently not directly observable. Given the variety of metrics, geographic diversity, sampling techniques, and methods employed in the studies reviewed, quantitative estimates of acceptance are neither absolute nor generalizable. Nevertheless, we note the amount of literature relevant to a stage or topic, the consistency of that literature, and the degree to which the literature conclusively supplies actionable recommendations for enabling PEV acceptance and for future research. In the interest of scope and readability, we aim to provide a faithful, not exhaustive, summary and synthesis of the literature and conducted an external peer review to ensure that objective was met, we engaged in a formal peer review. [68].

Overall, we believe there is reason to anticipate continued growth in PEV acceptance. However, current PEV adopters are currently concentrated in locations with pro-PEV policies and higher numbers of charging stations. Importantly, the experiences of current PEV adopters and of consumers in favorable locations do not fully reveal the mechanisms that will lead to large scale PEV adoption or the interventions that facilitate adoption among majority consumers. Capturing the mainstream comes down to the interactions of many decision-makers, in complex decision contexts, that are at various stages of a process. The process, which we represent with the 4-A framework, culminates in the first purchase of a PEV, potentially followed by future PEV purchases. First purchase of a new PEV is the focus of this literature review.

In the preceding sections, we have reported on the available research pertaining to stages of PEV acceptance for U.S. consumers, including the state of acceptance at each stage, enablers, and obstacles. We summarize those findings in Figure 8. Importantly, our review does not track all of the variability in the studies reviewed (e.g., methodology, data) in order to focus on the motivating questions as stated, to manage scope, and to speak to a multi-sector, multi-disciplinary, national audience. Additional information on cited studies is included in Appendix A, to allow interested readers to easily identify methods, sample sizes, and other features of these studies.

We now broadly address the state of the literature for PEV awareness, access, approval, and adoption. We note whether the stage is well studied, if there is a consistency in the reported findings, and whether research on the stage suggests a conclusive direction for interventions. We then assess each stage of PEV acceptance, highlight key enablers and/or obstacles, and pose questions and share general thoughts on future research. We close with general recommendations based on the literature reviewed.

## 7.1 Synthesis of Awareness

We define awareness as knowing about and having a generally correct understanding of PEVs. Overall, we found the literature on PEV awareness to be somewhat limited, largely consistent in terms of findings, and broadly conclusive in terms of policy directions. Notably, much of the work on PEV awareness comes out of a handful of research institutions. In addition, California is substantially better studied than other U.S. geographic regions. Furthermore, rural regions are particularly understudied for metrics of awareness, as awareness studies that do include multiple states often focus on urban centers.

Awareness studies derive largely from surveys and interviews. Thus, measures of awareness depend on what was asked (e.g., "have you heard of PEVs?"), the subset of the population that research subjects represent (e.g., self-selected, randomly selected, California residents), the timing of the study (e.g., year), and researchers' definitions of "awareness" or "knowledge" (e.g., affirms that they have seen a PEV, correctly names a PEV make and model). Studies also differ in the amount of information provided to respondents along with survey or interview questions,

[68]The report can be found in the Environmental Protection Agency's (EPA's) Science Inventory (https://cfpub.epa.gov/si/), Publication Number EPA-420-R-22-022.

which may influence the responses received. As a result, we observe a wide range of measures of awareness. The percent of U.S. vehicle consumers who are aware of PEVs ranges from roughly the mid-teens to the low eighties. Generalized metrics of awareness (e.g., "have you heard of PEVs?") are more thoroughly and consistently studied than metrics of specific knowledge of PEVs (e.g., "how far do you think a BEV can travel on one charge?", can accurately name PEV models). Generalized metrics are also associated with higher measures of awareness, whereas low levels of awareness are associated with studies that require correct or specific knowledge of PEVs. On balance – though without a systematic quantitative analysis of awareness results – we believe the literature supports the general conclusion that more than half of U.S. vehicle consumers know that PEVs exist and have some rudimentary understanding of how they work.

The fundamental obstacle to PEV awareness is exposure, which includes exposure to PEVs, charging infrastructure, other EVSE, incentives, and benefits. Exposure occurs through a variety of passive and active means, including advertising; education; vehicle search (i.e., part of the vehicle purchase process); on-line information, calculators, and tools; daily activities; social networks; and vehicle fleets (e.g., taxis, rental vehicles, car-sharing). Passive exposure via daily activities and social networks, for example, are especially powerful in the sense that they not only increase awareness but also normalize PEV technology. These effects are heightened in areas where PEVs already exist in higher volumes.

As the PEV market transitions from innovators and early adopters to the early majority (i.e., first wave of mainstream consumer), especially where PEV volumes are relatively low, the most effective interventions will inform and engage; target diverse consumer groups; and originate from numerous sources. First, the early majority is more diverse than current PEV adopters. Thus, a variety of interventions will have to reflect the many different types of consumers who are operating in very different contexts and at different stages of acceptance. For example, a consumer in urban California may need better information on how incentives work, while a consumer in a more rural area of the Midwest may benefit most from learning about the attributes of PEVs currently available and the locations of local charging stations. Second, different engagement strategies will also be needed for different consumer groups, whether the consumer group is defined according to geographic, demographic, and psychographic categories or by the so-called "problems" that bring consumers into the new vehicle market (e.g., vehicle failure, vehicle damage, change in needs). Third, a suite of interventions, originating from multiple sources is far more likely to promote awareness than any single intervention, type of intervention, or source. Though not exclusively, manufacturers advertise to differentiate, governments inform to educate, friends and relative tell stories, and personal vehicle owners project images or ethos aided by vehicle badging and styling. No single entity or individual is a trusted resource for everyone. No single message or method is universally engaging. While the literature suggests this general guidance, the design and effectiveness of any specific awareness intervention for any particular consumer group may well present a fruitful area of research.

Relatedly, any new information that consumers internalize becomes personal knowledge they can retrieve during the early stages of the vehicle purchase process. However, "internal search" remains one of the most elusive aspects of the consumer purchase process generally, and for PEV purchases specifically. How do consumers obtain, access, update, and process internal information about vehicles, vehicle technologies, and vehicle purchase? This question gains additional salience in the context of the rapidly changing market for PEVs. While the market may change to a suite of PEVs with attributes that better aligns with consumers' criteria, will consumers independently register these changes and incorporate them into their decision making? How can consumers be supported in assimilating this onslaught of information? Any new light shed on the ways in which consumers take in information and retrieve it during internal search will necessarily help to illuminate PEV awareness and connections between awareness, approval, and adoption.

### 7.2 Synthesis of Access

We define access in terms of physical proximity to PEVs and charging infrastructure; vehicle affordability; and eligibility for and ease of obtaining incentives and benefits associated with PEVs and PEV use. Overall, we found the literature on PEV access to be somewhat limited, largely consistent in terms of findings, and somewhat inconclusive in terms of policy directions. Unlike awareness, access is often directly observable. However, like awareness there is no single metric, and none are clearly objective. "Affordability" and "ease" are sufficiently ambiguous to support the claim on multiple, subjective measures of access. But even physical proximity is rife with measurement challenges and subjective judgements. For example, a consumer's physical access to PEVs can be measured by the number of PEVs or PEV models within a reasonable radius of home or work, the availability of a suitable PEV within that radius, the distance to a dealership, etc. Likewise, eligibility criteria can be difficult to decipher and as a result may differ "on paper" and "in practice."

As we have defined it, access is arguably the most complex of the four stages of PEV acceptance. Nevertheless, we can characterize access in the United States as low in general, higher in favorable locations, and growing. Key obstacles to access are clearly apparent. Until recently, few PEVs and few PEV models were available for sale, and PEVs were distributed primarily to states with the highest demand (e.g., ZEV states). In addition, PEVs are currently more expensive to purchase than internal combustion alternatives, and PEVs have not been available in the economy/affordable segment (e.g., less than $20,000). Because affordability can be defined in absolute or relative terms and in that sense overlaps with approval, we also note that the purchase price of PEVs currently exceeds estimates of consumer willingness-to-pay for PEVs. Similarly, the difference between the purchase price of PEVs and the purchase price of ICEVs exceeds estimates of consumers' willingness-to-pay for PEV-associated benefits (e.g., reduced operating costs, free parking, HOV lane access) and exceeds the value of most subsidies. Furthermore, in addition to sometimes (or often) complicated eligibility criteria, paperwork, and delays that can inhibit access, PEV incentives and benefits (e.g., subsidies, free parking, operating costs) vary by individual, locality, and state, making it difficult for consumers to fully assess and access the benefits of PEVs. Lastly, charging infrastructure is sparse in many locations. The merits of charging, and of home charging specifically, are not available to everyone,[69] and the challenge of charging at multi-unit housing has yet to be solved, though there is some early work on charging for people in multifamily housing that could serve as a foundation for more research in this area (e.g., Guerra and Daziano 2020)).

[69] Lack of understanding of the merits of home charging relates to awareness challenges but is also an example of how the status quo – fueling ICEVs away from home – can impede consumers' ability to envision themselves charging at home, which is typically less expensive than charging or fueling away from home. This failure, so to speak, to recognize the benefits of home charging is compounded the upfront expense associated with installation that is often characterized as "expensive" and unfamiliarity with charging installation. Because consumers are typically present biased, risk averse, and reference dependent, access to the benefits of home charging, even for those for whom it is feasible faces behavioral, as well as logistical and financial, obstacles.

In short, enablers of access are counterpoints to these obstacles. Namely, the production and distribution of more PEVs and more PEV models increases access. PEVs available at a wider diversity of price points, including lower price points, better satisfies the criteria of heterogeneous consumers. Access also increases with the expansion of one-time and daily use PEV benefits. Notably, as long as available PEVs have a price premium relative to ICEV equivalents, clear, timely, and easy to obtain incentives and benefits can close that gap for individuals who would not have purchased a PEV otherwise. [70]

In addition to increasing PEV offerings and availability, expanding and improving charging infrastructure is essential to access as well as being a critical enabler of awareness and approval. Specifically, public charging that is visible, conveniently located, easy to use, and affordable increases access while also increasing awareness (e.g., through exposure) and approval (e.g., through the salience of operating costs, alleviation of range anxiety, convenience of home charging). This is especially true for individuals who cannot charge at home. For those who can charge at home, home charging is clearly convenient, and access to level 2 home charging has been shown to support re-purchase of PEVs among PEV owners (Hardman and Tal 2021). Access to home charging can be improved if the process of electrical upgrades and charging installation is normalized, transparent, fairly priced, and easy to obtain.[71] Similarly, if appropriately addressed, PEV charging in multifamily housing could become an enabler of access for more consumers.

On a closely related topic, which we note overlaps with PEV awareness, it is not only the actual attributes of charging infrastructure that matter to PEV access (e.g., location, level, reliability, price). Consumer perceptions of charging matter as well. Even if sufficient chargers are conveniently available at affordable prices the degree to which consumers perceive charger access will shape their evaluation of PEV access overall, and thus their degree of PEV approval and decisions to adopt or not. Whether at home or away from home, there are technological and psycho-social puzzles to solve.

### 7.3 Synthesis of Approval

PEV approval begins with the assessment that PEVs are "as good as" ICEVs (e.g., viewed as a substitute for conventional vehicles, included in the consideration set). Full PEV approval is achieved with the intent to purchase. Depending on the consumer, intent is a rough equivalent for adoption or far from it. Overall, we found the literature on PEV approval to be extensive. This is perhaps the most thoroughly studied stage of PEV acceptance. Consistency of findings across studies is strong when comparing across similar consumer groups or research participants, but more variable if trying to summarize U.S. consumers as a whole. The literature does not fully coalesce around conclusive policy directions to increase consumer approval of PEVs. This is possibly due to an unspecified delineation of approval from awareness, access, and adoption as

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[70] Increasing the magnitude of financial incentives also increases access. However, large financial incentive become very costly with high levels of PEV market penetration. Instead, adaptive financial incentives could respond to market conditions, such as the decline in technology costs (e.g., battery costs) as well as the rise in PEV market share.

[71] This introduces at least two potential arguments. First, the capacity for some to charge at home could reduce congestion at public chargers. Second, the ability for some to charge at home, when others cannot, introduces significant differences in access and important equity considerations.

we have done here. Instead, the literature tends to focus on specific topics (e.g., various willingness-to-pay measures; intent to purchase; size, effect, or target population of incentives) rather than the more comprehensive questions we ask here (See Sections 1.4 and above).

Although, monetary and nonmonetary metrics and measures of approval vary widely, altogether the literature suggests that more than half of consumers believe PEVs are as good as ICEVs (e.g., Singer 2017). Importantly, this is a general assessment of vehicles and not necessarily an assessment of, for example, the convenience of charging, availability of a suitable make and model, personal assessment of affordability, evaluation of how a PEV fits one's lifestyle, or intent to purchase. Regardless of metric, approval varies according to consumer characteristics (e.g., demographics, psychographics), vehicle attributes (e.g., price, range, body style), and contextual factors (e.g., social, economic, and governmental systems). As with awareness and access, the literature shows that consumers in favorable locations (e.g., access to charging and incentives), with favorable demographics (e.g., high income, highly educated, home owners), or with favorable attitudes (e.g., technology forward, environmentally oriented) are more likely to approve of PEVs and to approve more strongly.[72] Among consumer characteristics that have been thoroughly studied, we observed variability in findings for some characteristics and consistency in others. For example, approval rates by age group have some variability across studies, but pro-environmental sentiments were consistently found to be linked to PEV approval. We also note higher approval among individuals with awareness of and access to PEVs, EVSE, and incentives. In short, awareness and access enable approval. These and other enablers of approval are rooted in the capacity of social, economic, and governmental systems to expand and enhance conditions that favor PEV acceptance (e.g., diverse PEV offerings, more charging infrastructure, more financial and non-financial incentives), increase the access to and salience of PEV benefits for more demographic groups (e.g., more education, more PEV options at more price points, greater appreciation of vehicle operating costs), and market the symbolic and emotional appeal of PEVs to more life-style segments (e.g., more and better advertising, firsthand experience).

Key obstacles to PEV approval relate to pragmatic concerns, such as vehicle price range, body style diversity, and infrastructure sufficiency. Key obstacles to PEV approval also relate to consumers' perspectives, perceptions, reference points, uncertainties, anxieties, and imaginations, which are shaped by their decision-making contexts. Consumers need to be able to envision their lives as PEV owners in a plausible, realistic context. The degree to which PEV attributes and the decision-making context help consumers establish new reference points, reduce uncertainty, quell anxiety, and stimulate imagination will determine the level and pace of PEV approval.

With improvements in charging infrastructure, PEV range, PEV options, and PEV prices, consumer belief in the competence and suitability of PEVs compared to ICEVs will likely continue to evolve toward intent to purchase. Likewise, the willingness-to-pay for PEVs and PEV prices will likely converge as more diverse PEV offerings and technological advancements provide more utility to more consumer segments. We cannot conclude, however, that this trajectory is set. There appears to be general consensus in the literature that consumer

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[72] Note that we use the word "favorable" to describe locations where PEV adoption, charging infrastructure, and pro-PEV policies co-occur. We also use the word "favorable" to describe the demographic and psychographic characteristics associated with current PEV adopters.

heterogeneity is a key research area. As the PEV-adopting population shifts from the early adopters into mass market adopters, there will necessarily be shifts in the predominant characteristics of adopters and likely adopters. Nevertheless, we expect that further study of the characteristics of consumers who do and do not approve of PEVs and the conditions under which they do and do not approve will remain valuable in crafting policies and other interventions as the PEV market changes in the coming years.

Key interventions for approval shape positive attitudes and the conditions under which new vehicle consumers evaluate vehicle options. Interventions that directly target approval surmount concerns (e.g., "where will I charge my vehicle?", "can I afford a PEV?"), build confidence (e.g., "will a PEV suit my lifestyle?"), normalize PEV ownership, convey PEV advantages (e.g., save on operating costs, convenient home charging, driving performance, environmental performance), and help consumers to internalize the benefits that PEVs provide. As a result, we conclude that personal interactions and firsthand experience with PEVs are most effective in shaping positive attitudes toward PEVs (e.g., achieved, for example, via social networks, ride-and-drive events, dealerships). Indeed, the positive experiences of current PEV drivers can positively influence potential adopters when opportunities to communicate occur. Current PEV drivers state that it is common for them to communicate with potential adopters about their vehicles. Thus, interventions that amplify those personal interactions and experiences increases PEV approval. Furthermore, because awareness and access are enablers of approval, interventions that support awareness and access also directly and indirectly enable approval (e.g., advertising, education, expanding charging infrastructure, financial incentives). These actions create the social, financial, and physical conditions that make a PEV an easily viable vehicle choice (e.g., "my friends and family admire my choice", "the purchase price and operating costs fit my budget", "I can charge my vehicle with ease").

### 7.4 Synthesis of Adoption

PEV adoption is the acquisition of a PEV via purchase or lease. Metrics for adoption include new vehicle sales, purchases, registrations, and production (i.e., as a proxy for sales) measured as counts and percentages. In this review, we have focused on the process leading to first purchase of PEVs, though clearly second and subsequent acquisition of PEVs will become increasingly important. Studies of adoption benefit from adoption being directly observable. However, a challenge for adoption studies is distinguishing factors that influence adoption separate from approval, access, and awareness. Another challenge in assessing what tips the balance in favor of a PEV adoption when available research subjects consist of very different subgroups, namely current PEV adopters (i.e., innovators and early adopters) and non-adopters (i.e., mainstream, mass market, majority consumers). With these challenges in mind, we characterize the literature on PEV adoption to be somewhat limited, somewhat consistent in terms of findings, and somewhat conclusive in terms of research and policy directions.

From the scientific literature and available data, we observe that PEV adoption is on the rise. In 2020, PEVs represented 2.2% of annual new vehicle sales in 2020, 4.62% in 2021, and 6.64% as of May 2022. This is a notable increase in general but especially in light of the lower number of new vehicle sales in 2020 that persisted in 2021. However, PEV adoption across the United States is currently concentrated in locations such as the coasts, ZEV states, and urban areas. As with awareness, access, and approval, locations with higher adoption rates appear to co-occur with two other traits, the availability of state and local PEV incentives and public charging. We refer to these as "favorable locations" due to the co-occurrence of relatively high PEV adoption rates, state and local incentives, and charging infrastructure. Just as certain areas of the country show higher levels of PEV adoption, specific demographic groups also dominate. Compared to light duty vehicle consumers, the PEV adopters are more likely to be male, have high incomes, high levels of education, own their homes, and live in single family dwellings. Furthermore, specific segments of the LDV market account for much of the PEV uptake thus far. Those segments include individuals with a strong affinity for technology, the environment, or vehicle operating costs. Locations, demographics, and attitudes that are currently associated with PEV adoption are also associated with PEV acceptance more generally.

Among adoption enablers, we observe four clear enablers in addition to awareness, access, and approval. Namely, firsthand experience with PEVs, financial and non-financial incentives, high fuel prices and low electricity prices, and good sales practices. As with approval, advantageous attributes of PEVs – such as driving performance, cost of ownership, and charging convenience – motivate adoption. Thus, experience with PEVs via, for example, dealership test drives and social networks not only gets PEVs into consumers' consideration sets but supports consumers in making the leap from consideration to purchase. In addition, PEV buyers often retrospectively identify incentives (e.g., subsidies, rebates, and tax credits) and use benefits (e.g., high occupancy vehicle lane access in California) as key enablers in their purchase. Furthermore, studies often find that high fuel prices, and to a lesser extent, low electricity prices are associated with PEV adoption.[73] Finally, there is a small but coherent body of literature demonstrating the importance of sales practices at the time of purchase, particularly at dealerships where most sales currently take place.

In contrast, PEV adoption can be curtailed by real or perceived disadvantages associated with PEVs. These obstacles include purchase price, range and charging concerns, confidence in PEV/battery technology, and general uncertainty. These obstacles most directly inhibit earlier stages of acceptance but may manifest at the time of purchase as lingering doubt. Education, advertising, social exposure, and firsthand experience could preempt that doubt, and appropriate sales practices could overcome it. Here, we emphasize the pivotal nature of the purchase experience. Yet the role of the vehicle purchase experience in the United States[74] is understudied.[75] In the absence of that research, the quality of the PEV purchase experience and its impact on PEV adoption will continue to largely be informed by a debate that has been playing out in the popular media (e.g., press releases, online information, newsletters) and in NGO reports (e.g., Le and Lindhardt 2019; Lunetta and Coplon-Newfield 2017). We also emphasize the importance of financial incentives. While awareness of and access to financial incentives supports PEV approval, the effort involved in obtaining the incentive, the timing of receiving it, the amount of the incentive, and any uncertainty associated with the effort, timing,

[73] It is not understood why this difference exists, though there are hypotheses. Firstly, electricity prices are generally lower that fuel prices, electricity prices are possibly less salient to consumers, and loss aversion may be at work (i.e., increased fuel prices evoke losses which are have an outsized effect on consumers relative to gains associated lower electricity).

[74] A more substantial amount of research has been conducted outside of the U.S., such as dealerships in Canada and Nordic countries (e.g., Zarazua De Rubens, Noel, and Sovacool 2018). U.S. decision-making would benefit from additional U.S.-specific research, as it is uncertain to what extent the findings of such studies can be applied to U.S. PEV adoption.

[75] Cahill (2015) is likely the most comprehensive academic research on dealerships. Given the rapid changes in the new vehicle market, this information may be outdated. More recent research is need.

or amount of the incentive could thwart an intended PEV purchase. For example, contrast "cash-on-the-hood" (i.e., a rebate received at the time of sale) with a tax credit that is tied to the nature of the vehicle and an individual's tax liability. The former is low effort, immediate, and certain at the time of purchase. The latter arguably is not. Efforts to better understand the impacts of incentive amounts, timing, effort, and certainty and inform effective implementation of incentives among diverse consumers is important research. Lastly, we emphasize other monetizable incentives (e.g., free parking, toll road access, free charging) and non-monetary incentives (e.g., HOV lane access, prime parking). Much of the existing research into these incentives derives from urban locations and reflects urban conditions (e.g., long commutes, scarce or expensive parking, congested roadways). As a result, those types of incentives have been shown to be effective in urban environments, but their effectiveness in other contexts is not clear. What types of non-monetary incentives could be effective elsewhere? How will they be implemented? And by whom?

| | | Awareness | Access | Approval | Adoption |
|---|---|---|---|---|---|
| | DEFINITION: Consumer ... | has generally correct PEV knowledge | has convenient access to PEV & EVSE | perceives PEV, minimally, as substitute | acquires (buy or lease) PEV |
| STATE OF ACCEPTANCE | • Metrics | • Know about, name, recognize vehicles and chargers; recognize PEV&EVSE-relevant signs and symbols; accurate knowledge | • Physical/geographic availability vehicles, charging, and other EVSE (e.g., #, proximity, and density of vehicles, vehicle models, body styles, charging sites, charging ports); affordability, purchase price, and ownership costs | • Stated preferences, such as: "consider purchase", "at least as good as", purchase intent; WTP > purchase price; WTP > TOC; included in consideration set or evoked set | • Sales, purchases, registrations, and production (as a proxy) |
| | • State of ... | • 50 - 80% Varies by metric. Geographically & socio-economically uneven. | • Geographically & socio-economically uneven access to vehicles and EVSE | • >50% Varies by metric. Geographically & socio-economically uneven | • ~4-5% of new vehicle sales in 2021<br>• Geographically & socio-economically uneven |
| | • Dynamics | • Stable/Stagnant | • More vehicle models, body style, and geographic distribution expected<br>• More public EVSE expected | • Increasing/Growing | • Projections vary widely |
| ENABLERS (OBSTACLES) | • Consumer<br>• Process<br>• Criteria<br>• Characteristics<br>• Segments | • Favorable location (i.e., access to public charging, incentives or benefits, & PEVs)<br>• Susceptible/Receptivity to information<br>• Processing ability | • Favorable location<br>• High income<br>• Home charging capable<br>• Workplace charging | • Favorable location<br>• Favorable demographics, such as high income, educated, homeowner, single family home<br>• Favorable attitudes, image and identity associations<br>• Charging convenience & concerns<br>• PEV experience<br>• Correct knowledge of PEVs & EVSE<br>• PEV & EVSE confidence | • Consumer Awareness<br>• Consumer Access<br>• Consumer Approval<br>• PEV experience |
| | • Vehicle<br>• Features<br>• Attributes<br>• Availability | • High PEV numbers/percentages<br>• High PEV & EVSE visibility | • Purchase price, TCO<br>• Supply & distribution of vehicles & models | • Price, TCO, range, body style, segment<br>• PEV driving performance<br>• Environmental Performance<br>• State of the art/Innovative | • Test drive |
| | • System<br>• Market<br>• Social<br>• Physical<br>• Government | • Exposure to PEVs, infrastructure, other EVSE, and incentives and benefits<br>• Targeted & abundant advertising<br>• Targeted & abundant education | • Availability reliable, convenient, low-cost charging<br>• Ease of obtaining incentives<br>• Eligibility for incentives | • Exposure to PEVs & EVSE<br>• Reliable, convenient, low-cost charging<br>• Financial/non-financial incentives/benefits | • Financial/Non-financial incentives/benefits<br>• Sales Practices<br>• High fuel prices<br>• Low electricity prices |

Figure 8. Summary of state of acceptance and enablers (obstacles)

## 7.5 Moving Forward

In general, but not always, policy recommendations from the scientific literature are not specific, which is reflected in our synthesis above. Among those general policy recommendations is the assertion that local level action will most effectively enable PEV acceptance and remove obstacles, especially if interventions reflect the characteristics of the local population (e.g., density, socio-demographics, stage of acceptance) and the opportunities and challenges specific to that population (e.g., multi-unit housing, low income, PEV density, climate, culture). However, most local entities cannot develop, implement, evaluate, and fund PEV acceptance programs independently. National, regional, and state level actions have a significant role to play. Both local level action and the interplay of local, state, regional, and national level actions were out of the scope of this literature review. Nevertheless, we emphasize that these are areas of important research and action moving forward. We also highlight that we refer only to local entities, not specifically local governments. There are a variety of actors with agency at the local level, including utilities, municipalities, dealerships, and PEV enthusiasts. There are also a variety of state, regional, national, and international actors with the capacity to influence local level PEV programs, such as manufacturers, governments, researchers, and non-governmental organizations.

To date, PEV adopters represent a relatively narrow band of consumer characteristics. For example, current PEV adopters are more likely than the average new car buyer to have a high income, have a high level of education, own their home, or live in detached homes. PEV adopters have also been more likely than average new car buyers to be environmentally oriented, technology forward, or cognizant of vehicle operating costs. In addition, the geographic distribution of PEV adopters has been uneven and concentrated in coastal and urban areas. For the diffusion of PEVs to proceed, PEV adopter characteristics must shift to better reflect mainstream buyers. Given automakers' announcements of plans to significantly expand PEV production, we expect many new PEVs to enter the new vehicle market in the near-future and over the coming years. In response to the introduction of more diverse PEVs, the characteristics of PEV adopters is also expected to evolve to more closely align with mainstream new vehicle consumers.

Indeed, it seems quite possible that conditions for the next wave of potential PEV adopters (i.e., the first wave of mainstream buyers also known as the early majority) are already amenable to PEV adoption (e.g., PEVs are affordable for this subset with or without incentives, public charging is accessible, home or work charging is feasible). The “heavy lift” lies in increasing awareness and approval, leveraging the advantages of PEVs to shift attitudes, and supporting an easy transition away from fueling to charging and away from fueling at commercial sites to charging at home and at work. Consumer demand will pull more support services like home electrical upgrades, home charger installations, and charging station maintenance into the market. However, the force and momentum of the transition to the early majority will rely on other sources, such as manufacturers, dealers, governments, non-governmental organizations, municipalities, utilities, and PEV enthusiasts.

Before we conclude, the authors of this review offer our own suggestions based on the literature regarding research and interventions. First, in the course of our review, we noted PEV policies that are at odds with each other. For example, there are locations with both sizable purchase incentives and sizable annual operation fees for PEVs (i.e., fees above and beyond those for ICEVs). The first encourages PEV purchase, and the other may suppress it. In contrast, a suite of PEV interventions that aligns with objectives and is directionally consistent will be more effective. For example, PEV daily use benefits, convenient charging station location and density, and reliable charging station maintenance all support PEV use and therefore PEV acceptance. Second, there already are and likely will continue to be opportunities for synergies with other policy realms. For example, synergies between solar, energy storage, and vehicle charging could be codified. Building codes that inadvertently present barriers to electrical access in the places where people regularly park could be revised. Identifying situations like these and responding accordingly could create as yet unforeseen opportunities to support PEV acceptance.

Third, vehicle consumers are clearly making high stakes purchase decisions in complex social, economic, physical, and governmental environments. Indeed, this is true of all the actors considered here – whether institutions, households, or individuals. Research and experience tell us that these decision makers are heterogeneous in ways that caution against generalizing from one group to another or to all. Going forward, research and intervention will have to continue to attend to consumer differences and their vastly different decision contexts. Fourth, researchers and practitioners should work together; research can inform interventions, and interventions can inform research.

Lastly, many enablers of PEV acceptance are specific to specific stages of acceptance, while many others cross the boundary of PEV acceptance stages. In the first case, the objective, measures, and metrics for research and interventions should be clearly defined and aligned with the stage of interest. For example, an informational campaign intended to increase awareness of incentives should reach prospective consumers early in the vehicle search process (i.e., before or during problem recognition and search) and should measure knowledge of incentives (e.g., not sales) before and after the intervention. In the second case, research and interventions can leverage design elements tailored to each stage. For example, a new charging station installation presents opportunities to address every stage of acceptance. Plans for new charging station installation could include high visibility signage and location (i.e., exposure for building awareness and perceived access), and/or a "grand opening" event that includes personal instruction on charger use and costs (i.e., education that supports access, approval, and adoption). The event and station signage could also include communication regarding charger reliability statistics and/or maintenance plans (i.e., information that builds confidence and contributes to approval and adoption). In summary, it would be important to align goals and actions, look for synergies across policy realms, tailor efforts to the target population, work together, and design and measure to reach intermediate and ultimate objectives.

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## APPENDIX A. DATA AND METHOD DESCRIPTIONS FOR CITED LITERATURE

In this appendix, we provide additional information about the studies cited in this report. We include the methods, as self-described within each paper, data type (e.g., sales data, survey - stated preference), sample frame (i.e., the particular population to which the study relates), sample size, data vintage, and dynamic elements. We note that this table includes fewer entries than our full list of references; we here include only studies with attributes that fit the table format, and exclude, e.g., websites, news reports, and papers predominately about theories.

| Citation | Methods | Data Type | Sample Frame | Sample size/ description | Data vintage | Dynamic elements (Panel/Cross-sectional/Projection) |
|---|---|---|---|---|---|---|
| Adepetu & Keshav (2017) | agent-based model | survey - stated vehicle and travel requirements | Los Angeles, California | n=42,500 | 2010–2012 | cross-section, used for projection/simulation |
| Archsmith et al. (2021) | probit model, forecasting EV demand | survey - revealed purchase, stated preferences for attributes | U.S. (nationally representative) | n=474,274 | 2017-2018 | cross-section |
| Axsen et al. (2015) | latent-class analysis of discrete choice experiment data | survey - stated choice experiment | Canada (new vehicle buyers) | n=1,754 | 2013 | cross-section |
| Bi et al. (2017) | correlation; ANOVA | survey - stated preferences, perceptions | U.S. (online survey - representativeness uncertain) | n=204 | 2009, 2016 | cross-section, time series |
| Brown et al. (2021) | descriptive statistics | automated collection from APIs, news releases | U.S. & Canada | n = 127,000 [EVSE] | 2020 | cross-section, time series |
| Brückmann et al. (2021) | generalized linear mixed-effects logit choice model | survey - revealed purchase, stated preferences | Switzerland | n = 5,325 | 2018 | cross-section |
| Bui et al. (2020) | descriptive statistics | sales data | U.S. | na | 2019, 2010-2019 | time series |
| Cahill et al. (2014) | descriptive statistics | survey - purchase experience satisfaction; survey - PEV purchase experience; interviews - car dealers and OEMs | California | n = 29,040; n= 7,000; n = 43 | 2013 | cross-section |
| Carley et al. (2019) | descriptive statistics; R-squared decomposition | survey - stated preferences, perceptions | U.S. (large cities) | n = 4,421 | 2011; 2017 | longitudinal |

| Citation | Methods | Data Type | Sample Frame | Sample size/ description | Data vintage | Dynamic elements |
|---|---|---|---|---|---|---|
| Chakraborty et al. (2021) | net present value | total cost of ownership estimate | California | na | 2020-2045 | projection |
| Chakraborty et al. (2022) | spatial analysis; Poisson count models | registration data by census block group | California | n = 20,560 | 2014-2016 | longitudinal |
| Chakraborty et al. (2022) | net present value | survey - costs, infrastructure availability | California | n = 13,549 | 2015-2018 | time series |
| Cherchi (2017) | hybrid choice logit model | survey - stated choice experiment | Denmark | n = 2,656 | 2014-2015 | cross-section |
| Degirmenchi & Breitner (2017) | structural equation modeling (SEM) | interview - stated preferences, purchase intentions; survey = stated preferences, purchase intentions | Germany | n = 40; n = 167 | 2015 | cross-section |
| Dehdashti et al. (2018) | latent class model | survey - vehicle purchase process | Northeast U.S. | n = 3473 | 1990, 2000, 2002, 2004, 2006, 2010, 2012 | time series |
| DeShazo et al. (2017) | logit choice model | survey - stated preferences | California | n = 1,261 | 2013 | cross-section |
| DeShazo (2017) | varied (regression, descriptive statistics, etc.) | various: registrations, Census, geospatial, etc. | California | various | various | various |
| Dumortier et al. (2015) | rank-ordered logit model | survey - stated preferences | U.S. metropolitan areas | n = 3,199 | 2013 | cross-section |
| Egbue et al. (2017 | logistic regression | survey - stated preference | U.S. (focus on engineering/technical background) | n = 122 | 2017 | cross-section |
| Fujita et al. (2022) | factor analysis, analytical hierarchy process | survey - stated preferences, revealed purchase | U.S. | n = 750,000 | 2014-2016 | cross-section |
| Ge et al. (2021) | descriptive statistics, binomial logit | survey - household parking availability & electrical access | U.S. | n = 3,772 | 2020 | cross-section |
| Greschak et al. (2022) | descriptive statistics, correlation | various: municipality policies, utility programs | U.S. | n = 2000 municipalities; n = 50 utilities | 2021 | cross-section |

| Citation | Methods | Data Type | Sample Frame | Sample size/ description | Data vintage | Dynamic elements |
|---|---|---|---|---|---|---|
| Guerra & Daziano (2020) | mixed logit; discrete choice; latent class analysis | survey: stated preference, willingness to pay | Philadelphia, PA | n = 1,545 | 2018 | cross-section |
| Hardman & Tal (2016) | descriptive statistics, qualitative analysis | survey, interviews: revealed purchase, stated preference (incentives) | California | n = 539 (survey), n = 33 (interviews) | 2015 | cross-section |
| Hardman et al. (2016) | means comparison, regression analysis | survey: stated preference, attributes of purchase | Worldwide, mostly U.S. responses; BEV owners | n = 340 | 2014 | cross-section |
| Hardman & Tal (2021) | descriptive statistics, $X2$ test results, logit regression | 5 surveys: demographics, behavior, PEV retention decisions | California BEV & PHEV owners | n = 1,842 | 2015-2019 | time series, panel |
| Hidrue et al. (2011) | laten class random utility model | survey: car ownership, driving habits, choice experiment, attitudinal and demographic questions | U.S. (potential car buyers) | n = 3,029 | 2008-2009 | cross-section |
| Higgins et al. (2017) | Multivariate analysis of variance, discrete choice models | Survey: household vehicle inventory, travel pattern, vehicle purchase plan, stated preference experiements, demographics | Canada | n = 20,520 | 2015 | cross-section |
| Jenn et al. (2018) | Fixed effect regression models | Vehicle registration data (R.L. Polk/IHS Automotive) | U.S. | n = 83,026,589 | Jan 2010 to Nov 2015 | time series |
| Jia & Chen (2021) | mixed logit model, lognormal Poisson, linear mixed effect model | various: survey of Virginia drivers (stated preference), DMV registration | Virginia | n = 837 (survey) | Survey: March-May 2018, DMV data: 2012-2016 | cross-section, time series |
| Karlsson (2017) | Mixed integer quadratically constrained programming model | GPS logging data | Gothenburg, Sweden | n = 64 two-car households | not reported | panel |
| Kurani & Buch (2021) | ANOVA, logistic regression models | various: survey (stated preference through vehicle design games), follow-up interview | 13 U.S. states (CA, OR, WA, DE, MA, MA, NJ, NY, CT, ME, NH, RI, VT) | n = 5,336 (new-car buying households) | late 2014 | cross-section |
| Kurani (2018) | Summary statistics, hypothesis testing, comparison analysis | Online survey (stated preference) | California (car-owning households) | n = 1,681 (Feb), n = 1,7060 (Jun) | Feb and Jun 2017 | cross-section |

| Citation | Methods | Data Type | Sample Frame | Sample size/ description | Data vintage | Dynamic elements |
|---|---|---|---|---|---|---|
| Kurani (2019) | Summary statistics, comparison analysis | Online survey (stated preference) | California (car-owning households) | n = 1,681 (Feb), n = 1,706 (Jun) | Feb and Jun 2017 | cross-section |
| Kurani et al. (2016) | Summary statistics, logistic regression, principal components analysis, cluster analysis | various: survey (stated preference through vehicle design games), follow-up interview | 13 U.S. states (CA, OR, WA, DE, MA, MA, NJ, NY, CT, ME, NH, RI, VT) | n = 5,654 (survey), n = 68 (interview) | Dec 2014 to Mar 2015 | cross-section |
| Kurani et al. (2018) | Qualitative analysis | Data captued in a constructed social setting (workshops) | California (Fresno, Sacramento, and Santa Clara) | n = 20 (Sacremento), n = 22 (Santa Clara), n = 17 (Fresno) | 2014 | cross-section |
| Kurani et al. (1996) | Hypothesis testing, choice experiments | Mail survey: household vehicle holdings, demographics, travel diary, informational video, choice experiments | California (multi-car households) | n = 454 | not reported | cross-section |
| Langbroek et al. (2016) | Hypothesis testing, choice experiments, mixed logit | Survey: stated preference, willingness to pay; travel diary | Sweden | n = 269 | 2014 | cross-section |
| Lee et al. (2019) | Bass diffusion model, cluster analysis | Survey: demographics, household characteristics | California | n = 11,037 | 2012-2017 | cross-section, time series |
| Liu & Cirillo (2017) | Dynamic discrete choice model | Survey: stated preference | Maryland | n = 3,598 obs., n = 456 households | 2015 | cross-section, projection |
| Matthews et al. (2017) | Multiple regression model | Mystery shopper visits (record of dealership experience) | Ontario, Canada | n = 95 obs., n= 24 dealerships | 2014 | cross-section |
| Meckler-Pacheco & Hardman (2022) | Descriptive analysis | Survey (sources of engagement and where buyers obtain information on PEVs) | California (PEV owners) | n = 5,329 | May to Oct 2020 | cross-section |
| Morton et al. (2016) | Principal component analysis, hierarchical regression analysis | Survey: stated preference | U.K. (Newcastle upon Tyne and Dundee) | n = 506 | winter of 2011=2012 | cross-section |
| Narassimhan & Johnson (2018) | Fixed-effect regression models | IHS Automotive vehicle registration data | U.S. | n = 523,000 | 2008-2016 | panel |

| Citation | Methods | Data Type | Sample Frame | Sample size/ description | Data vintage | Dynamic elements |
|---|---|---|---|---|---|---|
| Nazari et al. (2019) | Structural equation model, nested logit model | California Household Travel Survey: revealed preference | U.S. | n = 39,250 | 2012-2013 | cross-section |
| Neaimeh et al. (2017) | Descriptive analysis, linear regression models | Fast charging events data; driving days data | U.K. and U.S. | n = 9,000 fast charging events; n = 12,700 driving days | various time periods (2012-2013, 2014-2015 | time series, panel |
| Sheldon & Dua (2019) | Mixed logit model | New Vehicle Experience Study (NVES): revealed preference | U.S. (new vehicle buyers) | n = 275,000 | 2015 | cross-section |
| Sheldon et al. (2017) | Multinomial logit model | Survey: stated preference | California (new car buyers) | n = 1,261 | 2012 | cross-section |
| Shewmake & Jarvis (2014) | Hedonic pricing model, nonparametric regression models | Used car price data collected from newspaper, eBay and Autotrader.com | California | n = 12,470 | various time periods (2006-2009, 2008-2011) | panel |
| Shin et al. (2019) | ANOVA, multinomial logistic model | Survey: stated preference | Maryland (PEV owners) | n= 1,257 | 2015-2016 | cross-section |
| Singer (2016) | Descriptive analysis | Survey: stated preference | U.S. | n = 1,015 | 2015 | cross-section |
| Singer (2017) | Descriptive analysis | Survey: stated preference | U.S. | n = 1,017 | 2017 | cross-section |
| Singer (2020) | Descriptive analysis | Survey: stated preference (pre-, post- and follow-up) | Midwest, Pacific Northwest, Northeast in the U.S. | n = 9,000 (PEV showcase events attendees) | 2017-2019 | panel |
| Soltani-Sobh et al. (2017) | Bionomial logit share model, fixed effect model, random effect model, time series analysis | Various public data sources | AK, AL, AZ, CA, CO, FL, GA, IL, MA, MI, NC, NJ, NY, OH, OK. OR, TN, VT, WY | various sample sizes | 2003-2011 | cross-section, time series |
| Spurlock et al. (2019) | Linear probability model | Survey: stated interest in emerging technologies | Bay Area | n = 1,026 | March - June 2018 | cross-section |
| Tal et al. (2020) | Descriptive analysis, multinomial logit model | Survey; vehicle logging data, interviews | California (PEV owners) | n = 12,396 (survey); n = 264 (vehicle logging); n = 18 (interview) | 2015-2017 | time series, panel |
| Tanaka et al. (2014) | Conditional logit model | Survey: stated preference | U.S. (CA, TX, MI, NY) and Japan | n = 4,202 (U.S.), n = 4,000 (Japan) | Feb 2012 | cross-section |

| Citation | Methods | Data Type | Sample Frame | Sample size/ description | Data vintage | Dynamic elements |
|---|---|---|---|---|---|---|
| Wang et al. (2019) | Correlation analysis, linear regression model | various data sources | 30 countries | various sample sizes | 2015 | cross-section |
| Wang et al. (2022) | Latent class cluster analysis | Compilation of multiple data sources: 2017 NHTS, GDOT survey, targeted marketing data, land use data | Georgia | n = 1,111 | 2017-2018 | cross-section |
| White & Sintov (2017) | Hypothesis testing | Survey: stated preference | LA County | n = 355 | 2014 | cross-section |
| Xu et al. (2020) | Stimulus organism response model, hypothesis testing | Survey: stated preference | China (Beijing, Shanghai, Chongqing, Xi'an, and Hefei) | n = 692 | 2018 | cross-section |
| Yavorsky et al. (2020) | Descriptive analysis, multinomial logit model | Smartphone geolocation data about dealership visits, DMV registration data | Texas | n = 277,000 dealership visits, n = 195,000 vehicle registrations | 2016-2017 | cross-section |
| Zambrano-Gutiérrez et al. (2018) | Difference-in-differences model | state-level policies and PEV registrations | U.S. | not specified (50 PEV models across 50 states) | 2010-2016 | cross-sectional, time series |
| Zarazua de Rubens et al. (2018) | Mixed methods (qualitative, ANOVA) | shopping experience description (dealership visit questionnaire, dealership characteristics, and notes on shopping experiences) | Denmark, Finland, Iceland, Norway and Sweden | n = 126 shopping experiences, n= 82 car dealerships, n = 30 expert interviews | 2016, 2017 | cross-sectional |
| Zou et al. (2020) | Choice experiment, binomial logit | online survey: stated preference | U.S. | n = 1,028 | 2019 | cross-sectional |