ANL/ESD-21/2

Assessment of Light-Duty Plug-in Electric Vehicles in the United States, 2010 – 2020

Energy Systems Division

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by
David Gohlke and Yan Zhou
Energy Systems Division, Argonne National Laboratory

June 2021

CONTENTS

ACKNOWLEDGMENTS vi
LIST OF ACRONYMS vii
ABSTRACT 9
1 INTRODUCTION 9
2 DATA AND METHODOLOGY 11
3 NATIONAL-LEVEL IMPACTS 14
3.1 PEV Sales 14
3.2 Electric Miles Traveled 15
3.3 Electricity Consumption by PEVs 16
3.4 Gasoline Consumption Reduction 17
3.5 Carbon Dioxide Emissions 18
3.6 Contextual Comparisons 19
4 VEHICLE CHARACTERISTICS 21
4.1 All-Electric Range 21
4.2 Energy Efficiency 22
4.3 Size Class and Vehicle Weight 23
4.4 Vehicle Performance 25
4.5 Vehicle Manufacturing and Assembly 26
4.6 Vehicle Price 29
4.7 Battery Capacity and Cathode Chemistry 30
5 SENSITIVITY ANALYSES 32
5.1 Traveler Behavior 32
5.2 Vehicle Sales and Stock 32
5.3 Comparable ICE Vehicles 33
6 CONCLUSIONS 35
7 REFERENCES 37

FIGURES

1 Annual electric vehicle miles assumed to be traveled by PEV type and range; total PHEV VMT included for comparison 12
2 Baseline monthly vehicle miles assumed, derived from (FHWA, 2021) 13
3 Annual sales of PEVs in the United States by year 14
4 Sales shares of PEVs in the United States by manufacturer, 2011–2019 15
5 Electric vehicle miles traveled by LDVs by year 16

FIGURES (CONT.)

6 Electricity consumption by PEVs by year 17

7 Gasoline displacement from ICE vehicles by LDV PEVs by year 18

8 National average carbon dioxide emissions from electricity production by year (from EPA, 2021c) 19

9 Portion of key national metrics which are due to PEVs in the United States by year, 2010–2020 20

10 All-electric range for PEVs. Left side: sales-weighted average of range in new vehicles sold in each month. Right side: stock-weighted average range for all on-road vehicles. 21

11 Electric efficiency for PEVs. Left side: distance-weighted average efficiency for new vehicles sold in each month. Right side: distance-weighted average for all on-road vehicles. 22

12 Cumulative sales of PEVs by EPA size class 23

13 Average new PEV equivalent test weight compared with all LDV (all size classes, left; cars only, right) 24

14 Average performance indicators for PEVs sold in each month 25

15 Assembly location for PEVs sold in the United States through 2020 26

16 Assembly location by month and annual sales-weighted AALA domestic content for PEVs sold in the United States from 2010 to 2020 27

17 Assembly location by month for BEV and PHEV from 2010 to 2020 28

18 Average MSRP for PEV sold from 2010 to 2020; average expenditure for light-duty vehicles from BEA included for comparison 29

19 Battery capacity added each year for LDV PEVs in the United States 31

TABLES

1 Annual Sales of New PEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road PEVs 10

2 New Lithium-Ion Battery Capacity (GWh) for BEV and PHEV Each Year Since 2010 31

3 Comparison of Total Gasoline Reduction and CO_2 Emissions Reduction with Different ICE Vehicles for Comparison 34

4 Annual Sales of New PEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road PEVs (Duplication of Table 1) 35

TABLES (CONT.)

5 Annual Sales of New BEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road BEVs........................ 35

6 Annual Sales of New PHEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road PHEVs..................... 36

ACKNOWLEDGMENTS

This activity was supported by the Vehicle Technologies Office, Office of Energy Efficiency and Renewable Energy, United States Department of Energy. The authors would like to thank Raphael Isaac, Mark Smith, and Jacob Ward for guidance and feedback. The authors would also like to thank Luke Rush and Rebecca Schwartz, student interns in the Science Undergraduate Laboratory Internships Program, for assistance with data processing.

LIST OF ACRONYMS

AALA	American Automobile Labeling Act
BEV	Battery Electric Vehicle
CPI	Consumer Price Index
DOE	Department of Energy
EPA	Environmental Protection Agency
eVMT	electric vehicle miles traveled
FHWA	Federal Highway Administration
GWh	gigawatt-hour
ICE	internal combustion engine
kWh	kilowatt-hour
LDV	light-duty vehicle
LFP	lithium iron phosphate ($LiFePO_4$)
LMO	lithium manganese oxide
LTO	lithium titanate (Li_2TiO_3)
MDIUF	Multi-Day Individual Utility Factor
mpg	miles per gallon
MPGe	miles per gallon gasoline equivalent
mph	miles per hour
MSRP	manufacturer's suggested retail price
MY	model year
NCA	nickel cobalt aluminum
NHTSA	National Highway Traffic Safety Administration
NMC	nickel manganese cobalt
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
SAE	Society of Automotive Engineers
SUV	sport utility vehicle
VMT	vehicle miles traveled

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ASSESSMENT OF LIGHT-DUTY PLUG-IN ELECTRIC VEHICLES IN THE UNITED STATES, 2010 – 2020

ABSTRACT

This report examines properties of plug-in electric vehicles (PEVs) sold in the United States from 2010 to 2020, exploring vehicle sales, miles driven, electricity consumption, petroleum reduction, vehicle manufacturing, and battery production, among other factors. Over 1.7 million PEVs have been sold, driving 52 billion miles on electricity since 2010, thereby reducing national gasoline consumption by 0.42% in 2020 and 1.9 billion gallons cumulatively through 2020. In 2020, PEVs used 4.4 terawatt-hours of electricity to drive 13.7 billion miles, offsetting 500 million gallons of gasoline. Since 2010, 68% of PEVs sold in the United States have been assembled domestically, and 77 gigawatt-hours of lithium-ion batteries have been installed in vehicles to date.

1 INTRODUCTION

The market share of plug-in electric vehicles (PEVs) in light-duty vehicles has grown over the last decade as costs of lithium-ion batteries dropped while energy density improved (DOE, 2019). This report quantifies the environmental and economic effect of the growing PEV market, updating a report written last year, "Assessment of Light-Duty Plug-In Electric Vehicles in the United States, 2010–2019" (Gohlke and Zhou, 2018; 2019; 2020). Much of the methodology is similar as in the previous iterations, though estimations have been updated with improved data when possible.

While traditional gasoline- and diesel-powered internal combustion engines (ICE) are the most common light-duty drivetrain worldwide, alternative-fuel drivetrains are rapidly increasing in market share. PEV sales are among the fastest growing market shares worldwide, with over one million sales in 2020 in both China and Europe (Pontes, 2021a; Pontes, 2021b), and over ten million sales worldwide since 2015 (Irle, 2021). PEVs get at least a portion of their energy from electricity which is supplied to the vehicle through a charging cable. There are two types of PEVs: battery electric vehicles (BEVs) are powered exclusively by electricity, while plug-in hybrid electric vehicles (PHEVs) have a battery as well as a separate internal combustion engine for extended driving range.

Understanding the aggregate impact of electric vehicles is important when exploring electricity use and petroleum consumption. Electric utilities are working to understand the changes in electricity generation, demand, and required infrastructure (EEI, 2018; SEPA, 2017; Szinai, 2020). The growth of electric vehicles can offset petroleum consumption by conventional internal combustion engine vehicles, affecting oil prices and extraction (OPEC, 2018). Refineries need to know the potential impact on demand for their refining mix; gasoline and diesel are the two most common end products in the United States (DOE, 2017).

Likewise, knowing characteristics of the vehicles is important at a high level. Enumerating the total capacity of batteries installed in PEVs is necessary to understand the battery supply chain and the future demands of battery recycling (Xu et al., 2020; Zhou et al., 2021). Estimates of vehicle cost, weight, and performance are useful for assessing automaker trends and consumer preferences in the electric vehicle market (EPA, 2021a).

In this analysis, we present summary statistics for key metrics related to PEVs, and how most of these metrics have changed over time. Compiling data on vehicle sales and characteristics allows for a comprehensive assessment of the historical impacts of PEVs in the United States. Table 1 summarizes the high-level national impacts of these plug-in electric vehicles for PEV sales, electric vehicle miles traveled (eVMT), gasoline displacement, electricity consumption, and reductions in carbon dioxide emissions in each year from 2011 to 2020. As the market for PEV has grown along with the total on-road vehicles, each of these quantities has grown since 2011. Through 2020, over 1.7 million PEVs have been sold in the United States and have driven 50 billion miles, displacing more than 1.9 billion gallons of gasoline and nearly 10 million metric tons of CO_2, and consuming nearly 17 terawatt-hours of electricity.

TABLE 1 Annual Sales of New PEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road PEVs

Year	PEV sales (thousands)	eVMT (billion miles)	Gasoline reduction (million gallons)	Electricity consumption (gigawatt-hours)	CO_2 emissions reduction (million metric tons)
2011	18	0.1	2	20	0.01
2012	53	0.3	12	110	0.05
2013	97	1.0	37	330	0.15
2014	119	1.9	72	650	0.30
2015	114	3.0	110	1,000	0.50
2016	160	4.3	160	1,400	0.78
2017	196	6.0	230	2,000	1.10
2018	331	8.5	320	2,800	1.60
2019	320	12.5	460	4,000	2.50
2020	306	13.6	500	4,400	2.70
Total	**1,710**	**51.2**	**1,900**	**16,800**	**9.70**

Section 2 of this report details the data sources used in this report and summarizes the methodology and key assumptions. Section 3 highlights national scale impacts of the electric vehicle fleet. Section 4 explores how characteristics of PEVs have evolved over time. Section 5 presents a detailed sensitivity analysis on several assumptions, including vehicle sales, battery size, and driving behavior, to test the robustness of the results, and Section 6 summarizes key findings.

2 DATA AND METHODOLOGY

The source data used in this assessment is compiled largely from publicly available data. Including these data in one report allows for convenient reference and harmonization of assumptions on vehicle use. Sales estimates for this analysis come from Argonne National Laboratory (ANL, 2021), which are compiled from other sources including Wards Auto (Wards, 2021), Inside EVs (Inside EVs, 2020), and HybridCars (Cobb, 2018). Most of these sales estimates are informed by quarterly reports by automakers, though some automakers do not present sufficient information to determine exact sales numbers of each make and model. Within a model, it is possible for multiple variants which have distinct features of relevance within this report, such as high-capacity and low-capacity versions, or performance and standard trim levels. A parallel report (Schwartz et al., 2021) details estimated sales mixes for the individual variants of each of these models, using detailed registration data from twenty states. In this analysis, we assume that all PEV sold are still in operation and that no vehicles have been scrapped. As of December 2020, the average age for a PEV is 3.2 years, and so most plug-in electric vehicles are still in use, as described further in Section 5.2.

The all-electric range, vehicle efficiency, size class, and electric motor power come from the FuelEconomy.gov database, managed by the U.S. Department of Energy (DOE) and Environmental Protection Agency (EPA) (DOE and EPA, 2021). The carbon intensity of electricity comes from the eGRID database from the EPA (EPA, 2021c). These terms are used to quantify eVMT, gasoline reduction, electricity consumption, and emissions reductions, as presented in Table 1.

The manufacturer's suggested retail price (MSRP) of each model comes from FuelEconomy.gov and from Car and Driver magazine (Car and Driver, 2021). Vehicle curb weight comes from a mix of Car and Driver magazine, the Canadian Vehicle Specifications database (CARSP, 2021), and directly from the automaker websites and brochures. The equivalent vehicle test weight is published by the EPA (2021b). Vehicle assembly and origin of parts come from American Automobile Labeling Act (AALA) data from the National Highway Traffic Safety Administration (NHTSA) (NHTSA, 2021), and are supplemented by manufacturer press releases and news stories. Vehicle acceleration and battery capacity for each vehicle were established through a mix of data compiled by InsideEVs (Kane, 2021), press releases, news stories, and information on manufacturer websites.

For each vehicle make and model, its average monthly vehicle travel was estimated, accounting for all-electric vehicle range, and seasonal variations in driving behavior. We note that since PEVs are an emerging technology, these vehicles are on average newer than the average ICE vehicle, with an average age of only 3.2 years. According to mileage schedules from NHTSA and the EPA (Lu, 2006; EPA, 2016; NHTSA and EPA, 2018) and results from the National Household Travel Survey (Santos et al., 2011; McGuckin and Ford, 2018), the average ICE car is driven approximately 13,000–14,000 miles per year in its first three years. Therefore, as a baseline for this report, an annual baseline driving distance of 13,500 miles per vehicle, or 1,125 miles per month, is used.

We adjust this annual per-vehicle VMT in two ways. First, we make an adjustment to account for the distance driven using electricity. PHEVs can travel using a mix of gasoline and electricity. Because of the flexibility of a secondary fuel source, PHEVs are assumed to drive the same total distance as ICE vehicles, i.e., 13,500 miles per year. For PHEVs, the utility factor represents the fraction of total mileage run on electricity rather than gasoline. This utility factor is a function of the battery size; a battery with a longer all-electric range will have a higher fraction of miles driven using electricity. The utility factor for PHEVs in this report comes from the Society of Automotive Engineers (SAE) J2841 standard (SAE, 2010), specifically the multi-day individual utility factor (MDIUF). BEVs do not have a utility factor, as 100% of their driving is all-electric. BEVs have been found to generally drive less than PHEVs and ICE vehicles, though the majority of vehicles studied have all-electric ranges less than 150 miles (CARB, 2017a; CARB, 2017b; Carlson, 2015; Nicholas et al., 2017; Plötz et al., 2017; Smart and Salisbury, 2015). BEVs with longer ranges (e.g. Tesla Model S) have been found to drive comparable annual miles to PHEV and ICE vehicles. Some studies have even found BEVs with increased mileage relative to a gasoline ICE vehicle (CARB, 2017a; Figenbaum and Kolbenstvedt, 2016; RAC, 2020), though others have found VMT even lower than assumed here (Burlig et al., 2021). To account for the correlation of annual driving distance with driving range, we adjust the annual mileage for each vehicle dependent on its reported all-electric range, as if there is an effective utility factor for eVMT. This analysis uses the square of the utility factor for PHEVs as the effective utility factor for BEV, which has good agreement with real-world studies (Gohlke and Zhou, 2018). Empirically, the squared PHEV utility factor is very similar to an all-electric utility factor derived from National Household Travel Survey (NHTS) responses (Duoba, 2013). The utility factor for PHEVs and effective utility factor for BEVs are shown in Figure 1 in terms of the total annual driving distance, relative to a baseline of 13,500 miles per year.

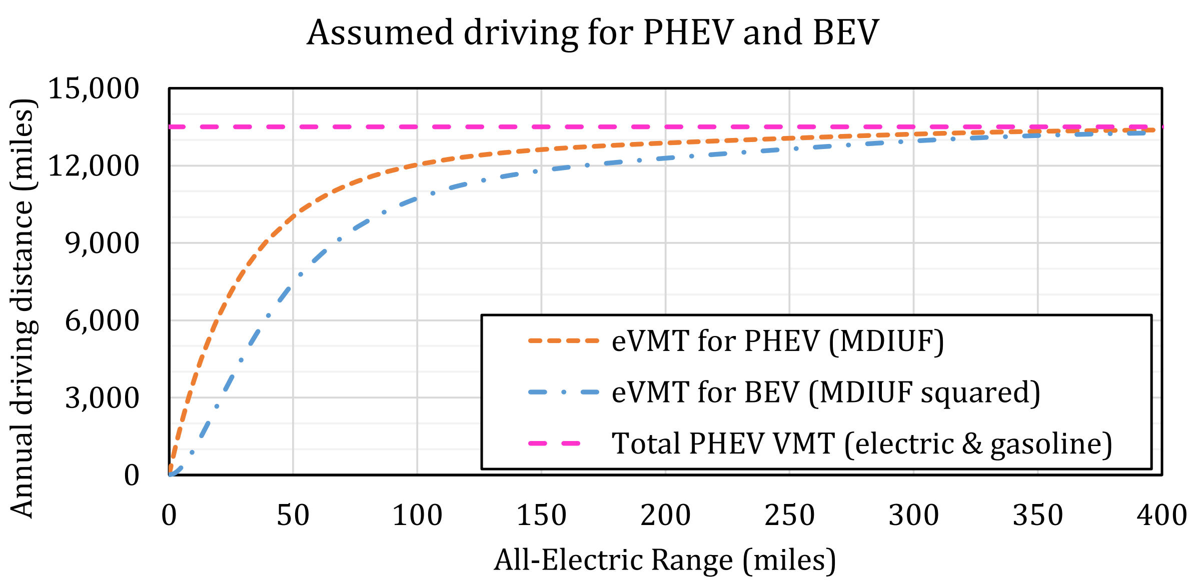

FIGURE 1 Annual electric vehicle miles assumed to be traveled by PEV type and range; total PHEV VMT included for comparison

The second adjustment for VMT holds for all vehicle powertrains. In a typical year, there are fluctuations in VMT throughout the year, with an increase in VMT in summer. We adjust the baseline VMT traveled by month (from 1,125 miles per month) to account for this seasonality. More impactfully, in 2020, due to COVID-19 pandemic, total VMT dropped in the United States by approximately 13.3% (FHWA, 2021). However, it is yet unknown what the impact of COVID-19 has been on eVMT. There are many competing forces at work when estimating the change in eVMT. While total VMT dropped, it is unclear how this was distributed across all vehicles. A disproportionate number of PEV are registered in California, which had a total VMT reduction of 14.6% in 2020, relative to 2019 (FHWA, 2021). Additionally, many electric vehicles are still comparatively new and thus owned by households with above-average income. While this leads to higher travel in general, these jobs may be more amenable to teleworking, leading to reduced VMT and eVMT. However, if daily travel is reduced, then PEVs are less range-constrained, and each vehicle may be able to drive a greater proportion of household travel. Conversely, another consideration would be the reduction in workplace charging due to teleworking, which in turn would decrease the effective utility factor. For this analysis, we assume a simple proportional decrease in monthly VMT for each PEV equal to the total nationwide reduction starting in March, using data from the Federal Highway Administration, as shown in Figure 2. Figure 2 shows the monthly baseline VMT for 2011–2019 and for 2020, with a notable drop in assumed VMT in spring 2020 due to COVID-19.

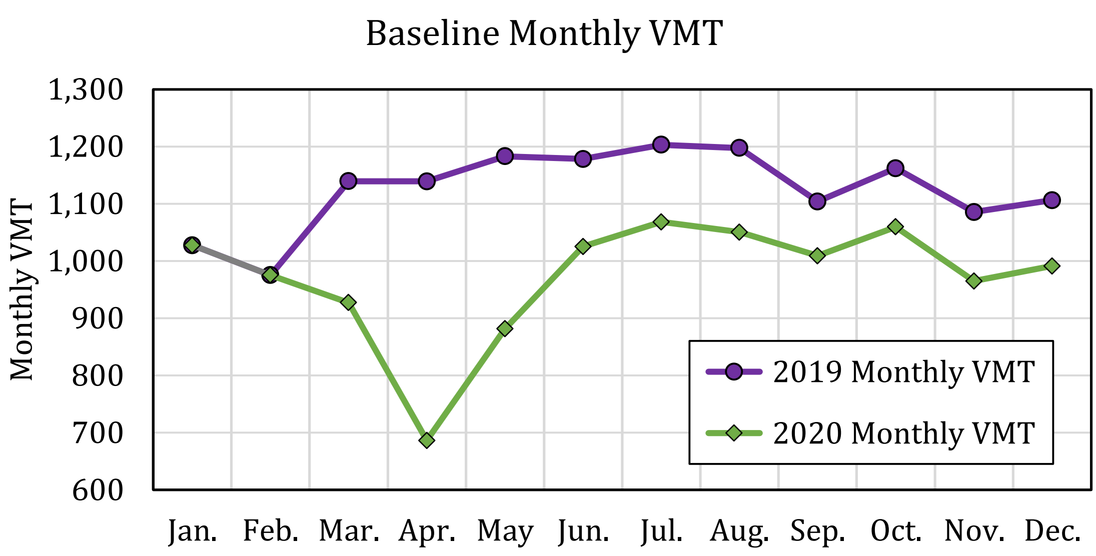

FIGURE 2 Baseline monthly vehicle miles assumed, derived from (FHWA, 2021)

Given the total VMT for each PEV in each month, we quantify the total electricity consumption using the vehicle efficiency from the FuelEconomy.gov database. We then estimate the counterfactual gasoline consumption by a replaced ICE vehicle, conservatively comparing the PEV with a new ICE vehicle with above-average fuel economy. This allows us to quantify gasoline displacement and carbon dioxide emissions reductions by PEV. Other metrics are quantified by sales-weigthed averages (typical vehicle characteristics) or in aggregate terms (such as total battery capacity).

3 NATIONAL-LEVEL IMPACTS

This section presents total national-scale metrics for PEVs, including vehicle sales, miles traveled, electricity consumed, gasoline displacement and carbon dioxide emissions. These numbers are then placed in a broader national context to show the impacts of PEVs.

3.1 PEV SALES

Over 306,000 plug-in electric vehicles were sold in the United States in 2020, a 4% decrease from 2019. Sales of all-electric BEVs grew 4% to 239,000, while PHEV sales decreased by 25% to 67,000. Relative to the total light-duty vehicle (LDV) market, total PEV shares grew from 1.9% in 2019 to 2.1% in 2020, as the overall LDV sales reduced by nearly 15% in 2020.

The historical trend in PEV sales is shown in Figure 3. Through 2019, a total of more than 1,700,000 PEVs have been sold, 61% of which have been BEVs. Before 2018, cumulative sales of PHEVs were slightly higher than of BEVs. In 2020, the continued decline in PHEV sales coupled with growth in BEV sales, particularly the Tesla Model 3, led to BEVs comprising 78% of the PEV market.

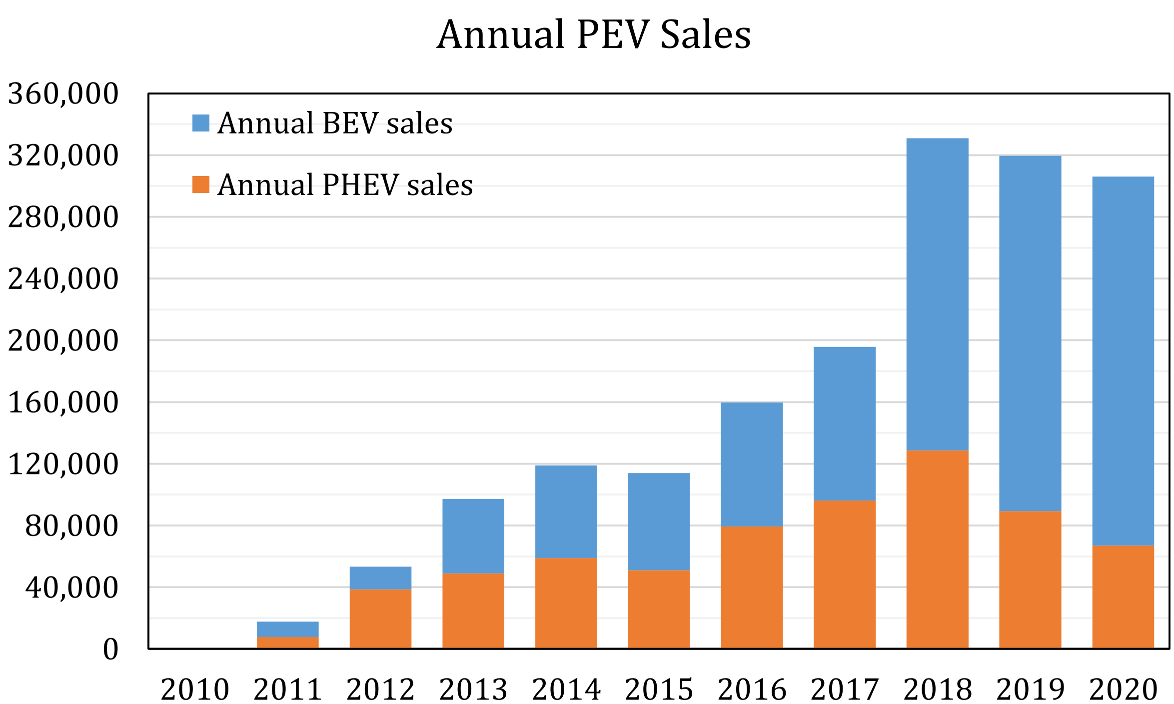

FIGURE 3 Annual sales of PEVs in the United States by year

From 2011 to 2020, annual PEV sales grew from fewer than 18,000 to more than 300,000, equivalent to an average year-over-year growth rate of 37%. As of 2020, twelve models of PEVs have sold more than 30,000 units in the United States: Tesla Model 3, Tesla Model S, Chevrolet Volt, Nissan Leaf, Toyota Prius, Tesla Model X, Chevrolet Bolt, Ford Fusion Energi, Tesla Model Y, BMW i3, Ford C-Max Energi, and the Honda Clarity PHEV. Of these, the Volt, Model S, Model 3, Leaf, and plug-in Prius have all sold more than 100,000 units. For the third consecutive year, the Tesla Model 3 was the top-selling PEV in 2020; nearly 100,000 of these vehicles were sold in 2020. The top-selling new model (and second-highest overall) was the Tesla Model Y, which sold over 58,000 units. The Tesla Model Y was the top-selling PEV starting in September 2020.

Figure 4 shows the percentage of all PEV sales by each automaker. Tesla, with 4 models in the overall top ten of U.S. sales, has the most sales with 40% of all of PEVs. General Motors, Nissan, Toyota, Ford, and BMW also each have at least 6% of domestic PEV sales.

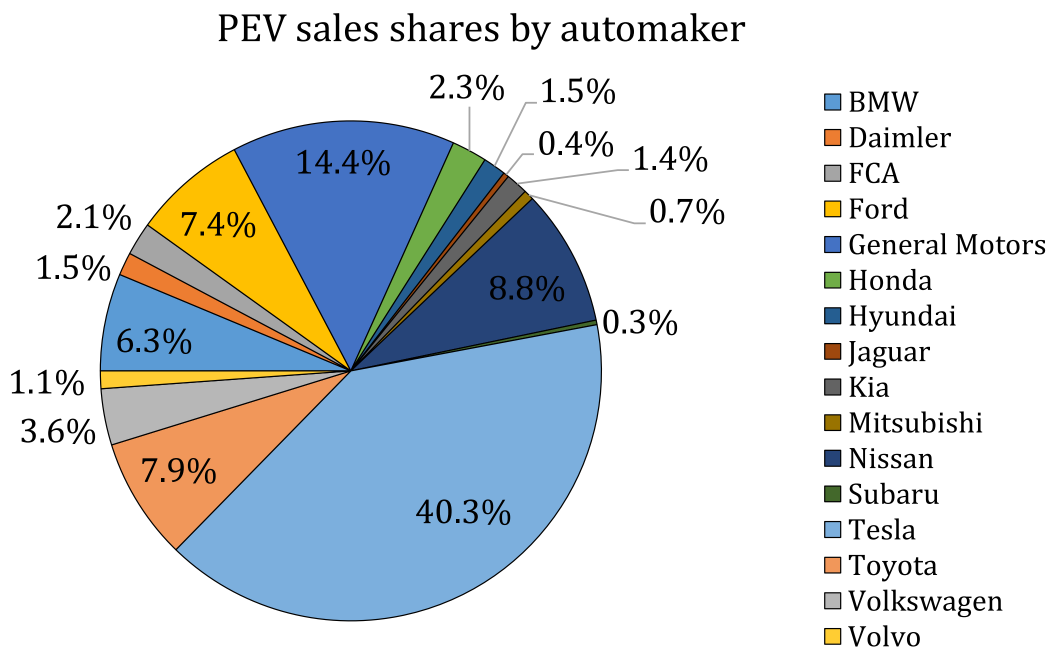

FIGURE 4 Sales shares of PEVs in the United States by manufacturer, 2011–2019

3.2 ELECTRIC MILES TRAVELED

The total annual vehicle miles traveled (VMT) for each PEV depends on traveler behavior and the vehicle's all-electric range. In this analysis, each vehicle's total travel is scaled relative to a typical ICE vehicle. PHEVs are assumed to drive the same total annual distance as ICE vehicles, with miles not supplied by electricity powered by gasoline like a hybrid. Conversely, the estimated annual mileage of each BEV is reduced relative to a comparable ICE vehicle in order to account for the limited driving range, as described in Section 2.

Given the total number of monthly PEV sales as well as the all-electric range and the effective utility factor for each vehicle, the total mileage driven in all-electric mode across the entire national LDV fleet can be estimated. Figure 5 shows the total eVMT by year in the United States. Through 2019, more than 51 billion miles have been driven powered by electricity. In 2019, 13.6 billion miles on the road were driven by light duty electric vehicles using electric power; approximately 71% of this was driven by BEVs. Even with the reduction in per-vehicle VMT in 2020 due to COVID-19, the total eVMT increased in 2020, owing to continued sales of new PEV.The average BEV in 2019 drove 10,500 miles, while the average PHEV drove 6,400 eVMT.

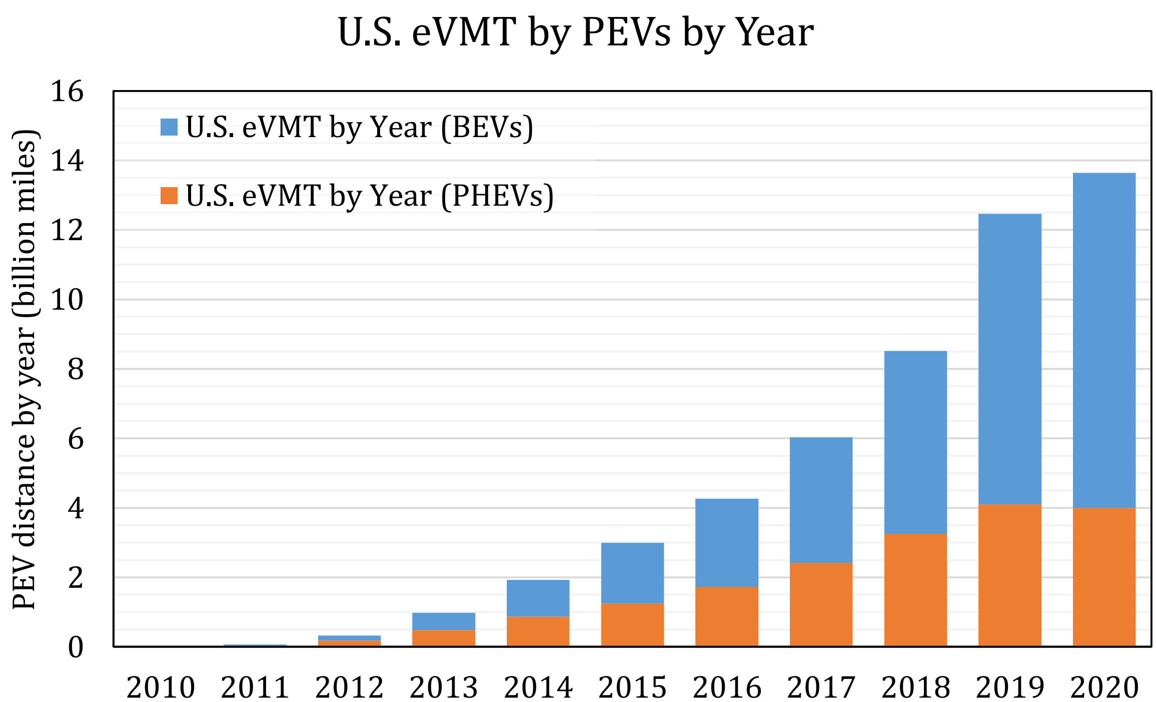

FIGURE 5 Electric vehicle miles traveled by LDVs by year

3.3 ELECTRICITY CONSUMPTION BY PEVs

Combining eVMT with knowledge of vehicle electricity efficiency allows us to determine the total electricity consumption by PEVs in the United States, shown in Figure 6. To find the total electricity consumption, the estimated eVMT in each month is multiplied by the electricity consumption per mile for each vehicle model. Through 2020, a total of 16.8 terawatt-hours of electricity have been consumed by PEVs. In 2020, the total electricity use for LDVs on the road was 4.4 terawatt-hours. In 2020, the average PHEV consumed 2,220 kilowatt-hours (kWh) of electricity, and the average BEV consumed 3,250 kWh of electricity. These numbers are both lower than in 2019 (Gohlke and Zhou, 2020), because of reduced per-vehicle VMT as a result of COVID-19.

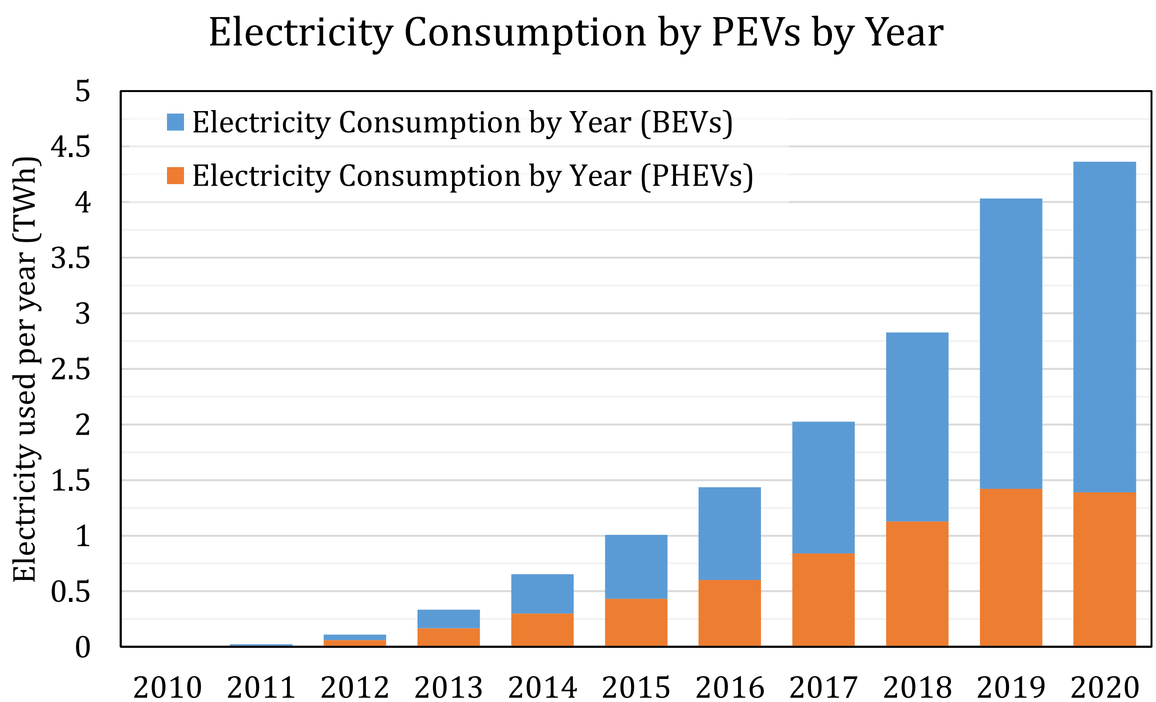

FIGURE 6 Electricity consumption by PEVs by year

3.4 GASOLINE CONSUMPTION REDUCTION

Use of electricity by PEVs displaces gasoline that would otherwise be used by an ICE vehicle.[1] To estimate this reduction in gasoline consumption, we need to make assumptions about how each mile would have otherwise been traveled. For each PEV, we select a comparable ICE in the same size class and model year in order to calculate the gasoline consumption offset by using electricity.[2] For example, a compact PEV offsets the fuel consumption of a compact ICE vehicle, rather than comparing with a fleet-wide average. Given the tendency for early adopters of electric vehicles to be interested in fuel economy and environmental benefits, the comparable gasoline ICE vehicle was assumed to be more fuel efficient than average, specifically, the 75th percentile of models available in that year in that size class. Section 5 examines the impact of varying the fuel economy of this reference vehicles.

The total gasoline displacement by year is graphed in Figure 7. In 2020, 500 million gallons of gasoline were offset by PEVs, with 72% of this total offset by BEVs. In 2019, the average on-road BEV offset 460 gallons of gasoline, and the average PHEV offset 260 gallons. Cumulatively, through 2020, PEVs have offset over 1.9 billion gallons of gasoline, 1,260 million gallons by BEVs and 640 million gallons by PHEVs.

---

[1] This analysis only counts gasoline usage that is offset when the car is operating in electric mode. For PHEVs operating in charge-sustaining mode (i.e., using only gasoline), the hybrid engines are also generally more efficient than the average ICE vehicle, but this reduction in gasoline is not calculated here.

[2] For each model year and each size class, vehicle fuel efficiencies were gathered from the FuelEconomy.gov database (DOE and EPA, 2021).

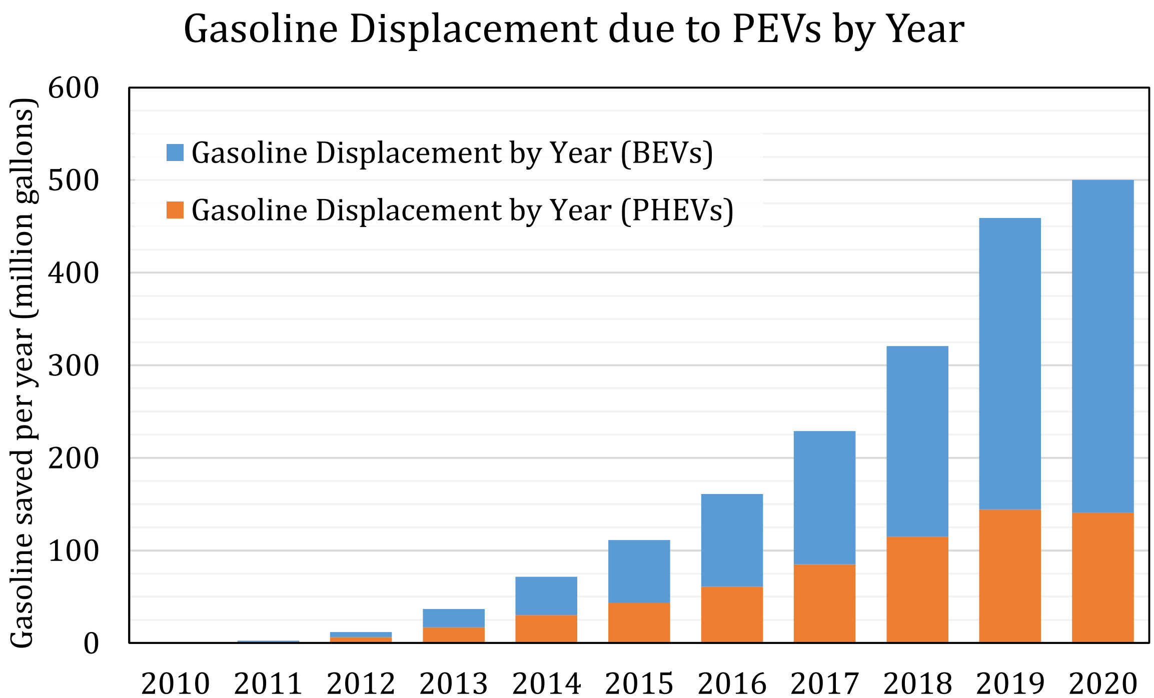

FIGURE 7 Gasoline displacement from ICE vehicles by LDV PEVs by year

3.5 CARBON DIOXIDE EMISSIONS

Operation of PEVs reduces emissions relative to use of a conventional ICE vehicle. The EPA states that combustion of each gallon of gasoline emits 8,887 grams of CO_2 (EPA and DOT, 2010).[3] The amount of tailpipe emissions from an ICE vehicle can be found by multiplying the miles driven by 8,887 grams CO_2 / gallon of gasoline and dividing by the fuel economy (in miles per gallon, or mpg). While the carbon content of gasoline is constant, emissions from electricity production have been decreasing, as seen in Figure 8. According to the EPA, electricity production in the United States emitted an average of 401 grams of CO_2 per kilowatt-hour in 2019 (EPA, 2021c), down 28% from the 559 g CO_2 / kWh emitted in 2010, as shown in Figure 8. The emissions to drive an electric vehicle are found by multiplying the miles driven by the electricity consumption (in kWh per mile) by the emission rate. As an example, an ICE vehicle consuming 30 mpg emits 300 g CO_2 / mile, while a BEV consuming 0.33 kWh / mile in 2019 was responsible for 132 g CO_2 / mile. Assuming the U.S. national grid average for emissions from electricity production, and comparing each PEV with the 75th percentile ICE vehicle for fuel economy in its size class in each year, PEVs have offset a total of 9.7 million metric tons of

[3] This calculation is for tailpipe emissions only; that is, it excludes upstream effects for refining and transportation of the fuel, as well as emissions from the production of the vehicles. For electric vehicles, the calculation is for the generation of the electricity for vehicle operation, again excluding vehicle manufacturing. The majority of emissions come from the operation, rather than the manufacturing, of both ICE vehicles and PEVs. A recent study found that tailpipe emissions from a midsize gasoline ICE vehicle were 68% of the total lifetime emissions, while electricity consumption for operation was responsible for 77% of the emissions from a midsize BEV (Elgowainy et al., 2016).

carbon dioxide during vehicle operation. In 2020, BEVs offset 2.0 million metric tons of CO_2 from replacing gasoline with electricity, while PHEVs offset 0.7 million metric tons of CO_2.

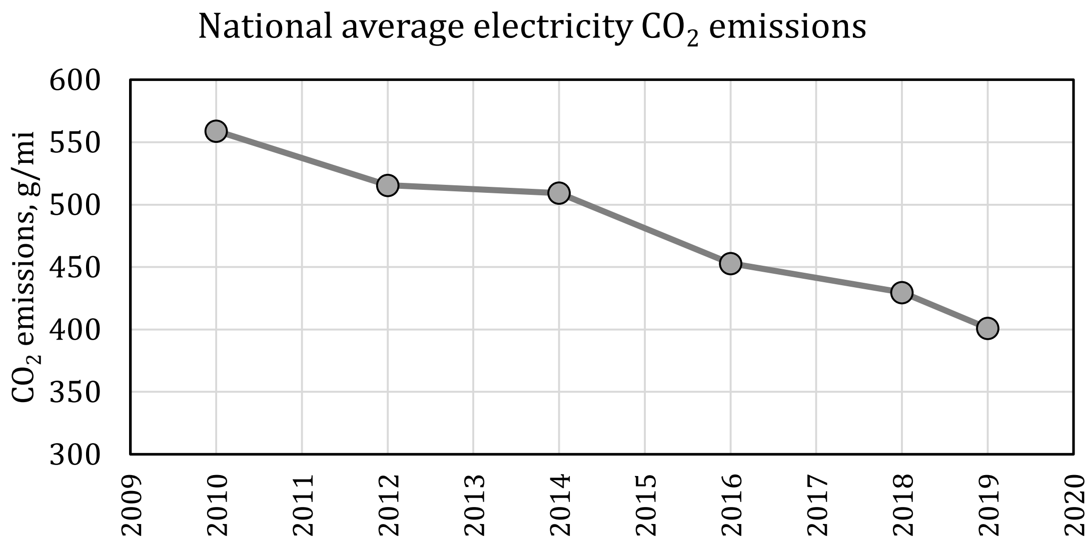

FIGURE 8 National average carbon dioxide emissions from electricity production by year (from EPA, 2021c)

3.6 CONTEXTUAL COMPARISONS

PEVs are a growing share of the vehicle market and are having increasing impacts on the transportation and energy sectors. Figure 9 highlights how these impacts have changed, comparing the quantities from PEVs for total number of on-road vehicles, miles driven, electricity consumption, and gasoline reduction with corresponding total national values.[4] In 2019, PEVs comprised 0.55% of the 253 million light-duty vehicle registrations (FHWA, 2020). Nearly 3 trillion miles are driven by light-duty vehicles each year (FHWA, 2020); in 2019 0.43% of that total was powered by electricity. In 2019, the total electricity use for LDVs on the road was 4.0 terawatt-hours. This compares with a total of 3,955 terawatt-hours (EIA, 2021), or 0.102% of the total national electricity generation. In 2018, 460 million gallons of gasoline were offset by PEVs, equivalent to 0.33% of the 138 billion gallons of gasoline used in the United States that year (EIA, 2021).

[4] For total light-duty vehicle registrations and VMT, 2019 is the latest year with full data availability as of the writing of this report (June 2021), so Figure 9 uses extrapolated values of LDV registrations and LDVVMT to estimate through 2020.

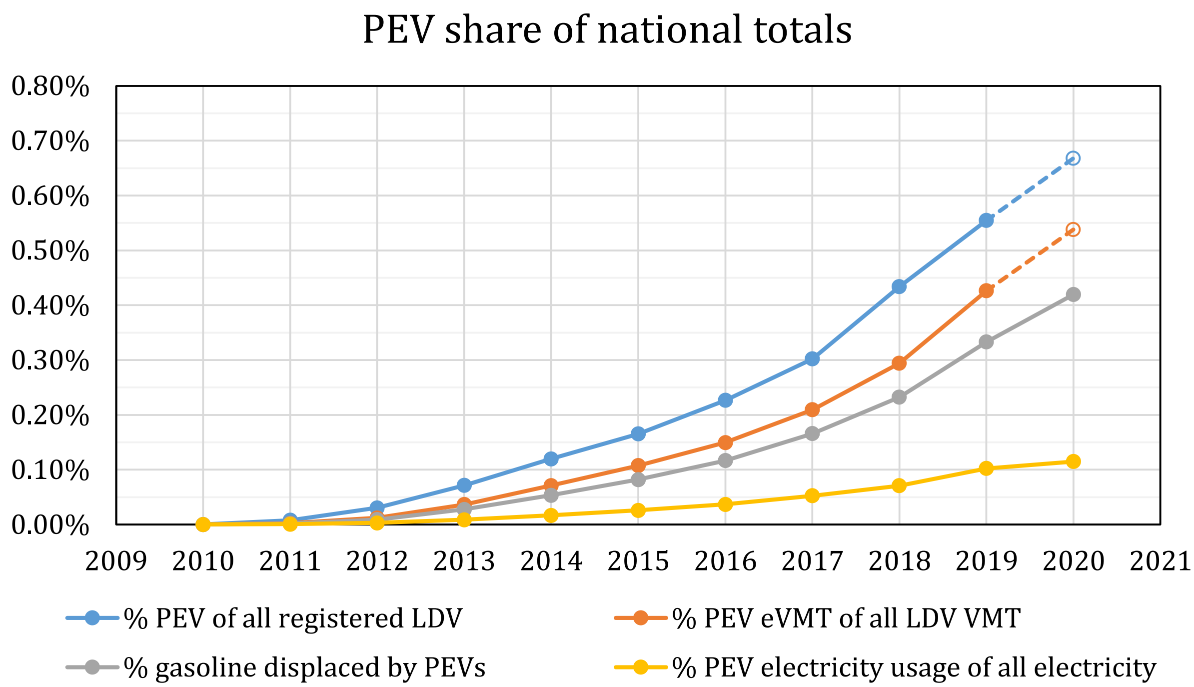

FIGURE 9 Portion of key national metrics which are due to PEVs in the United States by year, 2010–2020

Data on gasoline and electricity usage are available for 2020 as well (EIA, 2021). In 2020, total electricity consumption fell 3.9% nationwide, but PEVs increased national electricity consumption by 0.115%, using 4.34 terawatt-hours. Similarly, gasoline consumption dropped 13.7% nationally largely due to reduced travel from COVID-19, though continued improvements in ICE vehicle efficiency also played a role. PEV reduced gasoline consumption by 500 million gallons, or 0.42% of the total annual consumption.

4 VEHICLE CHARACTERISTICS

In addition to the total national-scale impacts of PEVs presented in Section 3, specific trends within the PEV market can be examined, including all-electric range, energy efficiency, vehicle size, performance, battery size, and manufacturing location.

4.1 ALL-ELECTRIC RANGE

The average range of PEVs has increased since 2010. This is largely due to the introduction and increased consumer preference of longer-range BEVs, which have become more economical due to the reduced cost of batteries. Figure 10 shows the average sales-weighted all-electric range for new vehicles (left side) and for all on-road vehicles (right side). PHEVs have consistently averaged between 20 and 35 miles of all-electric range while the average range of BEVs has more than tripled from approximately 70 miles to over 230 miles. The sharp growth in all-electric range for BEVs in early 2013 is due to the introduction of the Tesla Model S, with a range of up to 265 miles, while the increase in 2018 is largely due to high sales of the Tesla Model 3 with a range of up to 310 miles. In 2020, the sales-weighted range for new PEVs was 230 miles – 26 miles for PHEVs and 290 miles for BEVs.

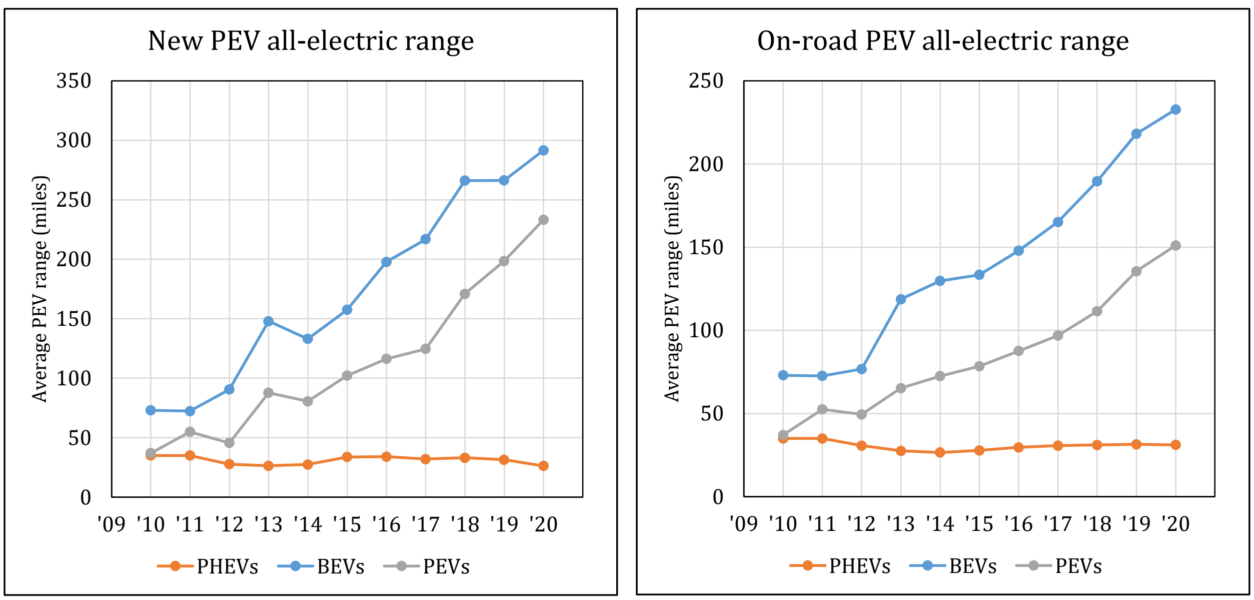

FIGURE 10 All-electric range for PEVs. Left side: sales-weighted average of range in new vehicles sold in each month. Right side: stock-weighted average range for all on-road vehicles.

4.2 ENERGY EFFICIENCY

Figure 11 shows the average (distance-weighted) energy efficiency of vehicles running on electricity for new vehicles (left) and the entire on-road fleet of PEVs (right).[5] Since 2010, vehicles have become more efficient on average, though there have been deviations from that trend. There are two notable reversals to the downward trends of energy consumption of the last decade. First, in 2016, there was a spike in fuel consumption for both BEV and PHEV. This corresponded with an increase in vehicle size, with SUVs reaching nearly 19% of the PEV market in that year with the introduction of the Tesla Model X and BMW X5 PHEV. In 2020, there was a marked increase in fuel consumption rates for PHEV, occurring beginning in March at the start of COVID-19 restrictions. This increased fuel consumption is correlated with an increased share of SUVs and higher average PHEV prices.

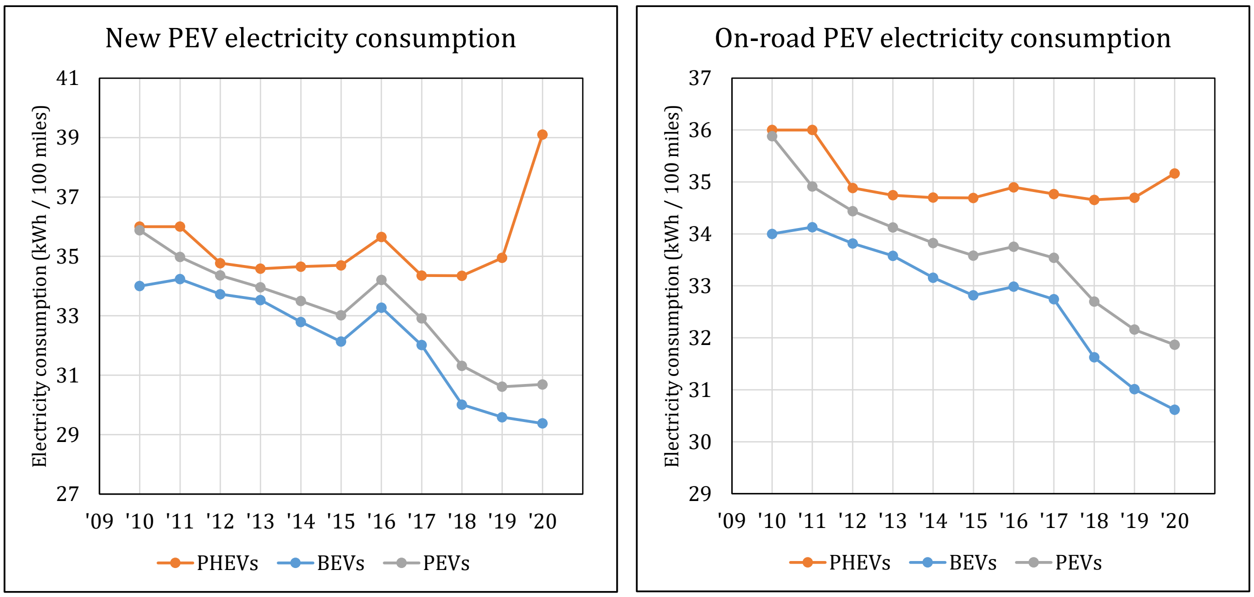

FIGURE 11 Electric efficiency for PEVs. Left side: distance-weighted average efficiency for new vehicles sold in each month. Right side: distance-weighted average for all on-road vehicles.

The average electricity consumption of the entire PEV fleet has dropped from nearly 36 kWh per 100 miles to approximately 32 kWh per 100 miles. BEVs sold in the United States have generally been more efficient than PHEVs. As of December 2020, the average on-road PHEV consumed 35.2 kWh per 100 miles driven in charge-depleting (all-electric) mode, while the average on-road BEV consumed 30.6 kWh per 100 miles.[6] In terms of miles per gallon of gasoline equivalent (MPGe), where 33.7 kilowatt-hours of electricity is equivalent to one gallon of gasoline (EPA, 2011), the average PEV fuel economy has increased from 94 MPGe to 106 MPGe.

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[5] A distance-weighted average (rather than a sales-weighted average) is used to give a proper comparison of electricity consumption of the entire PEV fleet.

[6] The per-mile energy consumption of PHEV is higher when accounting for miles powered by the ICE.

For new vehicles sold in 2020, BEVs used 29.4 kWh per 100 miles driven, PHEVs averaged 39.2 kWh per 100 miles, and the fleetwide average was 30.7 kWh per 100 miles. Through model year 2020, the most efficient vehicle in the FuelEconomy.gov database is the Tesla Model 3 Standard Range Plus, using 24 kWh / 100 miles. The next most efficient vehicles in the FuelEconomy.gov database are the Hyundai Ioniq BEV and Toyota Prius Prime PHEV, each consuming 25 kWh /100 miles when operating on electricity (DOE and EPA, 2021).

4.3 SIZE CLASS AND VEHICLE WEIGHT

Figure 12 shows PEVs sorted by size class. The most common PEV size class has been a midsize car in each year since 2011, which includes the Nissan Leaf, Toyota Prius Prime, and Tesla Model 3. This is followed by compact cars, which are more prominent for PHEVs, such as the Chevrolet Volt, and by large cars, such as the Tesla Model S BEV. Sales for sport utility vehicle (SUV) PEVs are growing, with standard four-wheel drive SUV (including the Tesla Model Y) being the second-best-selling size class of 2020.

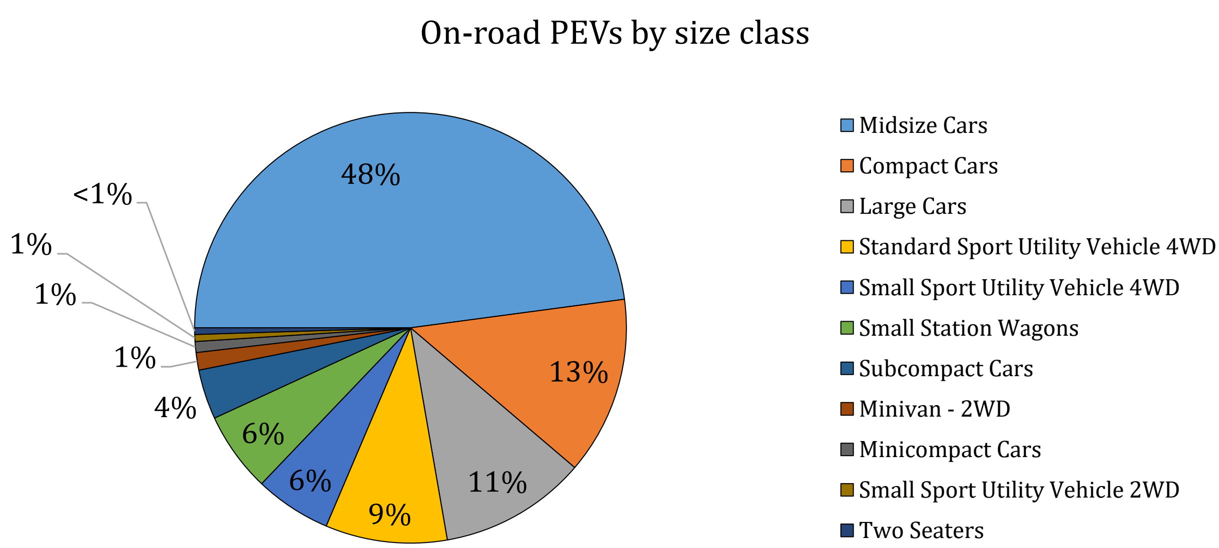

FIGURE 12 Cumulative sales of PEVs by EPA size class

The EPA splits LDVs into five different vehicle types: sedans/wagons, car SUVs, truck SUVs, minivans/vans, and pickup trucks (EPA, 2021a). Vehicles defined as sedans and wagon by the EPA make up 83% of total PEV sales, and 15% of PEV sales have been SUVs. In 2020, sedans and wagons were 61% of total PEV sales. In 2020, car SUVs comprised 37% of BEV sales. Truck SUVs were 39% of PHEV sales and minivans/vans were more than 6% of PHEV sales. In November and December 2020, the total car share of PEVs fell below 50% for the first time.

The EPA collects data on vehicle weights as part of the fuel economy testing process. The EPA maintains a publicly accessible database of the equivalent test weight of each vehicle, classified into 125- and 250-pound groups (EPA, 2021b).[7] The sales-weighted average of these equivalent test weights for PEVs has increased from 3,800 pounds in 2011 to 4,500 pounds in 2020. Over that timeframe, the sales-weighted average equivalent test weight has increased from 3,700 pounds to 4,500 pounds for BEVs, and from 4,000 to 4,500 pounds for PHEVs. This weight increase is due to increased battery capacity in BEVs and due to larger average size classes for both BEVs and PHEVs. Figure 13 shows the sales-weighted average equivalent test weight since 2011 for electric vehicles and for all powertrains (EPA, 2021a). The left graphic shows the vehicle weight averaged across all PEV size classes. There was a notable increase in vehicle weight in 2020, especially for PHEV, as the total share of PEV SUVs increased. Since 2015, the average PEV weight has been greater than the average weight across all light-duty vehicles, even though the total share of SUVs and pickup trucks is higher in the general population. The right graphic in Figure 13 shows the sales-weighted equivalent test weight only for cars, for PEV cars and for all sedans and wagons of all powertrains. PHEV cars have maintained a similar weight, while BEV cars have increased in weight since 2010. This shows the impact of larger batteries, as shown in Figure 10.

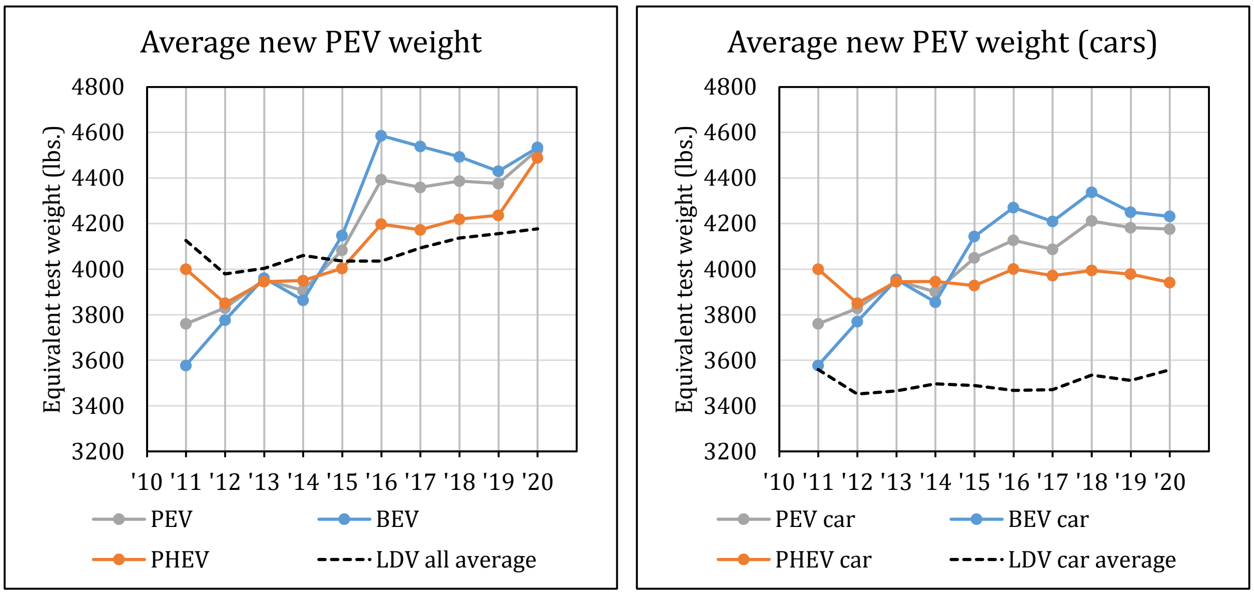

FIGURE 13 Average new PEV equivalent test weight compared with all LDV (all size classes, left; cars only, right)

[7] Because of this grouping of vehicles in the EPA database, the equivalent test weight group for each vehicle is similar to, but not exactly the same as, its test weight basis. On average, the equivalent test weight is about 300 lb heavier than the listed curb weight.

4.4 VEHICLE PERFORMANCE

Performance of electric vehicles has on average increased since 2010, as measured by electric motor power (in kilowatts) and by the acceleration time from 0 to 60 miles per hour (mph). Figure 14 shows the average total electric motor size and acceleration for PEVs sold in each year. For each of these metrics, much of the increase in vehicle performance for BEVs has been due to Tesla. The (sales-weighted) average motor size for a Tesla BEV has increased to 340 kW and to nearly 180 kW for BEVs sold by other automakers. For the Tesla vehicles, the total motor power is increased by having separate motors for front and rear wheels for their all-wheel drive variants. Since 2014, the average electric motor size for PHEV has remained steady at around 90 kW; PHEVs have an additional gasoline-powered engine for propulsion, and therefore have less need for a larger electric motor.

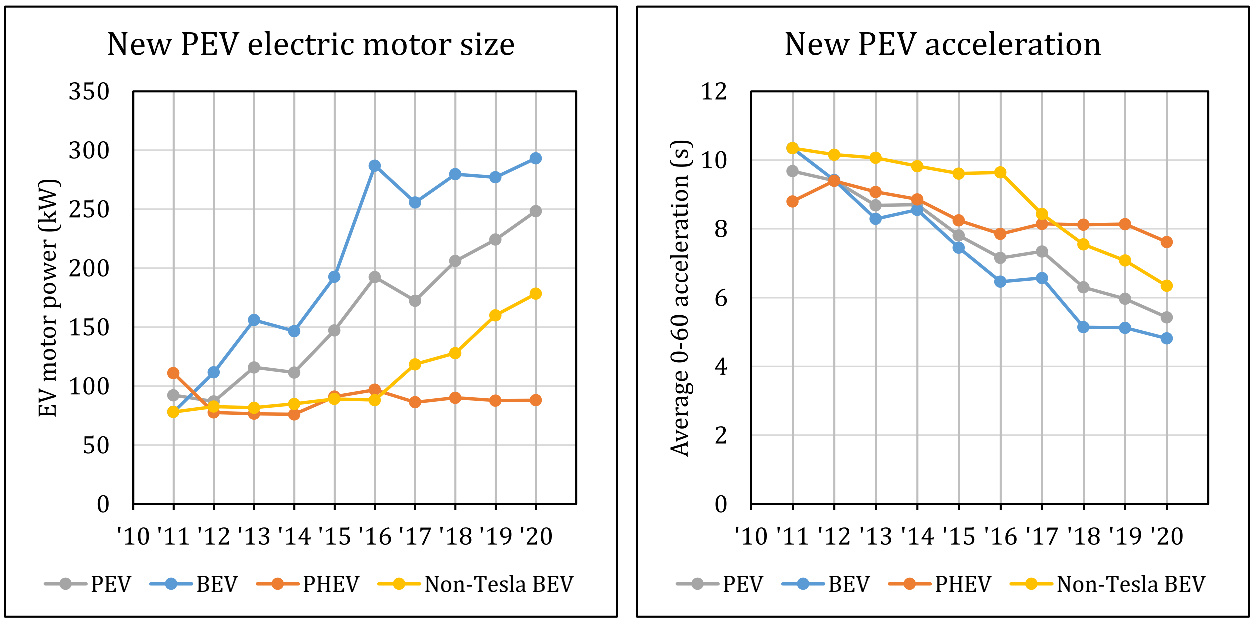

FIGURE 14 Average performance indicators for PEVs sold in each month

As PEV electric motors have become more powerful, vehicle acceleration has improved. The average time for a PEV to reach 60 mph is below 6 seconds. As with the electric motor power, much of the change since 2011 comes from Tesla vehicles. The fastest commonly available PEVs are the Porsche Taycan and the Tesla Model S, both of which have variants which can reach 60 mph in 2.4 seconds. The average 0–60 mph time for PHEVs had been consistently between 8 and 9 seconds since 2013, though the average acceleration improved to 7.6 seconds in 2020. Through 2016, the sales-weighted average 0–60 mph time for a non-Tesla BEV was 10 seconds, though this has dropped to 6.3 seconds by the end of 2020. This overall improvement in average PEV acceleration rates has multiple causes, including increased availability of models with faster acceleration and some specific models becoming quicker as technology improves.

4.5 VEHICLE MANUFACTURING AND ASSEMBLY

Most electric vehicles that have been sold in the United States were assembled in the United States, as shown in Figure 15. 87% of BEVs and 34% of PHEVs have been assembled in the United States. Most of the remaining PEVs sold in the United States were assembled in Japan, Germany, and Mexico. A higher fraction of PEVs have been assembled domestically than ICE vehicles since 2011.

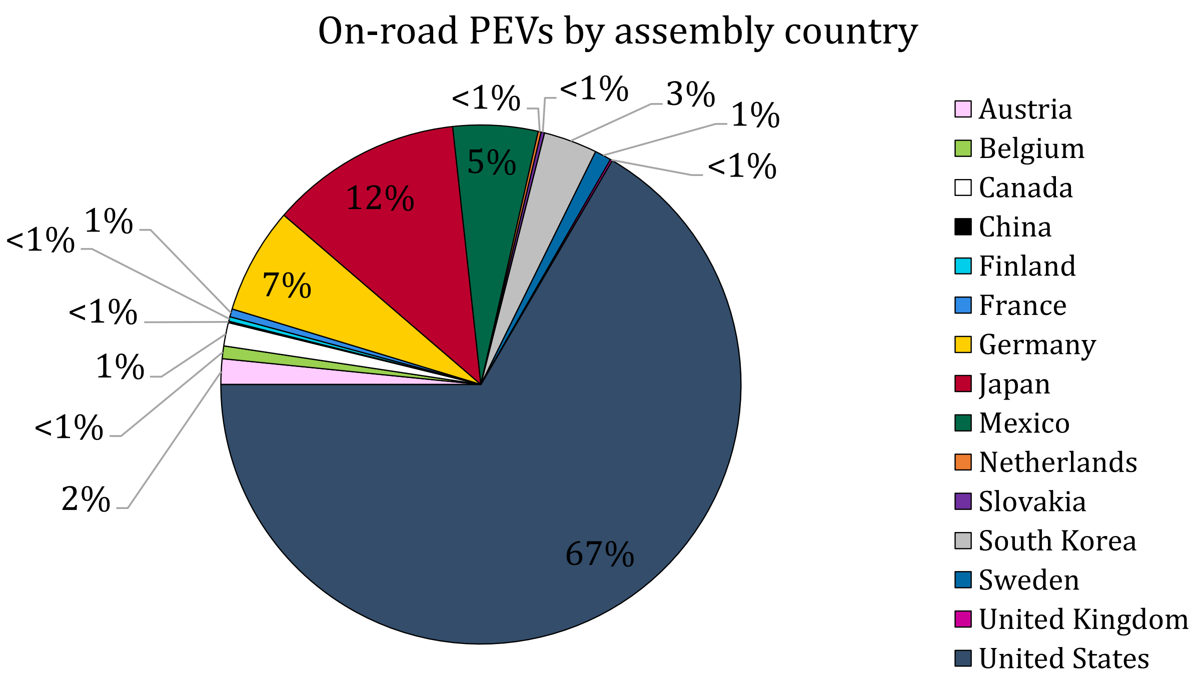

FIGURE 15 Assembly location for PEVs sold in the United States through 2020

Figure 16 shows how assembly location and vehicle content has changed over time. In 2011 and early 2012, most PEVs sold in the United States were assembled in Japan, led by the Nissan Leaf and Toyota Prius Plug-in. By the end of 2012, the Nissan Leaf was being produced in Tennessee and additional models (from Ford and Tesla) were being produced in the United States. From 2013 to 2017, about one-third of PEVs were assembled in foreign countries. In 2019, 70% of PEV were assembled in the United States, including 90% of BEV; for comparison, 51% of non-PEV vehicles were assembled in the United States, based on import data from the Department of Commerce (ITA, 2020). In 2020, largely due to the strong sales of Tesla vehicles, 74% of PEVs were assembled in the United States.

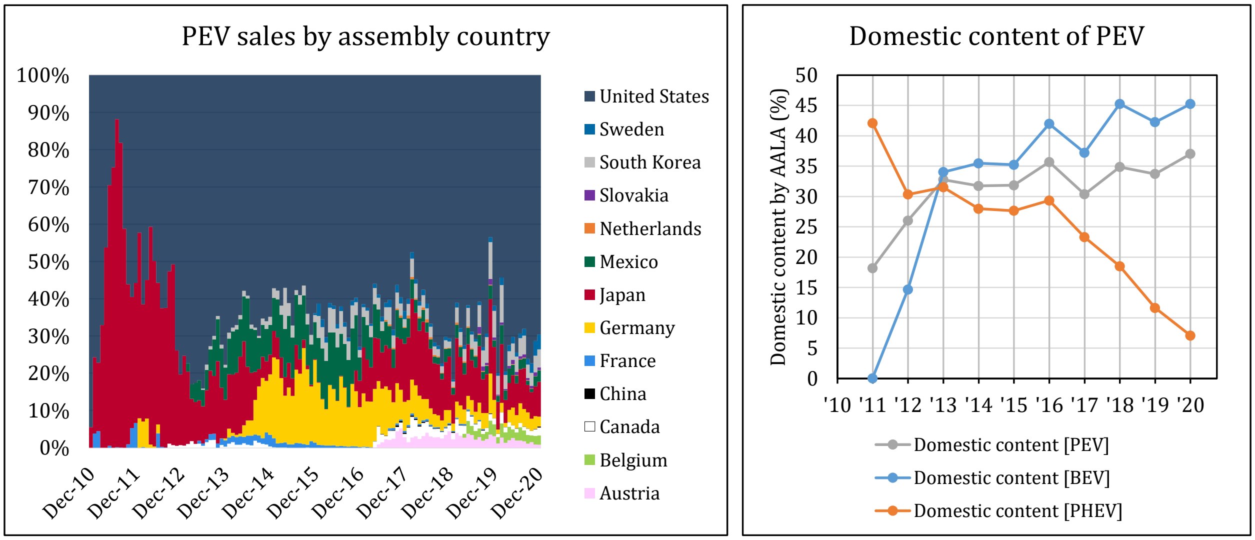

FIGURE 16 Assembly location by month and annual sales-weighted AALA domestic content for PEVs sold in the United States from 2010 to 2020

The fraction of vehicle components that are produced domestically (here defined as both United States and Canada) come from the AALA reports that are compiled by NHTSA for each vehicle model (NHTSA, 2021). Figure 16 shows the sales-weighted average of these AALA values for PEVs sold in the United States. This figure shows that the total amount of domestically sourced materials in electric vehicles has grown since 2011, with strong growth from 2011 to 2013 for BEVs. In 2013, about one-third of components in both BEVs and PHEVs were domestically sourced.[8] Since then, the fraction of domestic content in PHEVs has declined, largely due to an increasing selection of models produced throughout the world. The fraction of domestic content in BEVs has increased, due to the growth in sales by Tesla and the assembly of Nissan Leafs in the United States. The diverging trends of BEV and PHEV assembly are shown in Figure 17. For the BEV, shares have generally increased, beginning in early 2013 with the Tennessee-based production of the Nissan Leaf, and then increasing since 2016 as Tesla became the top-selling PEV automaker with vehicles from their California plant. On the other hand, domestic PHEV shares have dropped over time, reaching only 12% in 2020.

[8] AALA reports do not account for changes in manufacturing process throughout the year. For example, in early 2013 the Nissan Leaf was largely imported. By the end of the year, the Smyrna plant in Tennessee was assembling Nissan Leafs with a larger fraction of domestically sourced parts, but that does not show up in the AALA report for MY2013 vehicles (Voelker, 2013).

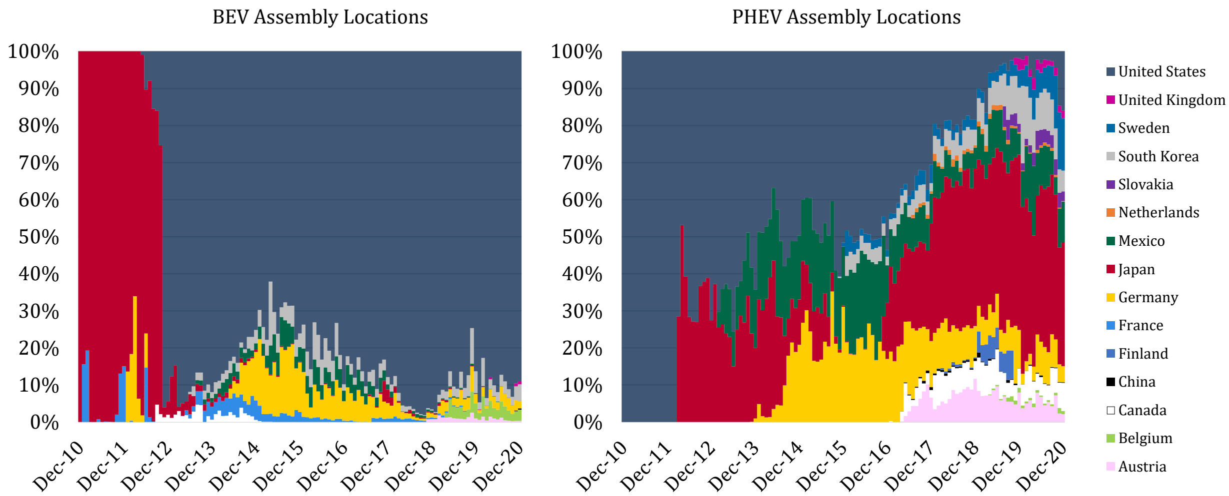

FIGURE 17 Assembly location by month for BEV and PHEV from 2010 to 2020

A similar quantification of U.S. manufacturing is put together by the Kogod School of Business at American University. In their 'Made in America' index they compile their estimate of domestic production which includes investment and different vehicle components (Dubois, 2020).[9] In the most recent 2020 Made in America estimate, the Tesla Model S and Model Y each ranked in the 97th percentile for vehicles, while the Tesla Model 3 and Model X were ranked in the 92nd percentile.

Argonne National Laboratory recently published a comprehensive assessment of the lithium-ion battery supply chain for PEVs in the United States (Zhou et al., 2021). In this analysis, it was found that the batteries used in PEVs sold in the U.S. have been largely domestically sourced. In terms of total battery capacity since 2010, over half of all cells have been produced in the U.S., as have nearly 90% of all battery packs. This trend toward domestic production has grown over time, with 70% of battery cells and 87% of battery packs produced in the U.S. in 2020. Panasonic and LG Chem are the two largest battery suppliers for PEVs in the U.S. market.

[9] A large portion of the Kogod Made in America Index is informed by NHTSA's AALA estimates, so they are not entirely independent of each other.

4.6 VEHICLE PRICE

Figure 18 shows the sales-weighted average MSRP for PEVs for 2010–2020.[10] The costs shown here are the base trim MSRP.[11] This is not necessarily the cost a consumer will pay for the vehicle (and does not include state or federal tax incentives) but is a price that can be referenced as a benchmark for each vehicle. For comparison, the average consumer expenditure for LDVs, as per the Bureau of Economic Analysis, is shown (BEA, 2021). The average cost of BEVs has gone up since 2010, while the average cost of PHEVs has remained mostly flat since then. The average MSRP for BEVs peaked in 2016 and has declined since then. In 2020, MSRP for BEV and PHEV both increased, as vehicle sizes shifted from cars to SUVs.

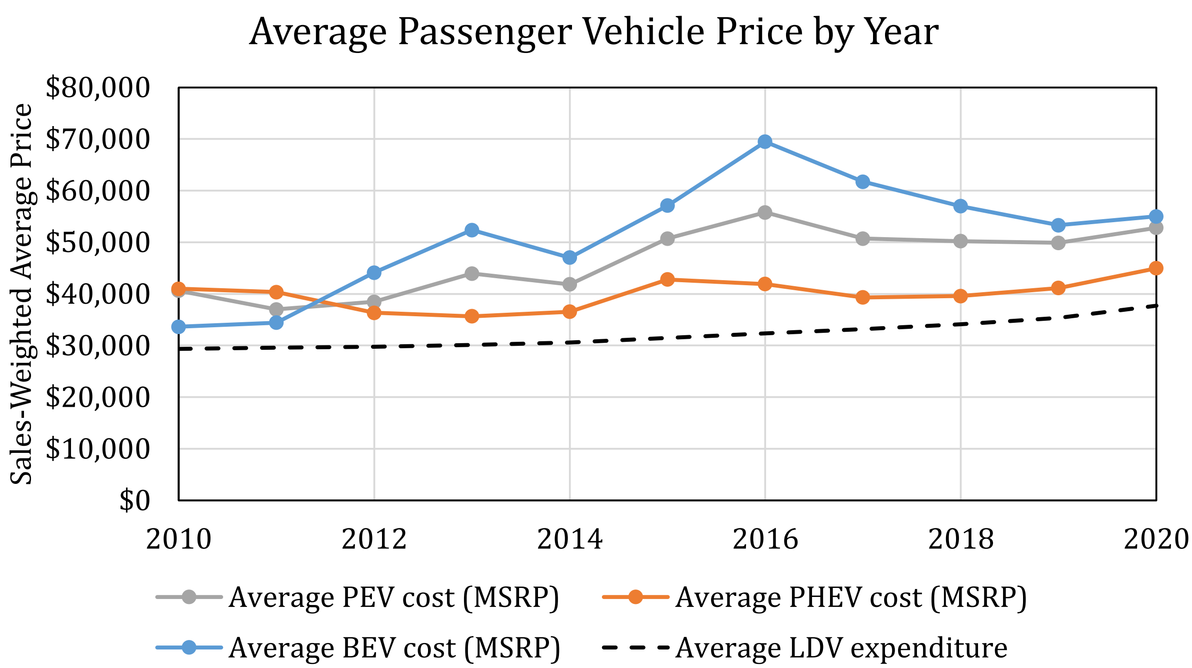

FIGURE 18 Average MSRP for PEV sold from 2010 to 2020; average expenditure for light-duty vehicles from BEA included for comparison

Purchases of PEVs are eligible for a federal tax credit of up to $7,500 (IRS, 2009). This tax credit exists until the automaker sells its 200,000th PEV, at which point the credit phases out over the next year. Tesla and General Motors have both reached the threshold for the tax credit to be phased out (IRS, 2018; IRS, 2019), with the tax credit for Tesla vehicles reaching zero in January 2020 and the tax credit for General Motors vehicles reaching zero in April 2020.

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[10] Values here are nominal dollars, not inflation-adjusted. From 2011 to 2020, the Consumer Price Index (CPI) increased by 1.6% per year, so a cost in 2011 would need to be increased by 15% to be adjusted for inflation to 2020$ (BLS, 2021).

[11] There are many vehicle models which have a large suite of optional features which can bring the cost higher than the base level. However, the base trim for many PEVs is often comparable to a higher trim level for ICE vehicles.

4.7 BATTERY CAPACITY AND CATHODE CHEMISTRY

Since 2010, the commercially available PEVs in the United States have used lithium-ion batteries for energy storage. These batteries are comparatively lightweight, and batteries with capacities of up to 100 kWh have been included in PEVs. The core components of lithium-ion batteries are the anode and the cathode. Most lithium-ion batteries have a graphite anode, though a few vehicles (e.g. Mitsubishi i-MiEV, Honda Fit) have used lithium titanate (LTO, $Li_4Ti_5O_{12}$) instead (Blomgren, 2017). The cathode is the most expensive component of the lithium-ion battery (Pillot and Sanders, 2017), and there are numerous competing chemistries for the cathode.

The most common cathode chemistries for lithium ion batteries for automotive uses are $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ (NCA), $Li[Ni_{1-x-y}Mn_xCo_y]O_2$ (NMC), $LiMn_2O_4$ (LMO), and $LiFePO_4$ (LFP). For a detailed description of the relative merits of each of these chemistries, see e.g. Berman et al. (2018), Andre et al. (2015) and Schmuch et al. (2018). These four cathode chemistries are the most common worldwide (EV Volumes, 2017; Azevedo et al., 2018). As of 2017, NMC and NCA each made up about one-third of the total installed capacity worldwide, and LFP and LMO comprised nearly all of the rest. There are trends toward higher nickel content (and lower cobalt content) in NMC batteries to reduce costs (Berman et al., 2018).[12] It is generally not reported what stoichiometry battery cathodes use in each PEV, though NMC-111 was the most common for the first mass-market PEVs in 2010, and NMC-622 and NMC-811 are now produced (Pillot and Sanders, 2017).

Figure 19 shows the primary cathode material for electric vehicles sold in the United States over time.[13] The left figure is a function of vehicle sales, and the right figure shows the total battery capacity (in GWh) for each cathode chemistry. Figure 19 shows that NMC and NCA are the dominant cathode chemistries in the United States in 2020. Further, NCA has been used in much larger packs, on average, than NMC, due to NMC being popular in PHEVs. In 2020, the average capacity for an NCA battery was 77.0 kWh, and the average capacity for an NMC battery was 37.6 kWh. For BEV alone, the average capacity was 77.9 kWh for NCA and 67.7 kWh for NMC.

[12] The stoichiometric ratio of nickel, manganese, and cobalt can be varied in NMC batteries. NMC batteries are often labeled as NMC-xyz, where x, y, and z are the ratios between Ni, Mn, and Co.

[13] It is common for cathode chemistries to be mixed. In particular, LMO and NMC are often mixed in batteries – for ease of representation, the present analysis shows only the primary cathode chemistry.

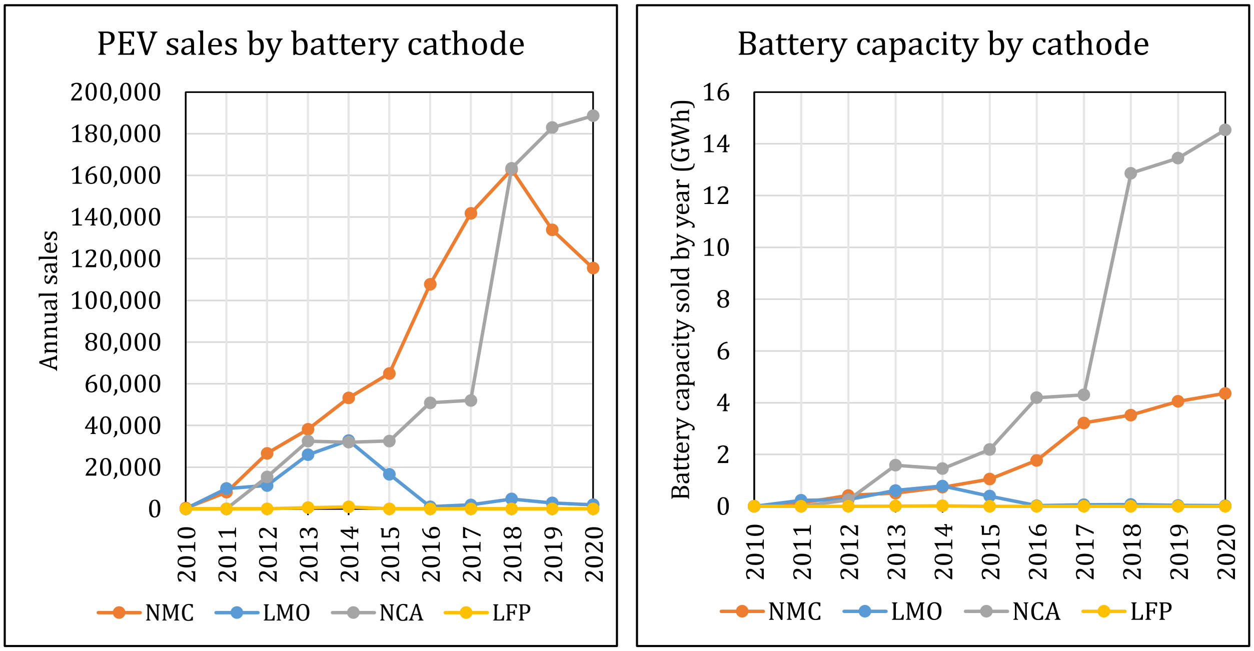

FIGURE 19 Battery capacity added each year for LDV PEVs in the United States

The aggregate battery capacity in PEVs sold in the United States is over 77 gigawatt-hours (GWh) through 2020. Table 2 and Figure 19 show the new batteries added to the road each year from 2010 through 2020; new battery capacity was nearly 19 GWh in 2020. Of this, 14.6 GWh used NCA cathodes, and 4.3 GWh used NMC cathodes. 93% of PHEVs sold in 2020 used lithium-ion batteries with NMC cathodes. More than 70% of the total battery capacity has used NCA cathodes, and most of these NCA batteries have been installed in Tesla vehicles. Table 2 shows total battery capacity by year for BEV and PHEV. Though BEV comprise only 61% of the total PEV market since 2010, 89% of all battery capacity has been installed in BEVs in the United States.

TABLE 2 New Lithium-Ion Battery Capacity (GWh) for BEV and PHEV Each Year Since 2010

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
BEV capacity (GWh)	0.0	0.2	0.5	2.2	2.4	3.0	5.0	6.4	14.8	16.4	18.1	69.0
PHEV capacity (GWh)	0.0	0.1	0.5	0.5	0.6	0.6	1.0	1.2	1.7	1.1	0.8	8.2
Total PEV capacity (GWh)	0.0	0.4	0.9	2.7	3.0	3.6	6.0	7.6	16.5	17.5	18.9	77.1

5 SENSITIVITY ANALYSES

This section explores variations in the input data and assumptions to examine the robustness of the results. This was done in detail in a previous iteration of this report (Gohlke and Zhou, 2018) and many results here reference that work. The largest variations in the results come from assumptions about traveler behavior and ICE vehicle replacement. Impacts from considering scrappage and end-of-life are also described in this section.

5.1 TRAVELER BEHAVIOR

The baseline VMT in this study was fixed at 13,500 miles/year. As noted above in Section 2, this corresponds to the average distance driven by a comparable ICE vehicle (Lu, 2006). Tuning this parameter affects all vehicles equally and acts as a simple linear scaling factor for eVMT, electricity consumption, gasoline displacement, and CO_2 emissions.

The fraction of PHEV VMT driven on electricity is determined by a utility factor, and BEVs have an effective utility factor in this report, which can be thought of as representing driver reluctance to fully discharge the battery or use BEVs for long-distance trips. These behavioral factors are strongly dependent on the vehicle make and model, and average values are used in this report. A previous iteration of this report (Gohlke and Zhou, 2018) explored these utility factors in depth. In that report, using the SAE Fleet Utility Factor resulted in 6% lower eVMT, while the utility factors from the World Harmonized Light Vehicles Test Procedure increased eVMT by up to 16%.

5.2 VEHICLE SALES AND STOCK

Default sales estimates in this analysis come from Argonne National Laboratory (ANL, 2021), Wards Auto (Wards, 2021), Inside EVs (Inside EVs, 2020), and HybridCars (Cobb, 2018). In 2019 many automakers stopped reporting monthly sales data for each model, so there are variations between these sales estimates, though the results are similar for all sales estimates considered. For several makes and models, a detailed VIN analysis of registered vehicles was performed in order to determine the mix of each variant (Schwartz et al., 2021). The aggregate battery capacity is the metric most impacted by this analysis, described in greater detail in other reports (Schwartz et al., 2021; Gohlke and Zhou, 2018).

Scrappage effects are currently small. Using National Highway Traffic Safety Administration's (NHTSA) 2006 report as the basis of scrappage rates, which uses historic data from ICE vehicles (Lu, 2006), 4.0% of PEVs sold have been taken off the road, as of December 2020.[14] This fraction is small because of the average age of PEVs. The average age of on-road PEVs is only 39 months, due to their recent introduction into the market and the rapid growth in

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[14] For the first several years of a vehicle's life, the scrappage rate from NHTSA is approximately 0.12% per month. The EPA Technical Assessment Report (EPA, 2016) assumes an even slower scrappage rate.

sales. If PEV sales remain steady at 2020 levels (25,000 sales per month), scrappage will not reach 10% until after 2025, and the overall fraction of scrapped vehicles will be lower still if PEV sales increase (due to a younger average PEV fleet).

A potentially larger impact comes from reduction of vehicle use as the vehicle ages. NHTSA has a vehicle mileage schedule for estimated travel by age of vehicle, based on historical ICE data (Lu, 2006). Translating this vehicle mileage schedule (for cars) to the PEV sales since 2010 yields a 4.5% reduction in VMT from 2010 through 2020. It is unknown if this methodology translates to eVMT driven by PEVs.[15] Using data from the 2017 National Household Travel Survey (NHTS), BEVs exhibit no clear reduction in mileage for vehicles dating back to 2011, while PHEVs show a decrease in mileage using NHTS's best estimate, but an increase in mileage when relying on self-reported mileage. In either case, the sample size for each of these vehicles is small.

Due to the effects of scrappage and vehicle travel effects, the impacts of PEV usage on gasoline displacement and electricity use may be overestimated. Combining the reduction in on-road vehicles with the reduction in mileage for older vehicles (both assuming equivalent reductions as ICE vehicles), the cumulative gasoline displacement and electricity use are potentially up to 7% lower through December 2020.

Because all-electric range has increased since 2010, the impact of scrappage on battery capacity is smaller than for the entire vehicle. As of December 2020, only 3.0% of lithium-ion batteries in PEVs (approximately 2.3 gigawatt-hours) will have been scrapped based on historic trends.

5.3 COMPARABLE ICE VEHICLES

As described in Section 2.4, the reduction in gasoline attributed to PEVs depends on the ICE vehicle that each PEV is assumed to replace. The baseline assumption in this report is that each PEV offsets the 75th percentile vehicle in its size class, however different comparison ICE vehicles can be compared instead. Table 3 shows the impact of changing the comparable vehicle. The total eVMT and electricity consumption do not vary, but the quantity of gasoline offset through 2020 ranges from 1.3 to 2.3 billion gallons and cumulative CO_2 reductions range from 4.2 to 13.2 million metric tons. The lower bound comes from all PEVs replacing an ICE vehicle consuming 40 miles per gallon, while the upper bound scenario has all PEVs replace the average on-road ICE vehicle in its size class.

[15] There are logical reasons that the eVMT could either be reduced or stay the same. For BEVs, a reduction in VMT is identical to a reduction in eVMT though travel behavior for BEV is not the same as ICE vehicles. For PHEVs, only a fraction of the miles are electrified; in particular, the first miles of most trips. If long-range travel is reduced as the vehicle ages, this does not impact the eVMT and instead raises the effective utility factor. If, conversely, fewer trips are taken, but at a proportionally longer distance, this would lower eVMT. Additionally, battery degradation can cause the all-electric range of PEVs to decrease as the vehicle ages, which would lower the potential eVMT.

In Table 3, the first row represents PEVs replacing a gasoline-fueled ICE vehicle equivalent in fuel economy to the 75th percentile vehicle in that size class for that year. The second row takes the harmonic mean of fuel economy for all vehicles in the size class for each year and uses that as the displaced vehicle. The next three rows treat all PEVs the same, regardless of size class, as if they are replacing an average ICE vehicle with fuel economy equivalent to the average vehicle sale in that year, 30 mpg, or 40 mpg, respectively. In the final row, rather than displace the purchase of a new ICE vehicle, the PEVs are displacing an average vehicle already in use when the PEV is sold.

TABLE 3 Comparison of Total Gasoline Reduction and CO_2 Emissions Reduction with Different ICE Vehicles for Comparison

Replaced ICE vehicle	Gasoline reduction (million gallons)	CO_2 emissions reduction (million metric tons)
75th percentile by size class [baseline]	1,900	9.72
Average by size class	2,210 (+16.2%)	12.5 (+28.2%)
Fleet average new LDV (EPA, 2021a)	2,080 (+9.2%)	11.3 (+16.0%)
30 miles per gallon	1,710 (-10.3%)	7.98 (-18.0%)
40 miles per gallon	1,280 (-32.8%)	4.19 (-56.7%)
Average on-road LDV	2,300 (+20.8%)	13.2 (+36.2%)

6 CONCLUSIONS

Since the latest generation of light-duty plug-in electric vehicles have been available in the United States, more than 1.7 million PEVs have been sold, driving over 51 billion miles on electricity. These 51 billion eVMT consumed more than 16.8 terawatt-hours of electricity while reducing gasoline consumption nationwide by 1.9 billion gallons. Table 4 reproduces Table 1, summarizing the total impacts of PEVs by year from 2011 to 2020. Mileage driven by PEVs and electricity consumption has grown, which has offset gasoline consumption and CO_2 emissions from ICE vehicles. Tables 5 and 6 present the same metrics for BEV and PHEV, respectively.

TABLE 4 Annual Sales of New PEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road PEVs (Duplication of Table 1)

Year	PEV sales (thousands)	eVMT (billion miles)	Gasoline reduction (million gallons)	Electricity consumption (gigawatt-hours)	CO_2 emissions reduction (million metric tons)
2011	18	0.1	2	20	0.01
2012	53	0.3	12	110	0.05
2013	97	1.0	37	330	0.15
2014	119	1.9	72	650	0.30
2015	114	3.0	110	1,000	0.50
2016	160	4.3	160	1,400	0.78
2017	196	6.0	230	2,000	1.10
2018	331	8.5	320	2,800	1.60
2019	320	12.5	460	4,000	2.50
2020	306	13.6	500	4,400	2.70
Total	**1,710**	**51.2**	**1,900**	**16,800**	**9.70**

TABLE 5 Annual Sales of New BEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road BEVs

Year	BEV sales (thousands)	eVMT (billion miles)	Gasoline reduction (million gallons)	Electricity consumption (gigawatt-hours)	CO_2 emissions reduction (million metric tons)
2011	10	0.0	1	10	0.01
2012	15	0.1	6	50	0.02
2013	48	0.5	20	170	0.09
2014	60	1.1	42	350	0.19
2015	63	1.7	68	570	0.33
2016	80	2.5	100	830	0.51
2017	99	3.6	140	1,200	0.76
2018	202	5.3	210	1,700	1.10

TABLE 5 (Cont.)

Year	BEV sales (thousands)	eVMT (billion miles)	Gasoline reduction (million gallons)	Electricity consumption (gigawatt-hours)	CO_2 emissions reduction (million metric tons)
2019	230	8.3	310	2,600	1.80
2020	239	9.7	360	3,000	2.00
Total	**1,050**	**32.9**	**1,300**	**10,500**	**6.80**

TABLE 6 Annual Sales of New PHEVs, and Total Annual eVMT, Gasoline Reduction, Electricity Consumption, and CO_2 Emissions Reduction by On-Road PHEVs

Year	PHEV sales (thousands)	eVMT (billion miles)	Gasoline reduction (million gallons)	Electricity consumption (gigawatt-hours)	CO_2 emissions reduction (million metric tons)
2011	8	0.0	1	10	0.00
2012	39	0.2	6	60	0.02
2013	49	0.5	17	170	0.06
2014	59	0.9	30	300	0.11
2015	51	1.2	43	430	0.18
2016	79	1.7	61	600	0.27
2017	96	2.4	85	840	0.38
2018	129	3.2	110	1,100	0.53
2019	89	4.1	140	1,400	0.71
2020	67	4.0	140	1,400	0.70
Total	**670**	**18.3**	**640**	**6,400**	**3.00**

On average, electric vehicles have become more fuel efficient and have had longer all-electric driving ranges as technology has advanced. This improvement in efficiency has occurred even while performance metrics (such as vehicle power or acceleration) have improved as well. Most of the PEVs on the road were assembled in the United States. The market has begun to grow beyond the midsize and compact cars which were most common, with plug-in electric SUVs becoming more popular as models become available.

Some of the results shown in Table 3 depend on assumptions on traveler and purchase behavior. A previous report (Gohlke and Zhou, 2018) showed that different assumptions about driving behavior can change eVMT and electricity consumption by up to 25%. Using alternative choices for the ICE vehicle travel displaced by a PEV yields anywhere between 1.3 and 2.3 billion gallons of gasoline displaced.

More than two-thirds of PEVs have been assembled in the United States, and more than one-third of the total content is domestically sourced. Over 77 GWh of battery capacity has been installed in PEVs since 2010, with nearly half of this total in 2019 and 2020.

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Energy Systems Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 362
Lemont, IL 60439-4832

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