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# REAL WORLD USAGE OF PLUG-IN HYBRID VEHICLES IN THE UNITED STATES

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# EXECUTIVE SUMMARY

Plug-in hybrid electric vehicles (PHEVs) have the potential to reduce emissions from light-duty vehicles and help ease the transition to fully electric, zero tailpipe-emission vehicles. Though PHEVs store less energy in their battery packs than fully electric vehicles, PHEVs can be designed with enough energy storage to cover most daily trips in the United States. As long as such vehicles begin with a full, or nearly full charge every day, they have the capacity to significantly reduce fossil fuel consumption.

Spurred by recent investigations into the real-world performance of PHEVs in Europe and China, this study examines the current state of PHEV usage in the United States. Previous research and data from early adopters of PHEVs in the United States demonstrated that PHEVs achieved real-world electric drive share close to that expected by the U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA). In this study, we present an analysis of more recent data from two previously unexplored sources: self-reported fuel consumption from Fuelly.com and engine-off distance traveled collected by the California Bureau of Automotive Repair (BAR). These new data cover a broader variety of PHEV models and newer model years than prior datasets. Unlike prior datasets, both Fuelly and BAR are actively growing. While Fuelly data are voluntarily reported, the data are collected for the benefit of site users, not for research, and are not limited to specific vehicle models. Additionally, the BAR data presents the first widespread, automatic direct measurement of real-world electric drive share in the United States.

The analysis in this paper arrives at the following conclusions:

**Real-world electric drive share may be 26%–56% lower and real-world fuel consumption may be 42%–67% higher than assumed within EPA's labeling program for light duty vehicles.** We find that current PHEVs show electric drive shares much lower than assumed in EPA labeling. Figure ES1 shows the regulatory label curve of drive share during charge-depleting mode (black), or utility factor, in comparison to the new Fuelly (blue) and BAR (orange) datasets. Each circle represents data for one vehicle model, and the larger the circle, the greater the sample size for that model. The best-fit utility factor curves for each dataset are shown in their respective color. Despite the different methods for estimating utility factor between the two datasets, the resulting best-fit curves show similar trends. These new datasets present strong evidence that real-world electric drive share is far below the utility factor label rating. A consequence of this comparatively low electric drive share is that real world fuel consumption is 42%–67% higher than EPA label fuel consumption.

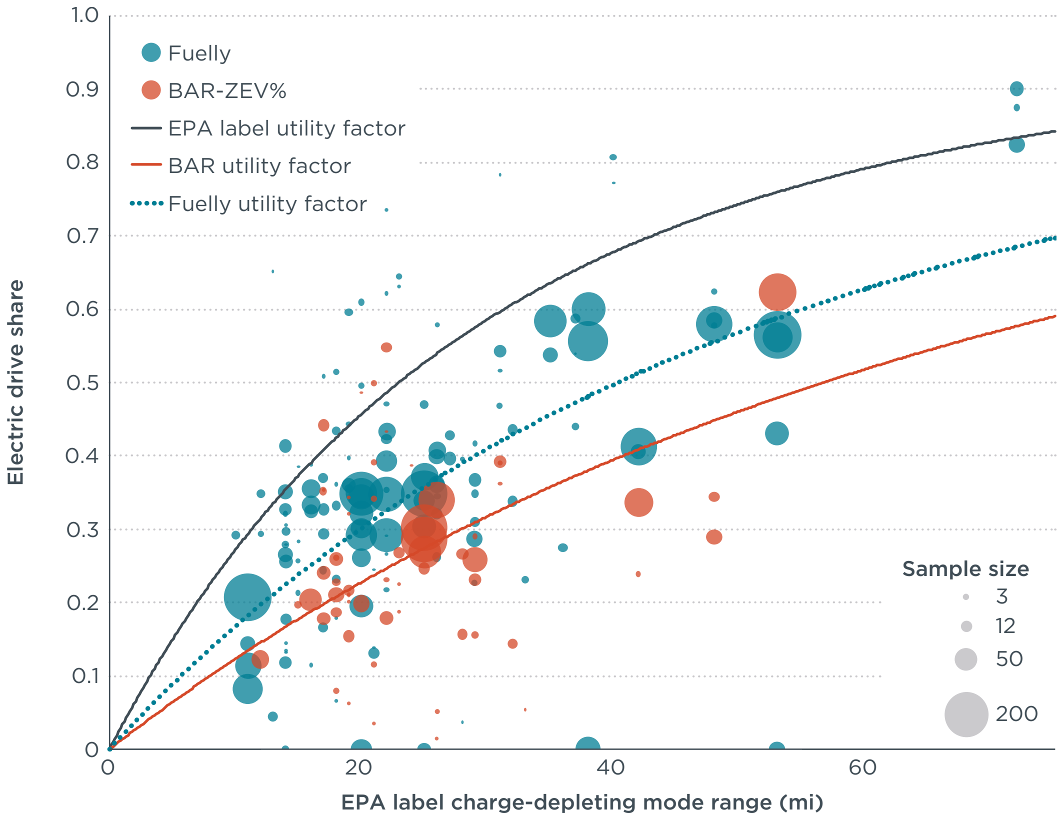


**Figure ES1.** Calculated electric drive shares and adjusted utility factor curves based on California BAR (using direct measurement of all-electric travel fraction) and Fuelly (calculated from fuel consumption) datasets.

**These results demonstrate that real-world electric drive share is lower than labeled, but more data collection could provide greater precision and clarity.** The datasets analyzed here are comprised of a variety of models of comparable sample sizes, which strongly suggest widespread deviation from U.S. Environmental Protection Agency (EPA) label electric drive share. However, as PHEVs are still a small share of the existing fleet and new sales, all data sources to date may be inherently biased towards early adopters. Such early adopters likely have easy access to charging, such that mainstream adopters may show worse electric drive share by comparison. Furthermore, all datasets examined suffer from some degree of self-selection bias, and potentially other confounding factors. At a minimum, the trends in the new PHEV data point to the need for closer inspection and broader investigation into PHEV usage to inform regulatory treatment. Through on-board diagnostic reporting requirements, EPA could readily obtain this data on a continual basis.

**There are many potential policy tools available to increase the electric drive share of PHEVs.** EPA could consider the following measures:

» Adjust the regulatory charge-depleting drive share (utility factor) downwards for PHEVs to reflect current real-world performance.

» Require in-use data reporting for specific PHEV models to receive a higher utility factor reflective of said in-use data.

» Adopt minimum electric driving range requirements, similar to California's range requirements for zero-emission vehicle crediting in its Advanced Clean Cars II regulation.

» Adopt other vehicle model-level technical requirements such as minimum all-electric power, maximum fuel tank size, fast-charging capability, and minimum cold weather performance.

» Establish a higher utility factor corresponding to demonstrated purchase of PHEV by drivers with home chargers or proof of manufacturer-provided charging access assistance.

Meanwhile, manufacturers could incentivize regular charging by assisting in home charger installation and by actively reporting cost of driving to users. Tax administrators can incentivize PHEV purchases by offering purchase or tax credits for PHEVs whose in-use data show high utility factor.

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# BACKGROUND AND POLICY CONTEXT

Plug-in hybrid electric vehicles (PHEVs) have both an engine and one or more electric motors coupled to a battery for electrical energy storage. Compared to hybrid electric vehicles with no plug-in capability, PHEVs have larger battery packs which can be recharged with an external charger and tend to have higher power electric motors than non-plug-in hybrids. Due to these characteristics, PHEVs can cover most daily trips using primarily or exclusively electricity, with substantially less need for fuel burn than non-plug-in hybrids.

PHEVs have two main driving modes: charge depleting (CD) and charge sustaining (CS). In CD mode, the vehicle drains the battery through electric propulsion, which, depending on the vehicle model and driving conditions, may be supplemented by burning fuel in the engine. As indicated by CD mode label fuel consumption in EPA's fuel economy guides, most PHEV models exhibit little to no fuel consumption during CD mode operation (EPA, 2022). However, on more demanding test cycles or under more varied ambient conditions, many PHEV models show significantly more fuel consumption in CD mode (Bieker et al., 2022; Dornoff, 2021a). In CS mode, the battery is held at a constant state of charge, with the engine taking over as the primary power source. Utility factor (UF) is defined as the share of miles driven in CD mode. It is important to note that electric drive share (EDS)—the share of total miles driven purely on electricity with the engine off—is not exactly equal to the UF. Similarly, PHEV all-electric range (AER) is not necessarily equal to CD range. This is because most new PHEVs today operate in a blended mode during charge depletion, with the engine supplementing motor power. Nearly all PHEVs sold since 2011 have a rated AER of within 5 miles of CD range, and the vast majority are within 2 miles of CD range (US EPA, 2022). All but one model year 2022 PHEV has AER within 1 mile of rated CD mode range. Since CD range and AER are very similar and label CD fuel consumption is generally zero or very little, it can be expected that label UF and label EDS are also quite similar. However, in real-world operation, UF and EDS can deviate significantly, and CD mode fuel consumption can be high. Since all-electric driving is the only way to eliminate tailpipe emissions during real-world operation and guarantee overall emission reductions, the estimation of real-world PHEV performance in this paper focuses on EDS.

## REGULATORY TREATMENT OF PHEVS

For assessing compliance with greenhouse gas (GHG) regulations and for fuel economy labeling, the U.S. Environmental Protection Agency (EPA) uses defined equations for determining a PHEV model's city, highway, and label UFs, based on vehicle testing in CD mode (40 CFR 600.116-12). The city and highway fleet UFs are used for compliance purposes. In contrast to the UF of a fleet of PHEVs, to convey the UF for an individual PHEV, the multiple day individual utility factor (MDIUF) is used for EPA labeling purposes. Because label efficiency, range, and UF are designed to approximate real-world performance, references to label UF throughout this study correspond to MDIUF. Furthermore, compliance values for efficiency and fuel consumption are less reflective of real-world operation than their respective label values, such that real-world performance differences compared to label are likely to deviate even more from compliance values. The UF corresponding to a vehicle model's full CD range is based on the following equation:

$$UF = 1 - \left[\exp\left(-\sum_{j=1}^{k}\left(\frac{CD}{ND}\right)^{j} C_j\right)\right] \quad (1)$$

where:

$CD$ = range in CD mode in miles

$ND$ = normalized distance (399 miles)

$C_j$ = weighting coefficient

$k$ = number of coefficients (9 for city, 6 for highway, 10 for label)

The coefficients defining the precise shape of each UF curve are listed in Table 5 of 40 CFR 600.116-12 and reproduced in Table 1. Additional details are available in the appendix.

**Table 1.** Coefficients of each regulatory utility factor curve

| Coefficient ($C_j$) | Fleet values for CAFE and GHG UF | | Multi-day individual value for label UF |
|---|---|---|---|
| | City | Highway | City or Highway |
| **1** | 14.86 | 4.8 | 13.1 |
| **2** | 2.965 | 13 | -18.7 |
| **3** | -84.05 | -65 | 5.22 |
| **4** | 153.7 | 120 | 8.15 |
| **5** | -43.59 | -100 | 3.53 |
| **6** | -96.94 | 31 | -1.34 |
| **7** | 14.47 | | -4.01 |
| **8** | 91.7 | | -3.9 |
| **9** | -46.36 | | -1.15 |
| **10** | | | 3.88 |

*Note:* Data taken from Table 5 of 40 CFR 600.116-12

Equation (1) is defined in SAE J2841, which itself estimated PHEV utility factor using data from the 2001 U.S. Department of Transportation National Household Travel Survey (NHTS) (SAE International, 2010). Since 2001, there have been two additional travel surveys, one in 2009 and another in 2017. Duoba (2013) updated the J2841 UF curve for PHEVs using NHTS 2009 data. The same methodology described in Duoba (2013) was used in this report to update the UF curve using 2017 NHTS data (Federal Highway Administration, 2017). Figure 1 compares all three UF curves. The EPA label curve represents the current UF curve used to determine UF based on label CD range. For the same CD range, the other two curves show 2%–13% lower UF than EPA label.

For a certain CD mode range, the figure shows the expected fraction of driving that can be accomplished in CD mode. The UF curve was originally developed based on the performance characteristics of a range-extended PHEV that begins each day with a full charge and drives on electricity until the battery is depleted. These early PHEVs were essentially electric vehicles whose range is extended by using the engine primarily to recharge the battery. Thus, the UF effectively represents the EDS for this type of PHEV. For example, at a range of 20 miles, a range-extended PHEV can expect to cover around 45% of daily driving in CD mode alone (EPA label curve). A 50-mile range enables close to 75% of driving to be in CD mode. According to the EPA label UF curve, more than half of all driving can be covered by CD mode operation with 23 miles of CD mode range, implying significant fuel savings and $CO_2$ emissions reductions even for PHEVs with modest AER. Importantly, most new PHEVs are not range-extended and may not begin each day with a full charge.

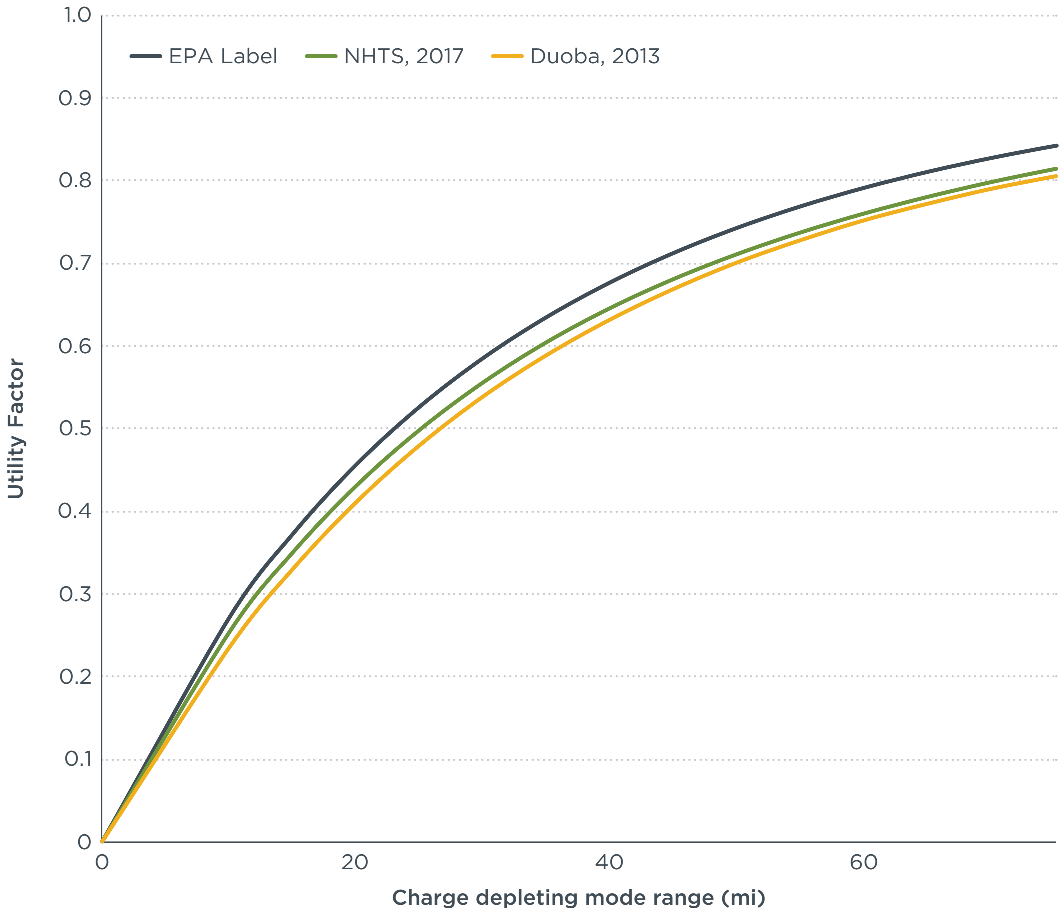


**Figure 1.** Comparison of utility factor curves based on travel survey data from 2001 (EPA label), 2009 (Duoba, 2013), and 2017 (Federal Highway Administration, 2017).

## PHEV USAGE IN EUROPE

The methodology for determining PHEV UF in Europe is very similar to that used in the United States, apart from differences in test cycle and UF curve equation coefficients. As described by Dornoff (2021b), the UF curve applied in the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) in Europe was developed when robust real-world data on PHEV driving behavior was unavailable, similar to the development of the UF curves used in the U.S.

Recent studies with user data from over 20,000 European PHEVs have shown that, in real-world usage conditions, the EDS of PHEVs falls far short of the UF curve assumed in the WLTP (Plötz et al., 2020; Plötz et al., 2022). For PHEVs owned by private individuals, the real-world fuel consumption is on average three times higher than the official WLTP values, while for company car PHEVs the fuel consumption is on average five times higher. Moreover, despite an increasing electric range and more public charging infrastructure, the deviation between real-world and official fuel consumption of PHEVs in Europe is observed to be growing.

In effect, the emissions benefit of PHEVs in Europe is much less than assumed to qualify for the substantial purchase subsidies and further tax incentives (Bieker et al., 2022). In addition, the unrealistic $CO_2$ emission values of PHEVs allow manufacturers to comply with the European Commission's $CO_2$ standards without appropriately reducing emissions. Compared to meeting the $CO_2$ standards by truly reducing the fuel consumption of combustion engine cars or deploying a higher share of battery electric vehicles, a higher share of PHEVs corresponds to an increase of real-world and life-cycle emissions (Bieker, 2022b). On average, each newly registered PHEV in Europe corresponds to additional emissions of 10 to 15 metric tons of $CO_2$ (Federal Environmental Agency, 2021).

The European Commission is addressing these issues by adjusting the original WLTP UF curve. According to a current proposal, a two-step adjustment bends the original UF curve to the real-world evidence of Plötz et al. (2022). For PHEVs registered in 2025 and 2026, the UF would be adjusted to the EDS observed for private PHEVs. From 2027 onwards, a second adjustment would be based on the EDS observed in the total private and company car fleet. If sufficient PHEV usage data from on-board fuel consumption monitoring (OBFCM) devices is available, the second adjustment would instead be based on OBFCM data. In the EU, OBCFM devices are mandatory for new vehicles since 2021 (Dornoff, 2021).

**Table 2.** Comparison of the market share of PHEVs and battery-electric (BEV) and fuel cell-electric (FCEV) vehicles in the United States and European Union.

| | 2019 | 2020 | 2021 | 2022 H1 |
|---|---|---|---|---|
| **U.S. BEV** | 1.4% | 1.8% | 3.3% | 5.5% |
| **U.S. PHEV** | 0.5% | 0.4% | 1.1% | 1.4% |
| **Europe BEV** | 1.9% | 6.2% | 10.0% | 10.0% |
| **Europe PHEV** | 1.1% | 5.2% | 9.0% | 9.0% |

*Note:* Europe passenger car data taken from Mock et al. (2022); US data for cars and light trucks taken from Marklines (2022).

The U.S. market share of PHEVs is about one third the share of fully electric vehicles. In Europe, the PHEV and fully electric market shares are very similar (Table 2). However, many of the conditions seen in Europe are already present in the United States. In both regions, current PHEV UF curves and testing procedures are based on limited data from a time when PHEVs were exceedingly uncommon and only few (range-extended) models existed. Similar to Europe, U.S. federal and state tax incentives currently exist for PHEVs. In some U.S. states, PHEVs are also incentivized by zero-emission vehicle regulations.

Thus, the conditions in Europe that led to the discovery of underperforming PHEVs, and the potential regulatory solutions, are also present in the United States. Absent regulatory action, current incentives could lead to PHEVs becoming compliance vehicles in the United States and costing the country millions in financial incentives, fuel costs, and $CO_2$ emissions. By acting quickly using updated real-world data, EPA can implement regulatory changes to incentivize better-performing PHEVs whose real-world benefits merit the incentives they receive.

## PREVIOUS DATA ON PHEVS DRIVEN IN THE UNITED STATES

Plötz et al. (2020) previously analyzed data on real-world electric drive shares of PHEVs in the United States, Europe, and China. The U.S. data from that study are summarized in the two figures below. We split these figures out to show the larger datasets (Figure 2) and smaller datasets (Figure 3) for better ease of viewing, but the data from both figures were analyzed together in Plötz et al. (2020). In each figure, each circle represents the weighted average of a single model in a single model year.

The two largest circles in blue in Figure 2 show data from a 2012 Chevrolet Volt (35 mi AER and CD mode range) and a 2015 BMW i3 range-extended obtained from California Air Resources Board (2017). The orange circles at 20-mile CD mode range represent 2013 Ford C-Max and Ford Fusion PHEVs from a 2014 Idaho National Laboratory study (INL, 2014). Purple circles represent 2011–2013 Chevrolet Volts from Smart et al. (2014). The dark gray circles correspond to 2011–2019 Chevy Volts from Voltstats.net (Voltstats, n.d.), with 2016–2019 Volts shown at 53 miles of CD mode and all-electric range. Though Voltstats data from Plötz et al. (2020) only covered through 2019, the points in the figure were updated to include all data through April 2021, when Voltstats stopped collecting data.

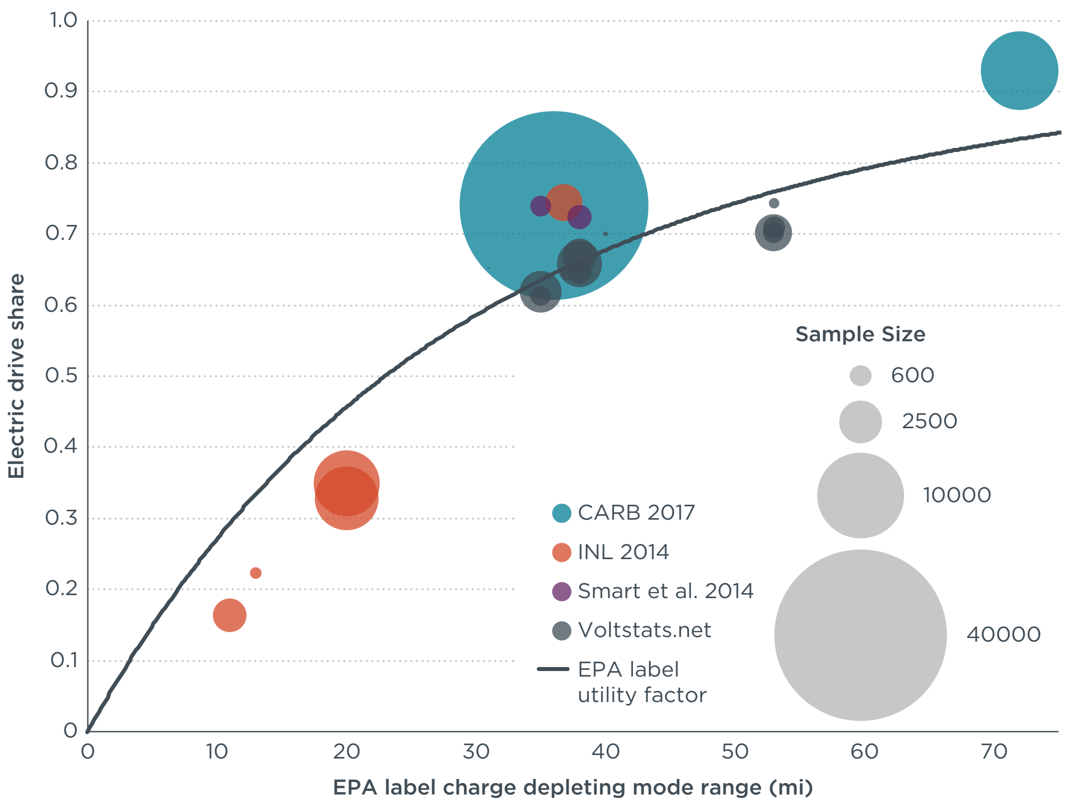


**Figure 2.** Data on real-world utility factors for PHEVs from larger datasets in Plötz et al. (2020). Volstats data updated to include data through April 2021.

The real-world data on the Volt EDS appears to consistently match the EPA label UF curve. Certain characteristics of the Volt help to explain this. Since they were first available, the Volt had the longest or second-longest CD mode range of all PHEV models (the i3 also shows real-world UF similar to the EPA curve at 72 miles of CD mode range). The Volt was designed primarily as a range-extended battery electric vehicle, whose engine serves mostly to power a secondary motor under rare circumstances, typically only after the battery has been fully depleted. Lastly, all Voltstats data is user self-reported and volunteered. This self-selection may bias the data in two ways. First, since many of the vehicles summarized in Figure 2 are from the first few model years after PHEVs were introduced, the data likely is biased towards early adopters, many of whom may have intentionally purchased PHEVs with environmental goals in mind and may have easy charging access. Second, users of self-reporting fuel consumption tools are potentially more cognizant of their fuel consumption (for cost or other reasons) and may tend to drive more efficiently and recharge regularly.

Figure 3 plots three other datasets in the same manner as Figure 2, with each circle representing the average EDS calculated from the reported fuel consumption of a single model in a single model year, and the size representing the number of vehicles considered in each average. Yellow circles correspond to a study by Raghavan and Tal (2020) on 2012–2016 Volt, 2016 Ford C-Max and Fusion, and 2015 Toyota Prius PHEVs. Green circles are from Tal et al. (2020) on 2014–2016 Volt, 2015 Prius, and 2016 C-Max PHEVs. The red circles are collected from the MyMPG website (US Department of Energy, 2022), which includes the MyMPG data from Plötz et al. (2020), as well as recent data through March 2022. As with Voltstats, the MyMPG data is self-reported. While the data in this figure generally indicates that longer-range PHEVs perform closer to the expected EPA label UF curve, there is a broad spread of real-world EDS, especially at 30 miles or less of range. Despite the self-selecting nature of the MyMPG database, a majority of MyMPG points in Figure 3 fall below the EPA label UF curve. As in Figure 2, data on Volts from a smaller dataset (Raghavan & Tal, 2020) in Figure 3 shows real-world EDS similar to the EPA label UF (yellow circles at 35-, 38-, and 53-mile ranges). Additional information on the updated Voltstats and MyMPG datasets, as well as the methodologies for calculating EDS from Voltstats and MyMPG data, are described in the appendix.

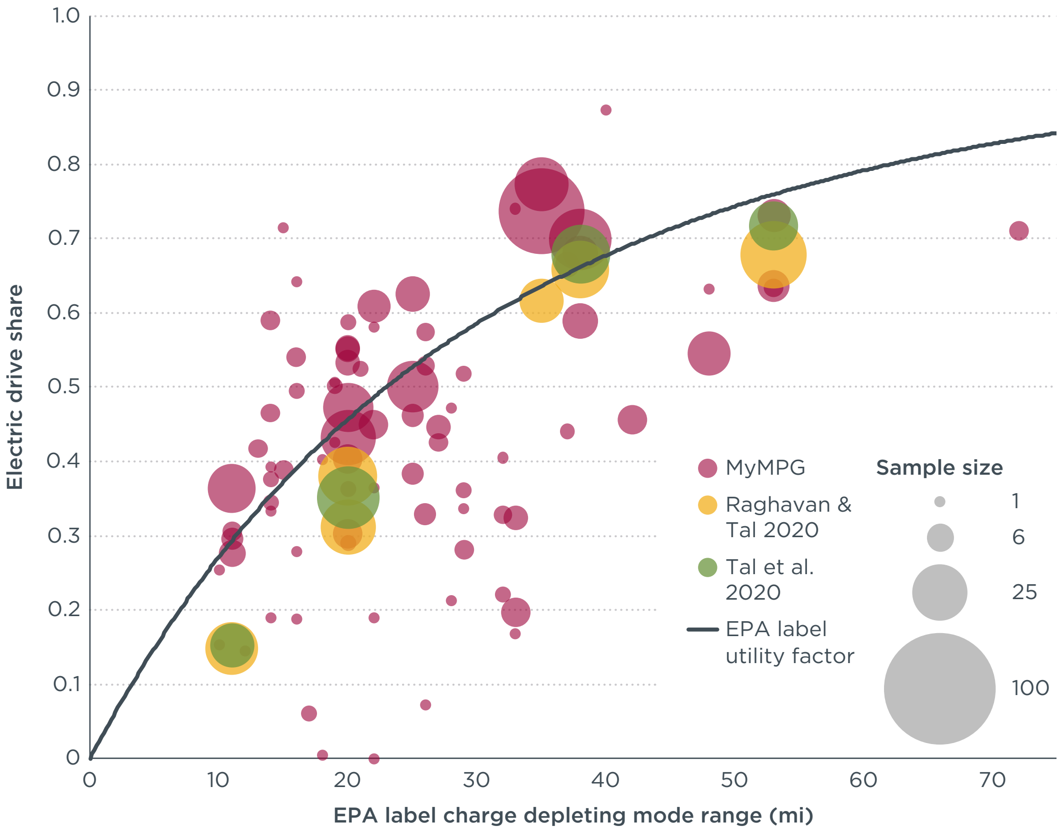


**Figure 3.** Data on real-world utility factors for PHEVs from smaller datasets in Plötz et al. (2020). MyMPG updated to include data through March 2022.

The points in both figures at and below 30 miles of CD mode range suggest additional data collection would be helpful to ascertain the real-world performance of PHEVs with limited range. In figures 2 and 3 taken together, 74% of the data is specifically for Volts, which is not a representative model for all PHEVs available for U.S. consumers today, most of which have shorter CD range and operate in blended mode. Moreover, as much of this data is volunteered through self-reporting or participation in studies by early adopters, less biased data from a broader range of consumers can reveal more about PHEV utilization among the general population.

## RECENT AND UPDATED SOURCES OF REAL-WORLD PHEV USAGE DATA IN THE UNITED STATES

This section presents two new sources of real-world PHEV usage data that were not included in the analysis in Plötz et al. (2020): Fuelly and the California Bureau of Automotive Repair (BAR). Fuelly is a website (with an accompanying smartphone app) through which users can record their fuel consumed and distance traveled between fuel-ups. The site then calculates average fuel economy per user, as well as aggregated fuel economy for individual models. Among U.S.-based users, Fuelly (2022) has user-reported data for 135 PHEV models, totaling 3,889 individual vehicles traveling over 97 million miles.

California's Bureau of Automotive Repair collects on-board diagnostic (OBD) data on all vehicles subject to testing (BAR, 2022). Through its 2015 OBD II provisions, new California-registered PHEVs must track relevant real-world energy consumption parameters, including total distance traveled and total fuel consumed, distance traveled and fuel consumed in CD mode (with engine on and off), and grid electricity into and out of the battery. Because the data reported to BAR is mandatory, this dataset avoids the self-selection bias inherent in the other datasets. However, since new cars are exempt from OBD testing and data collection for 8 years except for vehicles changing ownership or newly entering the state, the BAR dataset only contains those PHEVs subject to the exceptions. As such, many of the PHEVs in the dataset have low mileage or exhibit unrealistic/anomalous data. For purposes of this report, the BAR data were cleaned to include only PHEVs that showed self-consistent OBD data. The process of cleaning eliminated vehicles with under 3,000 km driven and those which had total mileage and total grid energy input that fell outside a 20% window compared to the odometer and total grid energy consumed. More details of this data cleaning process are included in the appendix. As of April 2022, the full dataset includes 111 PHEV models and 5,409 individual PHEVs that traveled over 62 million miles. The cleaned BAR dataset used in this analysis has 59 PHEV models and 1,465 individual vehicles that collectively traveled more than 24 million miles.

Combined, the two datasets include 5,354 individual vehicles that have traveled over 121 million miles, with a minimum distance-per-vehicle of 810 miles and a mean of 15,350 miles (median 13,211 miles). For comparison, studies of European PHEV usage include over 20,000 vehicles (Plötz et al., 2020 & 2022). VoltStats data contains over 11,000 Volts which have driven over 420 million miles. The Volt represents 19% of all vehicles in the combined Fuelly and BAR dataset. By incorporating a much more representative range of PHEV models, in part comprised of automatically-collected data, this dataset is thus much less biased by self-selection and early adopters compared to the previous U.S. dataset used in Plötz et al. (2020).

The method used to calculate EDS from real world fuel consumption data is the same as that in Plötz et al. (2020) and Plötz et al. (2022). Fuelly reports average fuel consumption, while BAR data contain lifetime fuel consumed and lifetime distance traveled, from which fuel consumption is readily determined. Electric drive share is then calculated as:

$$EDS^{real} = max\left[1 - \frac{FC_{real}}{FC_{CS}^{EPA}}, 0\right] \tag{2}$$

where $FC_{real}$ is average reported fuel consumption from Fuelly or BAR datasets, and $FC_{CS}^{EPA}$ is the EPA label fuel consumption in CS mode. In instances where overall real-world fuel consumption, $FC_{real}$, is greater than EPA-rated CS mode fuel consumption, EDS is set to 0.

The BAR data allows a second way to calculate EDS, as it also includes total distance traveled in CD mode with engine off. The share of total distance traveled that is driven in CD mode engine-off is precisely the electric drive share. This method should be more accurate than indirectly calculating the EDS from MPG. Both methods of EDS calculation are explored further below.

As shown in Figure 4, EDS calculated from average fuel consumption (Equation 2) tends to be lower than actual EDS calculated from the direct measurement of the fraction of all-electric travel. This discrepancy may be due to real-world fuel consumption in CS mode being higher than label CS mode fuel consumption. Calculated EDS is, on average, 12% lower than measured EDS. All vehicles which have a calculated EDS of 0 (average fuel consumption greater than $FC_{CS}^{EPA}$) have measured EDS of higher than 0 (recorded engine-off distance >0). Nevertheless, estimating EDS from fuel consumption represents actual EDS, as recorded by OBD systems in the BAR data, fairly well.

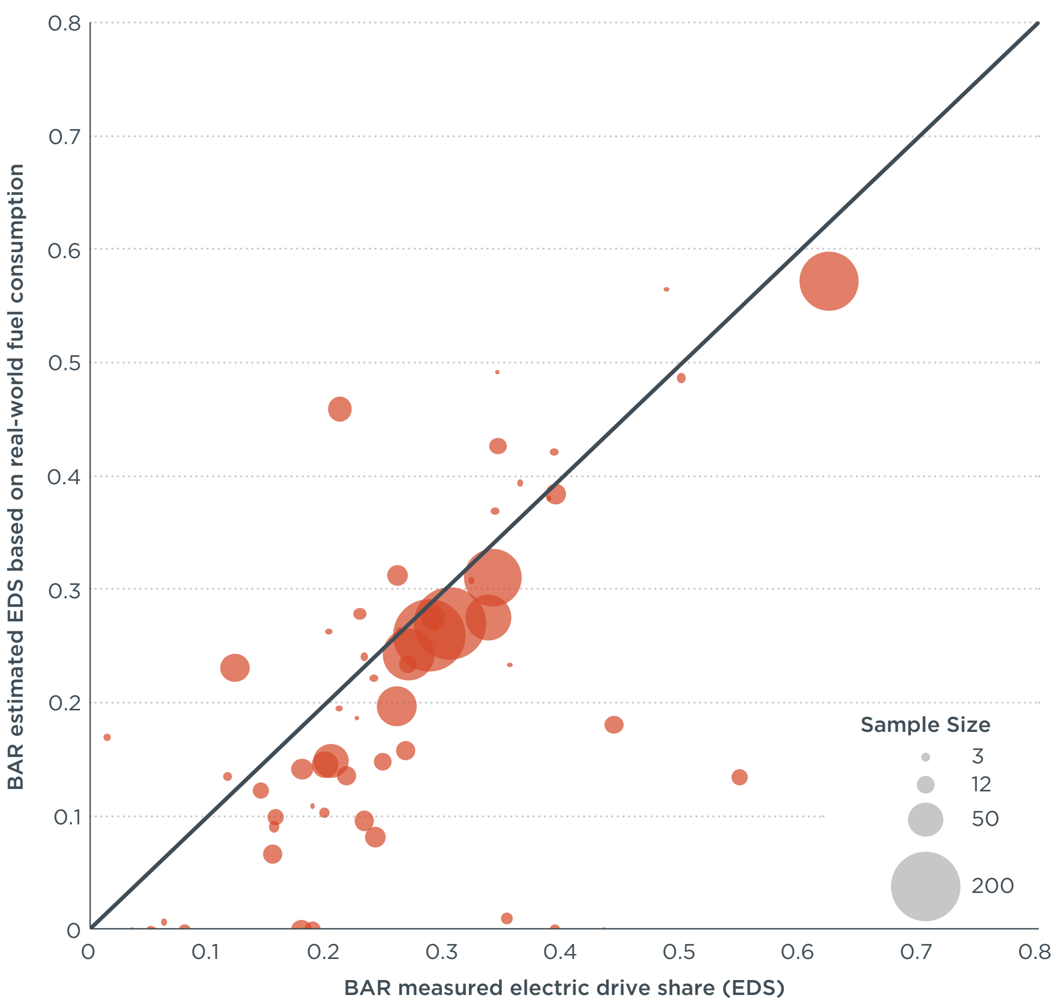


**Figure 4.** Comparison of EDS calculated from fuel consumption and actual EDS using direct measurement of all-electric travel fraction from BAR database.

Figure 5 plots the EDS calculated using Equation (2) (Fuelly; blue circles) and using direct measurement of EDS (BAR; orange circles), and compares the data to the EPA label UF curve (black). The datapoints overwhelmingly lie below the EPA UF curve. This trend suggests the EPA UF curve substantially overestimates the electric drive share of PHEVs. Given the variety of models and total distance traveled in the Fuelly and BAR datasets, the trends shown are likely representative of PHEV real-world performance. However, additional data collection could verify these results, as well as reveal factors affecting real-world EDS.

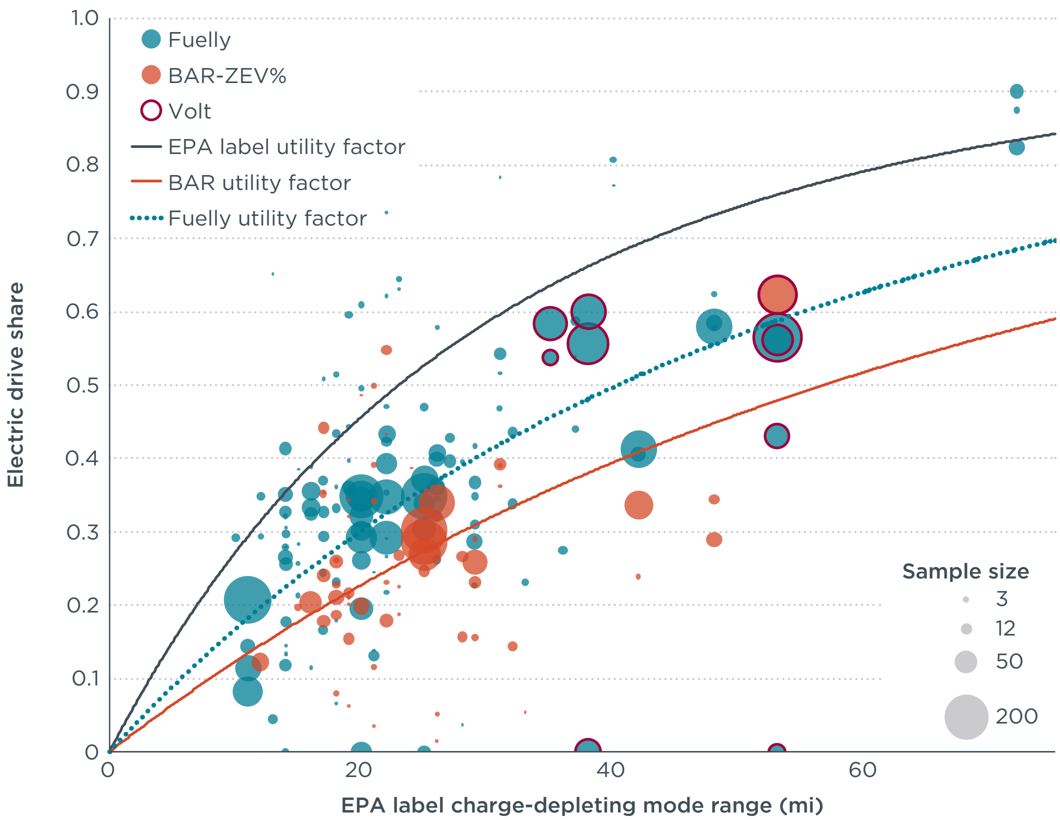


**Figure 5.** Calculated electric drive shares and adjusted utility factor curves based on California BAR (using direct measurement of all-electric travel fraction) and Fuelly (calculated from fuel consumption) datasets.

By adjusting the normalized distance parameter (*ND* in Equation 1), a new UF curve was developed for each dataset using sample-size weighted nonlinear least squares regression. Selecting normalized distance as the free regression parameter maintains the functional form of the UF curve, is simple to change in the regulation, and, as a range scaling factor, increasing normalized distance implies lower UF for the same CD mode range (Plötz and Jöhrens, 2021). The BAR UF curve (orange) has a normalized distance of 985 ± 118 miles (best fit ± two standard errors), 2.5 times the default normalized distance of 399 miles. (Weighting the BAR data by distance traveled results in a very similar normalized distance of 948 ± 104 miles.) The Fuelly UF curve (blue) has a normalized distance of 700 ± 64 miles. Across all CD ranges, the adjusted UF curves show lower UF than the EPA label UF curve. As the weighted average of real-world data for a given CD range, the adjusted UF curves are a better approximation of real-world PHEV usage than the current EPA label UF curve. In contrast to the Volts plotted in Figure 2 and in Figure 3, the corresponding points in Figure 5 (53 mile and

38 miles CD ranges, highlighted in red circles) are noticeably lower. Whereas the EPA UF curve estimates that 50% of driving needs would be met with about 23 miles of CD range, the adjusted UF curves indicate that only a quarter to a third of real-world driving is conducted in CD mode with this range. The 50% threshold isn't met for real-word driving until 41 and 57 miles of CD range is available, which is approximately double the current regulatory value. The sample-weighted average difference between EPA UF and adjusted UF is a 31%–44% reduction in UF in the real world. Among new PHEVs in model year 2022, rated range is 8–42 mi. Compared to the EPA label curve, such vehicles could exhibit a real-world UF reduction of 41%–56% (BAR) or 26%–39% (Fuelly).

As explored above, the new Fuelly and BAR datasets are large enough to show emerging trends. However, there are important limitations to the data. As with all previous data sources, Fuelly data are voluntarily self-reported. As such, they may be subject to the same types of self-selecting biases and self-reporting errors as other datasets (MyMPG, VoltStats, e.g.). Additionally, more than 75% of PHEVs in the Fuelly dataset are from 2018 and earlier model years. Thus, the Fuelly data may be biased towards early adopters who have easy access to charging and an eagerness to track fuel consumption data. Mainstream drivers with less access to charging may show even lower EDS.

While not volunteered by vehicle owners in the same way as other data sources, BAR data may still have some self-selection bias in that only vehicles which recently moved into California or those that changed ownership are currently represented in the data. Since only model year 2019 and newer PHEVs collect the relevant OBD data, the vehicles in the dataset have low mileage and are within the first few years of ownership. Data collection errors are attributable primarily to OBD collection errors. Furthermore, BAR vehicles may not represent average PHEV driver behavior if they are changing ownership after only a couple years due to, for example, unhappy consumers or rental car fleet selling after 1–2 years. Because BAR data is automatically collected, as the database grows, it will become increasingly representative of average real-world PHEV usage and the above concerns related to early data will diminish. Additionally, it is possible that there were data collection issues present among the first PHEVs whose data were recorded that have since been fixed.

The raw fuel consumption data in Fuelly and BAR offers an opportunity to compare it to EPA's combined fuel consumption, which is a UF-weighted average of CD combined and CS combined fuel consumption values. It is important to note the distinction between EPA MPG of gasoline-equivalent (MPGe) values and the EPA fuel consumption values shown in Figure 6. For labeling purposes, EPA calculates MPGe by converting the electrical energy consumed in CD mode into gasoline-gallon-equivalent and combining these MPGe values with MPG in CS mode (specifically, a harmonic average). To get a better sense of the total gasoline consumed during actual operation, the fuel consumption (in gallons per 100 miles) in both CD mode and CS mode as reported by EPA (EPA, 2022) are combined using the EPA label UF. This calculation gives the label fuel consumption, which can then be compared directly to real-world fuel consumption in the Fuelly and BAR data. Figure 6 depicts this comparison. Virtually all PHEV models have higher real-world fuel consumption than EPA label fuel consumption. Weighting by number of vehicles per model, real-world fuel consumption averages are 42%–67% higher (average of 49% across both datasets) than EPA label fuel consumption. This real-world fuel consumption shows the significance of the $CO_2$ emissions and fuel consumption impacts of under-performing PHEVs.

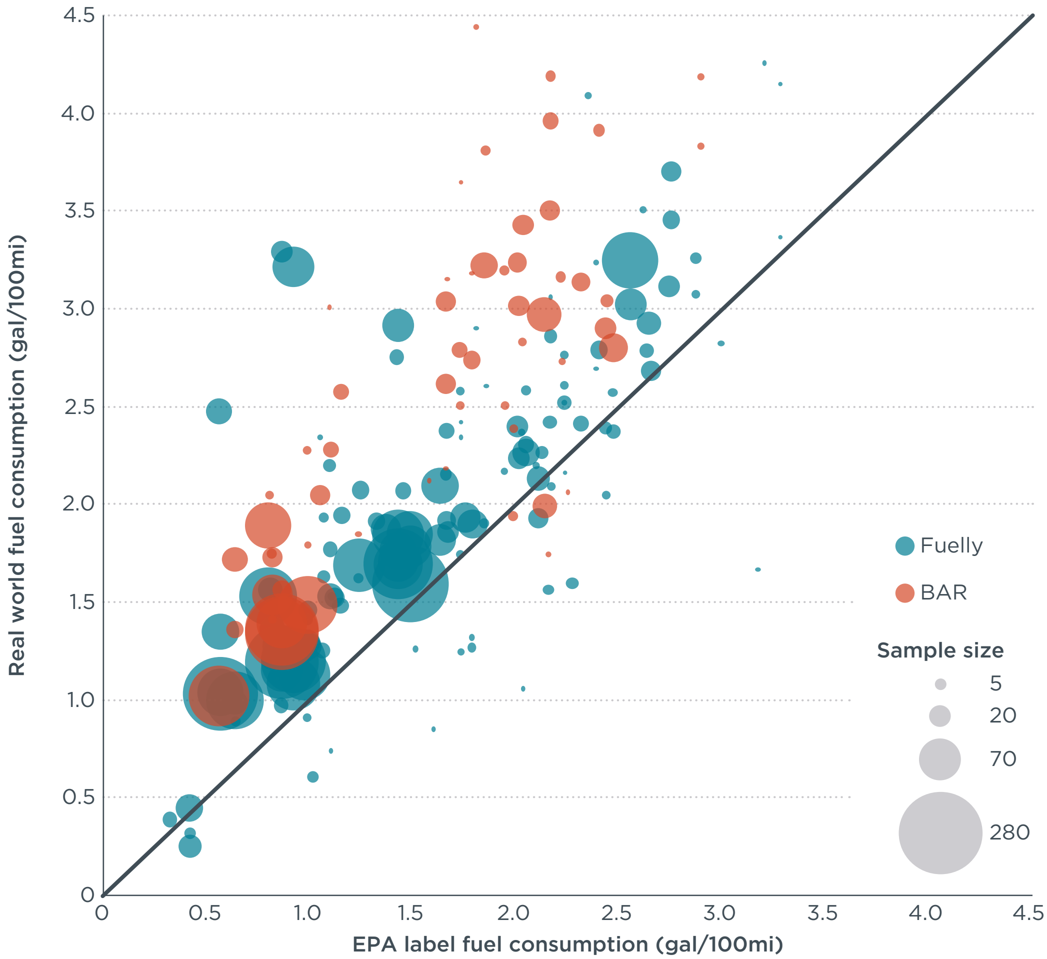


**Figure 6.** Comparison of real-world fuel consumption and EPA label fuel consumption.

The new PHEV real-world data implies PHEVs have consistently lower UF and EDS in the real-world than assumed in the EPA LDV GHG standards and NHTSA CAFE standards. Furthermore, they show consistently higher fuel consumption and $CO_2$ emissions than predicted for both labeling and for regulatory compliance. As these datasets, particularly BAR, continue to grow, the initial indications shown here should be updated. Additionally, more data will enable research into the impacts of engine power, electric range, and other characteristics on the EDS of PHEVs. Results from Europe and the Voltstats trends discussed above suggest that decreasing engine power and increasing range can positively increase PHEV UF (Plötz et al. 2020; Plötz et al. 2022).

## RECOMMENDATIONS FOR IMPROVING ELECTRIC DRIVE SHARE

Our results suggest that the electric capabilities of PHEVs are underutilized in average real-world usage conditions. The low real-world EDS we calculate indicates that many PHEVs are not plugged in daily. Many PHEV models may not have the capabilities for adequate driving experience while driving solely on electricity, considering both range and power. These shortcomings offer an opportunity for improvement, and this section presents several options for environmental regulators, auto manufacturers, and tax administrators to consider that could potentially lead to increased utilization of electric driving of PHEVs.

A simple testing criterion for PHEVs is a minimum range requirement; for example, a minimum requirement of 70 miles of 2-cycle CD mode range coupled with at least 40 miles all-electric range on US06 test cycle. The US06 cycle has the highest top speed and acceleration of all drive cycles, so ample all-electric US06 range is indicative of a PHEV's capability of meeting average power and acceleration requirements solely with electricity, while also avoiding the need for engine starts altogether over the minimum all-electric range requirement. Similar minimum all-electric range requirements could also be implemented on other test cycles. California's Advanced Clean Cars II regulation introduces a minimum 70-mile CD mode range requirement for full PHEV crediting in its zero-emission vehicle regulation and for all crediting after 2028 (CARB, 2022). While this requirement does not guarantee all or even mostly electric driving in PHEVs, it will at least ensure that all PHEVs credited in the zero-emission vehicle regulation have the capability for high electric drive share.

As mentioned previously, studies in Europe and some evidence from Chevy Volt usage in the United States indicate that reducing engine power can reduce fuel consumption and increase EDS. In the case of the Volt, much of the engine's usage is intended as a range extender, enabling operation in a window of peak efficiency. To ensure adequate performance capabilities, setting minimum motor power requirements or asserting an engine power-to-weight limit can serve to improve real-world PHEV emissions reductions.

Additional options to improve the all-electric usage of PHEVs include the following potential requirements for vehicles: maximum fuel tank size and vehicle all-electric range, vehicle active reporting of instantaneous and average fuel consumption and cost per mile, adequate cold weather all-electric range, and fast-charging capability. Failure to meet the above technical requirements could relegate a non-compliant PHEV to the same regulatory treatment and compliance testing as a conventional, non-plug-in hybrid.

Beyond vehicle-specific characteristics, regulators can directly incentivize manufacturers to sell PHEVs with high real-world EDS by adjusting the UF curve. The most accurate and fastest way to adjust the UF curve is to use the OBD collection of key fuel and energy consumption metrics already imposed on new PHEVs sold in California. This data can be used in the near term to adjust the current UF downwards to be closer to the average in-use EDS. This initial adjustment would ensure actual $CO_2$ reductions match predictions. Through the continued accumulation of real-world data and mandatory data reporting, this initial adjustment can be revised for fleet-average or model-specific UFs, assuming sufficient evidence exists to support the increase. In this way, the UF can meet the goal of projecting average in-use fuel consumption while remaining valid for as many vehicles as possible.

Another minimally burdensome method that may improve the all-electric usage of PHEVs is offering a higher default UF for presence of a home charger (see Table 3). To enter this tier, for each PHEV sold a manufacturer must provide evidence of a buyer's home charger or its installation, or evidence of assistance with installation of a charger. This strategy, which may be used in combination with the previous UF adjustments discussed above, incentivizes automakers to take voluntary action to help consumers install chargers or provide access to charging.

Lastly, tax incentives for PHEV purchases can be linked to real-world EDS data, with the level of incentive dependent on proven real-world average fuel consumption. Purchase incentives can be combined with free charger installation or with charging cards for users without access to home charging. All the above policy levers are summarized in Table 3, grouped by actor.

**Table 3.** Policy options for increasing PHEV all-electric drive share and decreasing fuel consumption.

| Stakeholder | Policy option | Rationale |
|---|---|---|
| **Regulator: Fleet-level** | Reduce default regulatory UF and increase the UF for specific models based in-use data | Incentivizes manufacturers to implement vehicle and consumer strategies that increase PHEV electricity operation and UF values over default regulatory values. |
| | Minimum requirements for real-world OBD data reporting for the opportunity to be granted higher UF | Increases the growth rate of real-world PHEV usage database(s), permitting faster and more accurate UF adjustments |
| | Grant higher UF with proof/installation of home charger upon purchase | Ensures PHEV owner can recharge daily, thereby beginning each day with the maximum available electric range |
| **Regulator: Vehicle model-level** | Minimum 2-cycle all-electric range | Ensures a useful amount of overall electric range |
| | Minimum US06 all-electric range | Ensures better all-electric capability under high load and high-speed scenarios; reduces real-world need for engine starts. |
| | Motor power minimum or engine power to weight limits | Shifts more driving to the motor; treats engine as efficient range extender |
| | Maximum fuel tank size or vehicle range | Limits fuel consumption, encourages maximum efficiency of fuel consumed, and encourages drivers to recharge |
| | Fast-charging capability requirement | Allows drivers to recharge rather than refuel when on long trips, which may otherwise be outside vehicle's rated range |
| | Minimum fully electric capability in cold weather | Permits drivers in all climates to obtain the fuel saving benefits of PHEVs |
| **Manufacturer** | Active fuel consumption/cost-per-mile reporting to drivers | Indicates to drivers when they are using fuel and paying more for driving; enhances feedback to highlight electric driving experience |
| | Assist in home charger installation | Ensures PHEV owner can recharge daily |
| **Tax administrators** | Offer tax incentive only if real-world data supports | Where robust in-use data allows, manufacturers would benefit from decrease in sales price of high-achieving PHEVs |

Given the potential of foregone benefits associated with favorable treatment of PHEVs, there is a risk that PHEVs could be used by manufacturers to comply with regulatory obligations, while the climate benefits are not achieved. An additional major concern is that PHEV testing does not adequately capture the real-world CD and all-electric ranges, as evidenced by recent datasets from Fuelly and the California BAR. Since the point of the UF is to model the emissions from PHEVs in real-world use, adjusting the current UF curve is likely necessary to accurately reflect PHEV emissions. Unrealistic

PHEV $CO_2$ emissions values used for compliance allows manufacturers to meet vehicle standards without appropriately reducing emissions. Compared to meeting standards by reducing fuel consumption of non-plug-in vehicles and increasing the share of fully electric vehicles, increasing PHEV market shares could increase $CO_2$ emissions on a fleet level (Bieker, 2022b).

The real-world UF adjustment approaches outlined above are illustrated in Figure 7. Though not analyzed in this report, the California BAR data contains recorded grid energy into the battery. This specific data could be used as a proxy for charging frequency to adjust the UF curve if needed to account for presence of a home charger.

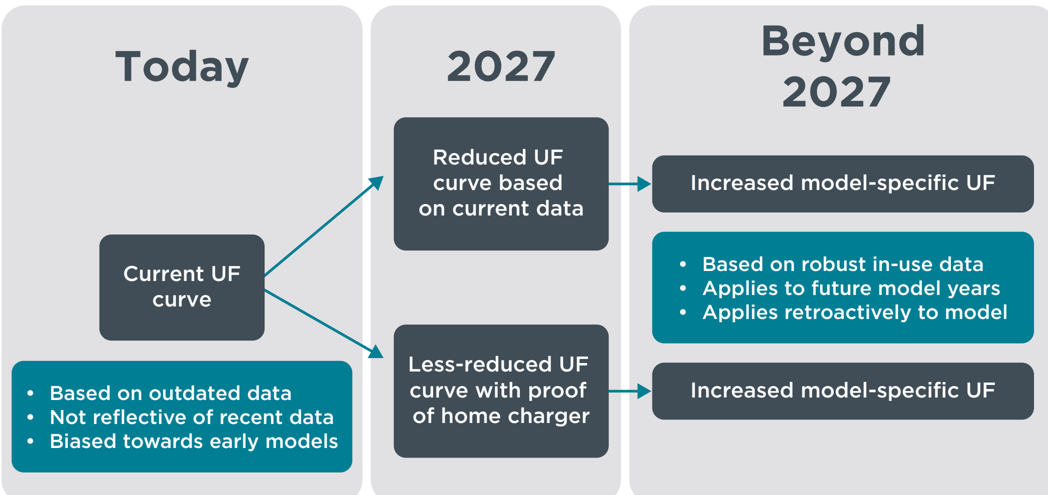


**Figure 7.** Example regulatory UF adjustment based on real-world driving and charging availability.

# CONCLUSION

This paper updates previous analyses of U.S. PHEV usage using more recent data. Our findings indicate that the current regulatory UF curve may not accurately predict the electric share of PHEV driving. More data collection is warranted along with the continued study of other factors that impact all-electric usage. The following conclusions can be drawn from this study:

**Real-world electric drive share may be 26%–56% lower than assumed within the EPA labeling program.** We find that current PHEVs show electric drive shares much lower than assumed in EPA labelling. New datasets indicate that real world fuel consumption is on average 42%–67% higher than EPA label fuel consumption. There is a risk that PHEVs will be used by manufacturers for compliance with future regulations, although they do not reduce emissions in real-world operation.

**While these results clearly demonstrate that real-world electric drive share is lower than labeled, more data collection could provide greater precision and clarity.** New, growing datasets indicate PHEVs are not achieving the emissions reductions they are assumed to generate for compliance and labeling purposes. As PHEVs are still a very small share of existing fleet and new sales, data sources to date may be inherently biased towards early adopters. Furthermore, all datasets examined herein suffer from some degree of self-selection bias and potentially other confounding factors. Still, the trends in the new PHEV data clearly point to the need for much closer inspection and broader investigation into PHEV usage to inform regulatory treatment. The EPA can require OBD reporting in order to obtain additional data.

**There are many potential policy tools available to increase the electric drive share of PHEVs.** As a regulator, EPA could implement the following:

» Adjust the regulatory utility factor downwards for PHEVs to reflect current real-world performance.

» Require in-use data reporting for specific PHEV models to receive a higher utility factor reflective of said in-use data

» Adopt minimum electric driving range requirements, similar to California's range requirements for zero-emission vehicle crediting in its Advanced Clean Cars II regulation

» Adopt maximum engine power-to-weight limits

» Establish a higher utility factor corresponding to the purchase of PHEV by drivers with demonstrated home chargers or manufacturer assistance with charging access

Meanwhile, manufacturers could incentivize regular charging by assisting with home charger installation and by actively reporting cost of driving to users. Additionally, tax administrators can incentivize PHEV purchases by offering purchase/tax credits only for PHEV models whose in-use data show high utility factor.

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# APPENDIX

## U.S. EPA UF CURVES AND LABEL UF VALUES

The three UF curves (city, highway, label) are plotted in Figure A1. Note that the city and highway curves are used for compliance purposes only, not for labeling. The label utility factors of each PHEV model available from 2011 to 2022 are also shown (black squares) (EPA, 2022). The outlying label UF values shown as empty red squares correspond to the handful of models whose CD range was voluntarily lowered by manufacturers. According to the fuel economy guides from which these data come, EPA awards the higher UF to these vehicles as though the CD range had not been lowered.

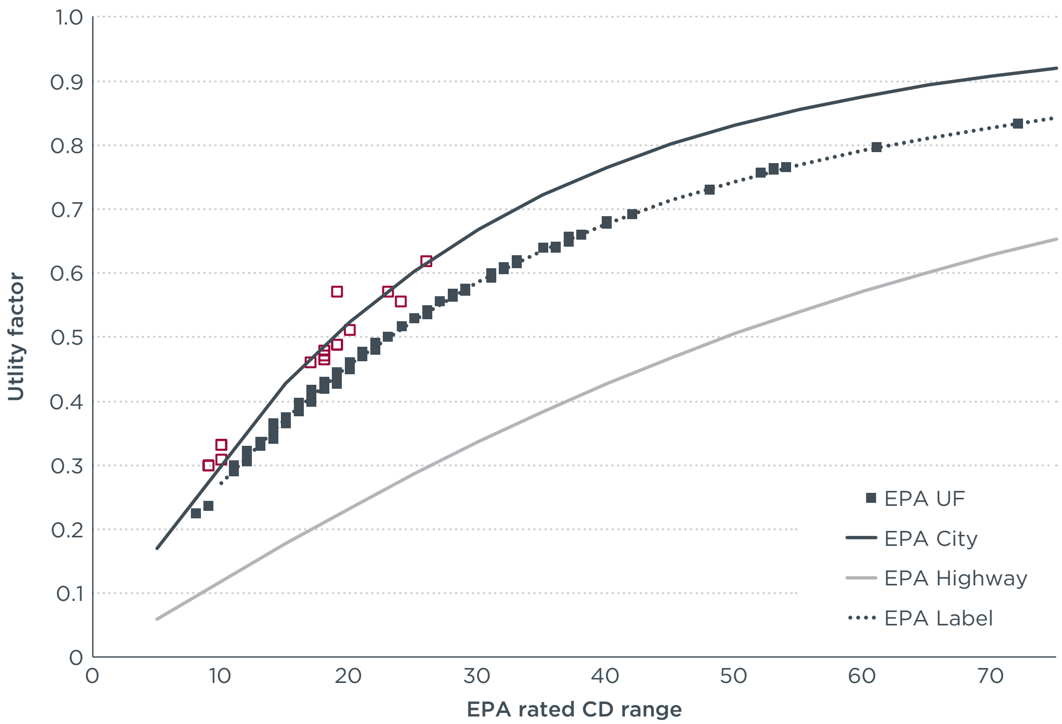


**Figure A1.** EPA utility factor curves and label values

## IN-USE DATA PROCESSING

### Voltstats

Voltstats collects data by individual user/vehicle. Data collected includes miles driven solely on electricity and total miles driven. All data entries for all users (over 11,000) were manually downloaded and EV miles and total miles were aggregated by model year. Dividing EV miles by total miles gives the UF directly. No additional data cleaning was performed.

Of the full dataset, more than half of users drive 2011–2013 Volts, which account for over half of total miles driven and EV miles driven. Over 10% of users reported EDS>0.9 (over 90% of driving on electricity alone) and over 45% reported EDS>0.76. The EPA label UF for the Volt increased from 0.64–0.66 (model years 2011–2015) to 0.761–0.764 (model years 2016–2019). Since users of Voltstats are largely early PHEV adopters and voluntarily report their driving patterns, it is highly likely the data skews towards higher shares of electric driving due to self-selection bias.

### MyMPG

Data from MyMPG were manually collected using the “power search” function, selecting only PHEVs (U.S. Department of Energy & U.S. EPA, 2022). The data is provided as a running average MPG-equivalent for each user, as well as date of last update. The data for certain users also includes fractions of city and highway driving. Despite certain high values of user-reported MPGe, all data were included in the analysis.

The MyMPG data contain 450 PHEVs, with only 26% receiving an update since January 2020. EDS was calculated according to Equation (2). Although users can directly record their fuel economy in miles per gallon-equivalent, they can also input fuel consumption and distance traveled, with which a calculator automatically generates MPGe. In addition to similar self-selection bias as present in the Voltstats data, MyMPG may also have data quality issues due to inconsistent methods of calculating MPGe.

### BAR

The newest database examined here comes from California’s Bureau of Automotive Research. The database contains information gathered upon every official inspection during which OBD data were collected. Each entry, which had all personally identifiable information removed, contains a wealth of information on vehicle performance history. Critical data include total distance traveled and total fuel consumed. For PHEVs specifically, important energy-related data include distance traveled in CD mode with the engine on and with the engine off, total grid energy consumed in CD mode with the engine on and with the engine off, and total grid energy into the battery.

Because California’s PHEV OBD reporting requirements only apply beginning in model year 2019, the majority of PHEVs with recorded data are within their first few years of operation. The first year of the new OBD phase-in could have had data issues that were resolved for 2020.  Furthermore, new vehicles are ordinarily not subject to inspection in California for 8 years. The PHEVs in the BAR database are those that fall under the specific circumstances of either migrating into the state or being sold. New vehicles being sold after only a few years of ownership may be biased towards users who were unsatisfied with their PHEV, or fleet owners that sell after a few years and higher-than-average driving. Thus, there still may be a degree of self-selection bias present in the BAR data, albeit of a different type than in previous, volunteer-only databases.

Around 349,000 model year 2019+ vehicles in the BAR database have a recorded lifetime distance traveled of any value (separate from odometer reading). Of these, 5,409 vehicles have recorded lifetime distance traveled in CD mode with engine off, indicating they are PHEVs. These vehicles recorded nearly 63 million miles traveled. The cleaned data is a subset of the data from these vehicles. However, even this larger dataset of 5,409 vehicles shows results similar to the cleaned data. Figure A2 and Figure A3 compare the two datasets. The larger dataset shows a greater spread between calculated EDS and measured EDS than does the cleaned data. Overall, the larger set shows calculated EDS to be a reasonable estimate of actual EDS, but with the same tendency to slightly underestimate actual EDS. Plotting measured EDS against rated CD range (Figure A3), the larger dataset is consistently lower in average measured EDS than the cleaned dataset.

To minimize the potential biases and select only vehicles with enough driving such that the OBD data has settled, vehicles with <3000 km of total travel were culled, leaving 269,000 model year 2019+ vehicles. To eliminate non-PHEVs (and potentially some PHEVs), vehicles without a record of distance traveled with the engine off were removed (vehicles with a record of 0 km remained in the database). These two steps left around 4,000 vehicles. Subsequent cleaning steps included eliminating vehicles whose total grid energy input was not within 20% of total grid energy consumed (2,000 vehicles remaining) and eliminating those whose odometer reading was not within 20% of lifetime distance traveled (around 1,500 vehicles remaining). These final two steps sought only the entries with the best evidence of a properly functioning OBD and uniformly collected data. Collectively, the remaining vehicles had traveled over 24 million miles. Total distance per vehicle in the BAR data is only about 12% lower than total distance per vehicle in Fuelly data.

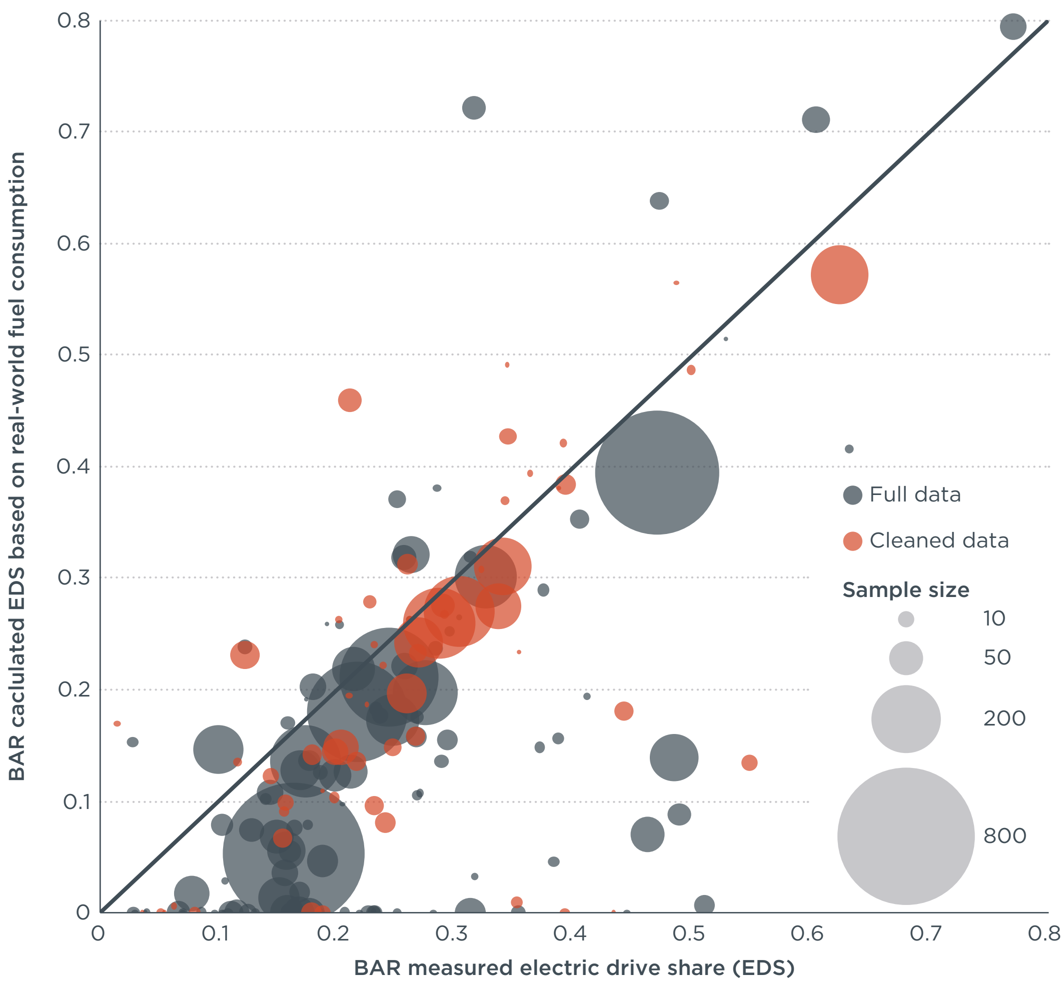


**Figure A2.** Comparison of calculated (from fuel consumption) and actual (using direct measurement of all-electric travel fraction) EDS from BAR database; cleaned data (orange) and full data (gray).

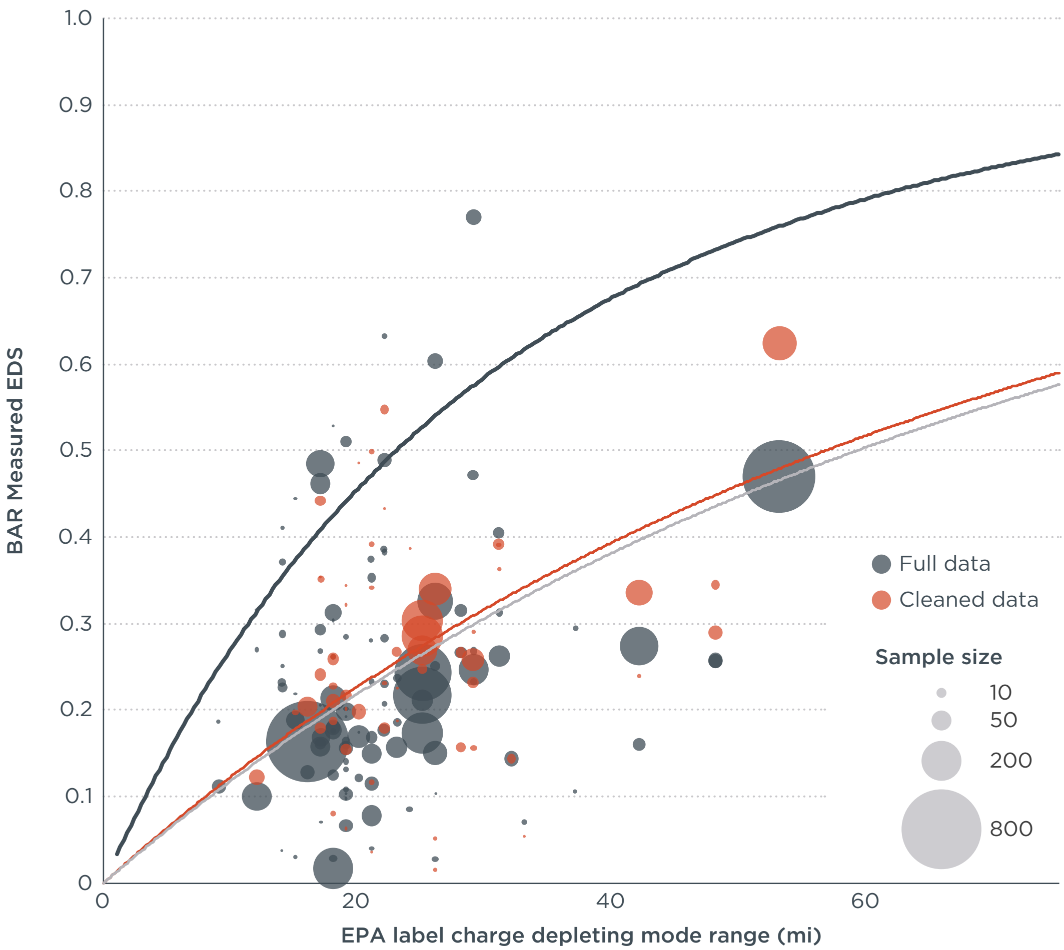


**Figure A3.** Comparison of EDS (recorded directly on-board) between BAR clean data (orange) and full data (gray)

## Fuelly

Fuelly is very similar to MyMPG in terms of user-reported data of fuel economy. However, Fuelly specifically requires the input of fuel consumed and distance traveled. The site aggregates fuel consumption data among all users of the same model and reports a fuel economy value for that model. Although this aggregated data is available, for this paper all individual user fuel consumption data were collected. The UF calculation was performed using Equation (2).

In addition to self-selection bias potentially present among any set of voluntarily reported data, users assign their own model variants to their vehicles in Fuelly. Consequently, there can be several names or configurations for the same model PHEV. While most of the data collected from Fuelly were clearly designated as a PHEV, some data from PHEVs on Fuelly may be missing.

The Fuelly database consists of 3,889 vehicles, 135 distinct models, and over 97 million miles. Fuelly also gives users the option to report specific location data, and 950 users reported their location. Among these, 226 (24%) were from California. The remainder represent all U.S. states except Alaska, Hawaii, and Montana. Note that there may be additional users based in those three states, however they are not among the user group that reported its location. Figure A4 illustrates the distribution of users across the United States, with California excluded.

Distribution of Vehicles (excl. CA)

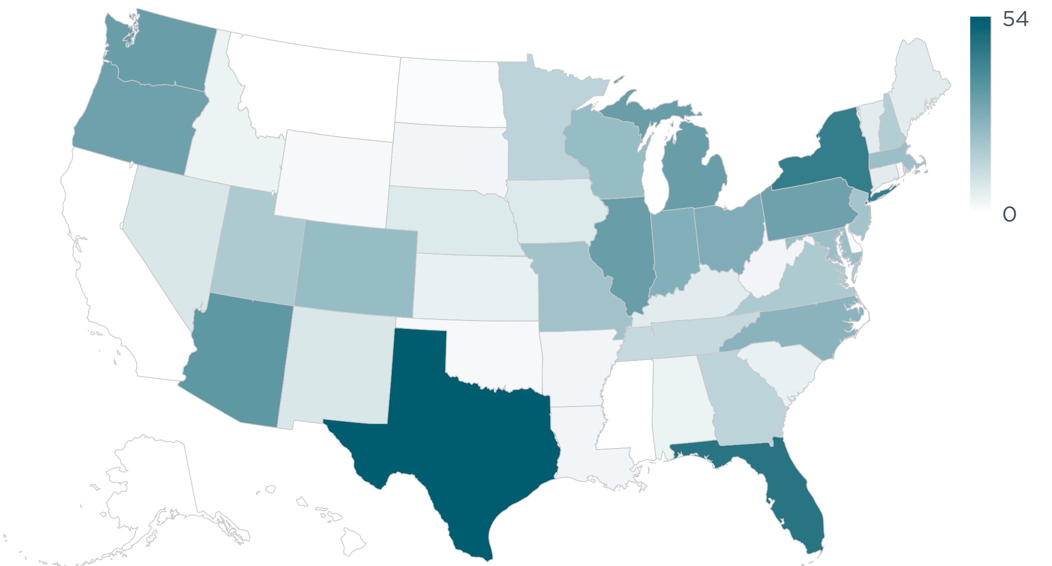


**Figure A4.** Distribution of Fuelly users from reported location data (excluding California).