ANL/ESIA-24/1

# Adoption of Plug-in Electric Vehicles: Local Fuel Use and Greenhouse Gas Emissions Reductions Across the U.S.

Energy Systems and Infrastructure Analysis Division

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# Adoption of Plug-in Electric Vehicles: Local Fuel Use and Greenhouse Gas Emissions Reductions Across the U.S.

by
Xinyi Wu, Yan Zhou, and David Gohlke
Energy Systems and Infrastructure Analysis Division, Argonne National Laboratory

February 2024

# CONTENTS

## TABLES

## FIGURES

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# LIST OF ACRONYMS

| | |
|---|---|
| BEV | Battery Electric Vehicle |
| CMAP | Chicago Metropolitan Agency for Planning |
| $CO_2e$ | Carbon Dioxide Equivalent |
| CUV | Crossover Utility Vehicle |
| DCFC | Direct Current Fast Charging |
| eGRID | Emissions & Generation Resource Integrated Database |
| EIA | U.S. Environment Information Administration |
| EPA | U.S. Environmental Protection Agency |
| GHG | Greenhouse Gas |
| GREET | Greenhouse gases, Regulated Emissions, and Energy use in Technologies (tool) |
| ICEV | Internal Combustion Engine Vehicle |
| LDV | Light-Duty Vehicle |
| PEV | Plug-in Electric Vehicle |
| PHEV | Plug-in-Hybrid Electric Vehicle |
| PTW | Pump-to-Wheel |
| PV | Photovoltaic |
| SUV | Sport Utility Vehicle |
| VMT | Vehicle-Miles-Traveled |
| WTP | Well-to-Pump |
| WTW | Well-to-Wheel |
| ZEV | Zero Emissions Vehicle |

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# ABSTRACT

The dependence on gasoline-powered light-duty automobiles has made U.S. households vulnerable to the burden of fuel costs. Tailpipe emissions from these vehicles constitute 58% of greenhouse gas (GHG) emissions in the U.S., which are damaging to the environment (EPA, 2023). The adoption of plug-in electric vehicles (PEVs) has been shown to effectively reduce fuel costs and GHG emissions. However, local effects on these benefits are not well understood by American consumers, potentially limiting adoption and therefore the realization of PEV benefits at scale (MacInnis & Krosnick, 2020; EY Americas, 2023). To fill this research gap, this study estimates the fuel cost savings and GHG emission reductions at the state and ZIP code levels by considering local fuel prices, vehicle class preference, average vehicle model year, fuel efficiencies, and driving intensities. The study's findings reveal that the adoption of PEVs can yield substantial benefits in terms of fuel cost savings and GHG emission reductions nationwide. Specifically, driving a battery electric vehicle (BEV) is estimated to result in annual savings of up to $2,200, while driving a plug-in hybrid electric vehicle (PHEV) can lead to savings up to $1,500, when compared to an internal combustion engine vehicle (ICEV) of equivalent size. Moreover, using population-weighted averages by ZIP code, BEVs and PHEVs show the potential to save 400 and 200 grams of carbon dioxide equivalent per mile, respectively, compared to a representative ICEV of the same class. The magnitude of fuel cost savings and emissions reduction vary by region due to various factors. Generally, regions with high gasoline prices, low electricity prices, preferences for larger vehicles, and high driving intensities tend to see relatively large fuel savings. The emissions reductions are more pronounced in areas with clean grids where consumer preferences lie with large vehicles. This regional variability underscores the importance of considering local contextual factors when assessing the potential benefits of PEV adoption. In more than 99% of U.S. ZIP codes, PEVs result in overall savings in fuel use (and subsequent costs) and GHG emissions. While not a central focus of this analysis, reductions in GHG tailpipe emissions from PEV adoption would also come with reductions in criteria pollutant emissions, contributing to improved local air quality depending on the PEV penetration, population density, and electricity generation infrastructure in the locality.

## 1. INTRODUCTION

Most residents in the U.S. rely on automobiles for daily travel. Traditionally, travelers depend on petroleum-powered internal combustion-engine vehicles (ICEVs). Overall, about 90% of the U.S. transportation sector is powered by petroleum products, among which light-duty vehicles (LDVs) account for more than half of the total (EIA, 2022a). This dependence on petroleum has made U.S. households vulnerable to the volatility of gasoline prices (Anair and Mahmassani, 2012). On average, a U.S. household spends about 3.3% (over $2,000) of its annual income on vehicle fuels, mostly comprised of gasoline (Zhou et al., 2020). The usage of gasoline-powered vehicles also results in extensive greenhouse gas (GHG) emissions as well as criteria pollutants, causing environmental concerns across the country (Razeghi, et al., 2011; Gohlke et al., 2022; Vega-Perkins et al., 2023). Research has shown that the adoption of plug-in electric vehicles (PEVs), including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), can ease the burden of fuel costs and reduce GHG emissions (Anair and Mahmassani, 2012; Harto, 2020; Vega-Perkins et al., 2023; Woody et al., 2023, Kar et al., 2022) by displacing petroleum-fueled vehicle miles with those powered by electric energy charged from the grid and stored in the vehicle battery. Some studies have further shown that fuel prices, vehicle classes, and driving intensities all contribute to the amount of fuel cost saved by switching from ICEVs to PEVs (Anair and Mahmassani, 2012; Vega-Perkins et al., 2023). However, most existing findings were drawn from scenario analyses with limited discussion on context-specific vehicle preferences and travel behaviors at finer geographic resolutions.

Studies have shed light on PEV fuel cost savings from various perspectives. Anair and Mahmassani (2012) found that BEVs can reduce fuel costs by 50–85% compared to average compact ICEVs, achieving an average annual savings of $750–$1,200. However, the magnitude of fuel cost savings is impacted by both petroleum-based fuel costs as well as local electricity costs. Borlaug et al. (2020) estimated the lifetime (15 years, 161K miles) fuel cost savings from driving a BEV could range from $6,200 (TN) to $12,200 (CA) depending on the regional gasoline and electricity prices. Vega-Perkins et al. (2023) compared BEV fuel cost savings under several scenarios with different assumed parameters such as driving intensities, fuel prices, and emission intensities. Their findings show that over 90% of households across the country will see some level of savings on fuel costs if switching to BEVs from ICEVs. Harto (2020) examined the fuel cost savings by major vehicle class and found that BEVs cost 60% less to fuel than comparable ICEVs of the same classes, resulting in a $600–$1,300 savings per year, assuming 15,000 miles driven annually. Several studies have also examined the GHG emissions reduction from PEV adoption. Vega-Perkins et al. (2023) found that 60% of U.S. households would see moderate to high GHG reductions from PEV adoption. Kavianipour et al. (2023) focused on intercity travel, and their results show that, in Michigan, having 6% BEV fleet penetration can result in a 5.9%–8.3% reduction in annual $CO_2$ emissions from light-duty vehicles. Research has also shown that vehicle size is an essential factor in estimating the emissions benefit and that PEV adoption has the potential to offset the upsizing of LDVs in the U.S. (Gohlke et al., 2023).

Despite the valuable insights from existing findings, several use an average ICEV class, fuel efficiency, or annual mileage for comparison with a PEV. The findings resulting from these comparisons often overlook the geographic variability inherent in vehicle class preferences, fuel prices, electricity prices, and driving intensities. This oversight prevents understanding local factors in fuel cost savings when transitioning from an ICEV to a PEV. To address this research gap, the current study estimates fuel cost savings and GHG emissions reductions at a finer geographic resolution. This approach considers local factors such as fuel prices, vehicle class preferences, average vehicle model years, fuel efficiencies, fuel prices, and driving intensities, thus providing a more nuanced and context-specific assessment. An online tool, called “Driving Electric: Local Fuel Savings Calculator,” was developed based on the methodology in this report, allowing users to estimate local fuel savings that could be realized by switching to a PEV (Argonne 2024).

## 2. DATA AND METHODOLOGY

### 2.1 Output Metrics

The fuel cost savings of driving a PEV (including BEVs and PHEVs) compared to a representative ICEV were estimated by ZIP code and state. Based on the representative vehicles identified, all vehicles are compared on a like-to-like basis (e.g., ICE sport utility vehicles [SUVs] vs. electric SUVs). Data in Table 1 were used to quantify local fuel cost savings relative to multiple regional factors. Study outputs include three metrics: cost savings per mile, cost savings per tank, and annual fuel cost savings. The calculation follows the following equations:

- **Savings per mile:** $ICEV\ Fuel\ Efficiency\ \left(\frac{gallons}{mile}\right) \times gasoline\ price\ \left(\frac{\$}{gallon}\right) - EV\ Fuel\ Efficiency\ \left(\frac{kWh}{mi}\right) \times electricity\ price\ \left(\frac{\$}{kWh}\right)$
- **Savings per tank:** $Tank\ Size\ (Gallons) \times [ICEV\ Fuel\ Efficiency\ \left(\frac{gallons}{mile}\right) \times gasoline\ price\ \left(\frac{\$}{gallon}\right) - EV\ Fuel\ Efficiency\ \left(\frac{kWh}{mile}\right) \times electricity\ price\ \left(\frac{\$}{kWh}\right)]$
- **Annual fuel savings**: $Annual\ Household\ VMT\ \times [ICEV\ Fuel\ Efficiency\ \left(\frac{gallons}{mile}\right) \times gasoline\ price\ \left(\frac{\$}{gallon}\right) - EV\ Fuel\ Efficiency\ \left(\frac{kWh}{mile}\right) \times electricity\ price\ \left(\frac{\$}{kWh}\right)]$

*Table 1 Data Sources*

| Data | Sources |
|---|---|
| Annual VMT per vehicle by ZIP code | Zhou et al., 2020 |
| Vehicle registration by ZIP code | Experian, 2022 |
| Average vehicle model year by ZIP code and vehicle class | Experian, 2022 |
| Gas prices by ZIP code | GasBuddy, 2023 |
| Home charging percentages | Blonsky et al., 2021 |
| Residential electricity prices by state | EIA, 2022 |
| Public charging costs | EV Watts, 2022 |
| ICEV Fuel economy by vehicle class and model year | Hula et al., 2022 |
| EV Fuel Economy | ANL, 2023 |
| PHEV utility factor | SAE J2841 |

## 2.2 Annual Vehicle-Miles-Traveled (VMT) Per Vehicle

Two key metrics were incorporated at the ZIP code level to capture the heterogeneity in local travel behaviors and vehicle efficiency: annual vehicle-miles-traveled (VMT) per vehicle and the most popular vehicle class based on registration data. The Bureau of Transportation Statistics (2023) estimates average annual VMT per household to be about 13,200 miles. However, almost 60% of American households own two or more vehicles (Davis and Boundy, 2022[a]). In this study, the fuel cost savings *per vehicle* is estimated.

The annual VMT per vehicle by ZIP code used in this study comes from the projections of Zhou et al. (2020). Zhou et al. (2020) identified variables on household VMT and disaggregated the data into 18 geographic regions as well as urban, suburban, and rural groups based on driving intensities. Based on these regional classifications, they then used a gradient boosting model to predict tract-level household VMT by evaluating key variables such as demographic and socioeconomic characteristics. Using this data, tract-level annual miles traveled per vehicle were calculated by dividing the household VMT by the average number of vehicles in that tract. Thereafter, these tract-level VMTs were assigned to ZIP codes based on their geographic locations. Specifically, a ZIP code is assigned the VMT of the census tract with which this ZIP code has the largest overlap. Additionally, the VMT per vehicle used in this analysis depends on the average vehicle age per ZIP code, and a newer vehicle tends to be driven more (Davis and Boundy, 2022[b]) than older counterparts. National Household Travel Survey data shows that on average a new vehicle is driven 13,000 miles in the first year (NHTS 2017).

### 2.3 Vehicle Registration and Fuel Efficiencies

Using Q4 2022 vehicle registration data from Experian, the number of vehicles registered in each ZIP code were estimated across six classes: car (sedan), crossover utility vehicle (CUV), sport utility vehicle (SUV), van, pickup truck, and sports car. The most popular vehicle class in each ZIP code with the highest number of registrations was defined as the "representative vehicle size" of that ZIP code. Figure 1 shows the distribution of representative vehicle sizes by ZIP code nationwide. In general, cars tend to be popular along the East and West Coast and in urban areas, whereas pickup trucks dominate the rest of the land around the country.

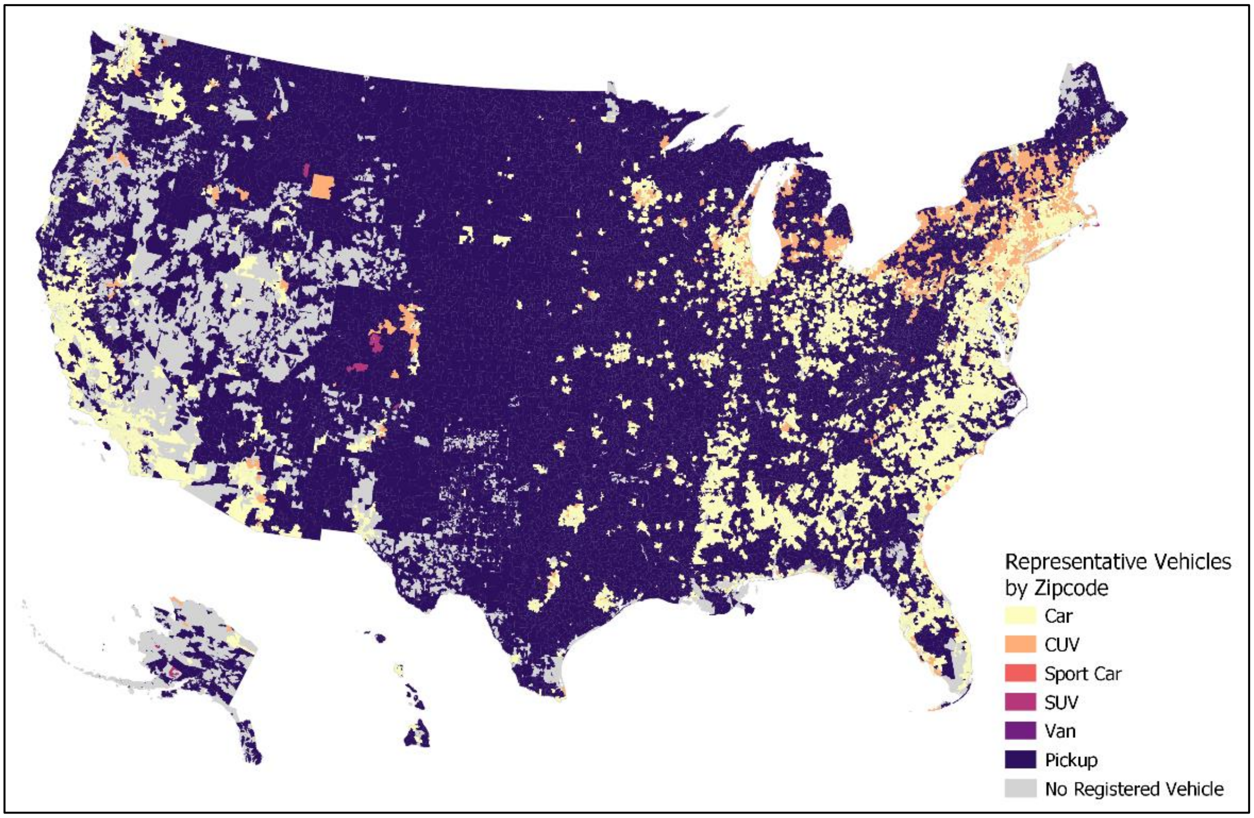


*Figure 1 Representative Vehicle Class by ZIP Code*

After identifying the representative vehicle classes, the average model year by ZIP code was calculated using Experian registration data. Additionally, average fuel efficiency was calculated using the Automotive Trend Report published by the U.S. Environmental Protection Agency (U.S. EPA, 2021). The fuel efficiencies of new LDVs have been gradually improving since the mid-1970s (Figure 2). The average fuel efficiency by ZIP code depends on the representative vehicle class and average model year. For a given ZIP code, holding representative vehicle size constant, it can generally be stated that the newer the vehicle model, the higher the average fuel efficiency.

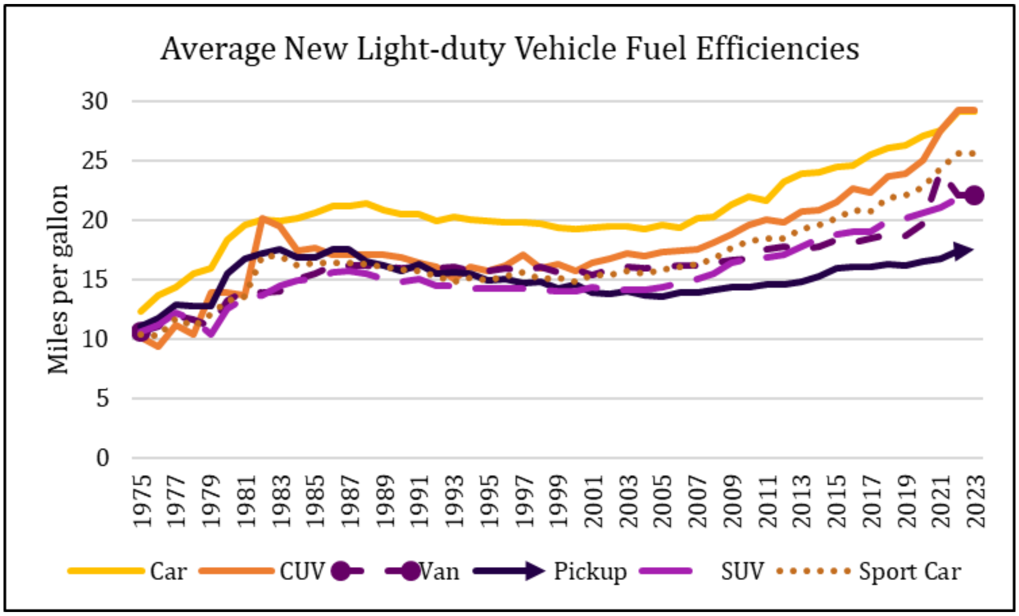


*Figure 2 Average New Light-duty Vehicle Fuel Efficiency (Hula et al., 2022)*

## 2.4 Fuel Prices

The other key component in calculating vehicle fuel cost savings is the fuel price itself, including both gasoline and electricity (residential and public charging). State-level and ZIP-code-level gasoline prices were collected from GasBuddy.com (GasBuddy, 2023) based on data reported on December 15, 2023. The analysis shows that the national average gas price for this particular day ($3.06) ranked in the 50th percentile of gasoline prices over the past five years, indicating that this temporal snapshot of gasoline prices can serve as a representation of national prices. To account for gasoline price outliers and drivers fueling vehicles in ZIP codes adjacent to their ZIP codes of residence, prices were averaged with the same 3-digit prefixes instead of using the price of a 5-digit ZIP code. Over 30,000 ZIP codes were therefore aggregated to 883 regions as shown in Figure 3. Overall, gasoline prices tend to be high in the western and northeastern parts of the country. In southern and midwestern states, gasoline prices tend to be relatively low.

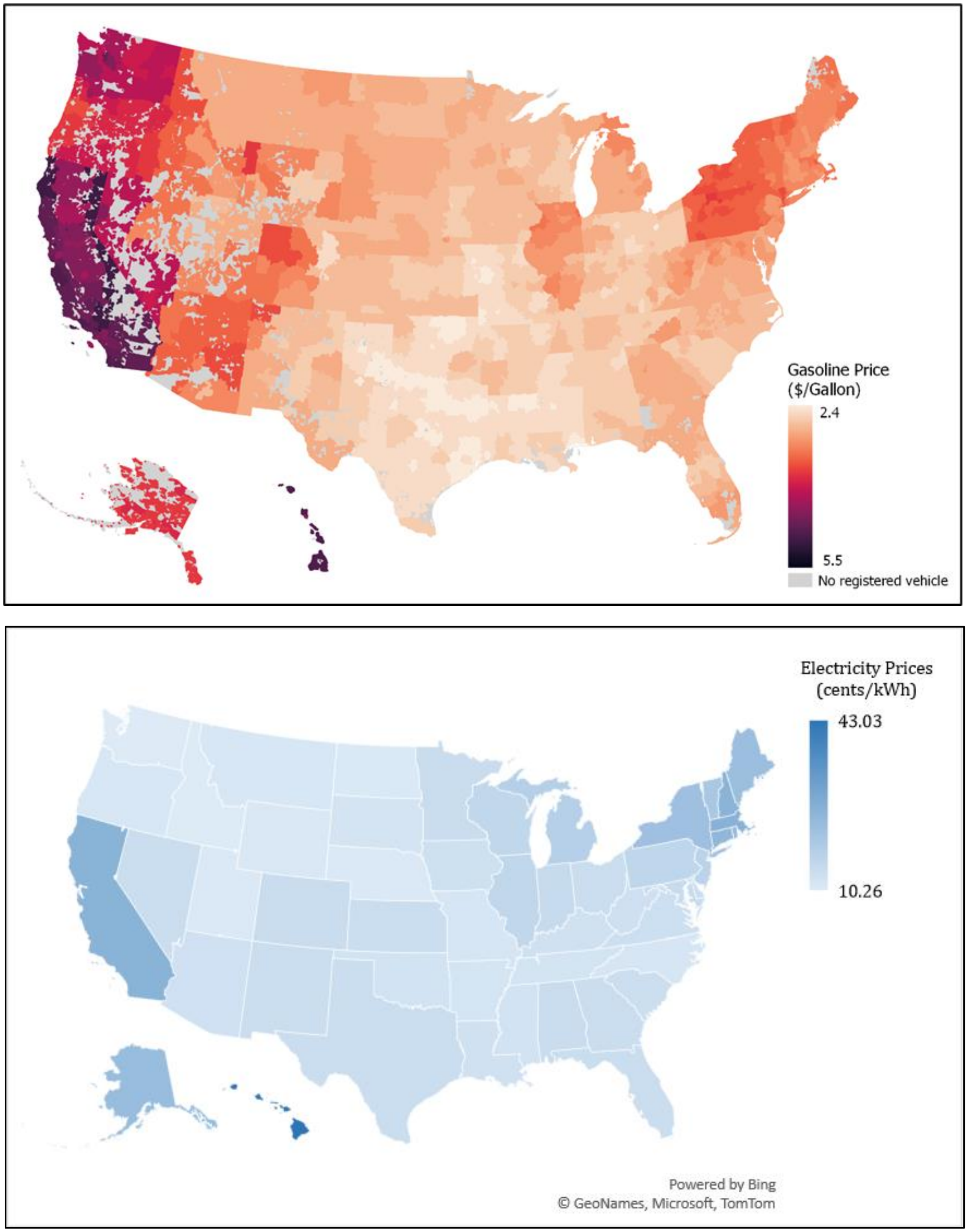


*Figure* 3 *Fuel Prices by Region: Gasoline Prices as of December 15, 2023 (top) and Residential Electricity Prices as of 2022 (bottom)*

For home charging electricity costs, the 2022 average residential retail electricity prices from the U.S. Energy Information Administration (EIA, 2022b) were used, as seen in the bottom portion of Figure 3. Hawaii has the highest electricity prices, followed by California. The resulting average was $0.16/kWh. In the context of public charging electricity costs, a national average price per kWh was computed based on data from over 250,000 paid public charging sessions in the U.S. for the year 2021, sourced from Energetics (2021); the resulting average was \$0.29/kWh. Aligning with Blonsky et al. (2021), this study assumes 80% home charging and 20% public charging for both BEV and PHEV. Note that although most early PEV adopters have reserved space to charge at home, about 50% of Americans may not have dedicated off-street parking at an owned residence where they can install a charger (Traut et al., 2013). Depending on the cost of public charging, relying on it instead of home charging might reduce the fuel cost-savings benefits of driving a PEV.

### 2.5 GHG Emissions Intensity

PEV adoption can substantially reduce GHG emissions across different regions (Vega-Perkins et al., 2023), depending on vehicle fuel efficiencies and the local GHG emissions intensity of the electric grid. This study estimates the ZIP code-level GHG emissions reductions that result from adopting PEVs, accounting for local average vehicle fuel efficiencies using a well-to-wheels (WTW) approach. This approach considers the entire life cycle of the consumption of a certain energy source. A WTW process can be divided into two components: well-to-pump (WTP) and pump-to-wheels (PTW). WTP covers the process of recovering and transporting the feedstock to the production and distribution of fuels, whereas PTW refers to the process of combusting the fuel in vehicle operation.

This analysis estimated the reduction of carbon dioxide equivalent ($CO_2e$) per mile when driving a PEV compared to an ICEV. Gasoline produces 10,741 grams of $CO_2e$ per gallon under a WTW approach (ANL, 2021). On the other hand, emissions from electricity generation vary based on the emissions intensity of the electric grid. To consider this variability, the U.S. Environmental Protection Agency's (EPA) emissions rates for the 26 subregions across the country were leveraged from its Emissions & Generation Resource Integrated Database (eGRID) (EPA, 2022)[1]. Using this data, Gohlke et al. (2022) estimated the WTW emissions intensity for each subregion using GREET 2021 (Argonne, 2021) and assigned subregional intensities to ZIP codes according to geographic locations as seen in Figure 4. Furthermore, Gohlke et al. (2022) also considered the effect of photovoltaic (PV) solar systems on grid emissions using capacity and generation data provided by the EIA. Using the ZIP code-level emissions intensities and state-level solar adjustment factor estimated by Gohlke et al. (2022), the emissions reduction from PEV adoption was calculated at each ZIP code using the following equation:

$$\begin{aligned} Emissions\left(\frac{g}{mi}\right) &= UF \times Electricity\ Consumption\left(\frac{kWh}{mile}\right) \times Grid\ Intensity\left(g\frac{GHG}{kWh}\right) \\ &+ (1-UF) \times Gasoline\ Consumption\left(\frac{gallon}{mile}\right) \times 10{,}741\ g\ GHG/gallon \end{aligned}$$

---

[1] The GHG emissions intensities from eGRID do not account for future reductions in grid-associated emissions resulting from, for instance, provisions in the Inflation Reduction Act (IRA), so the eGRID represents a higher estimate of emission intensities (Steinberg et al., 2023).

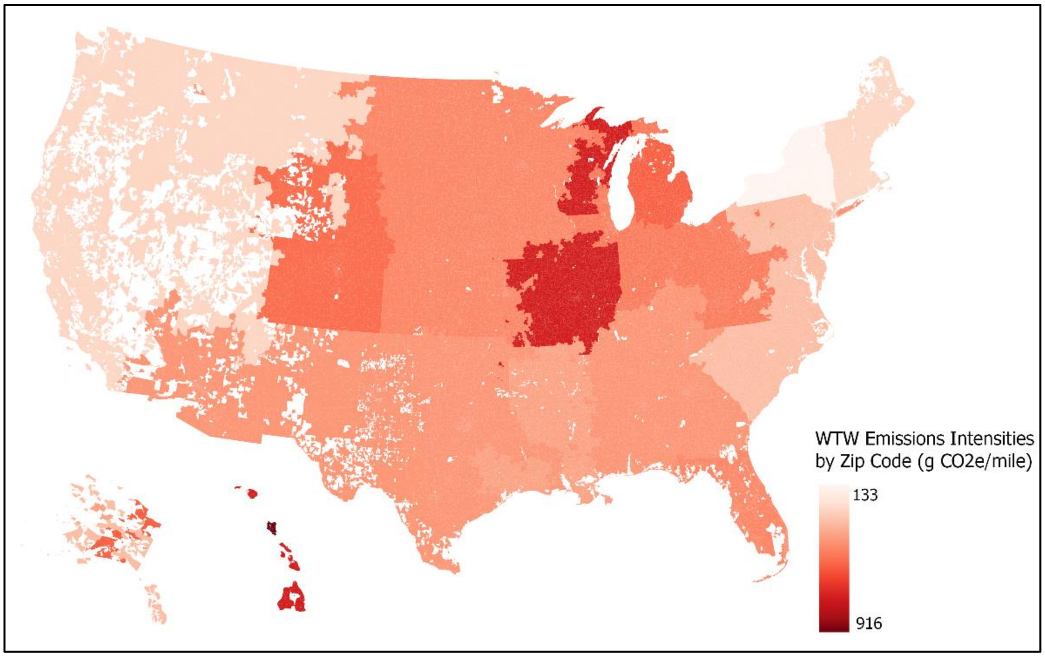


*Figure 4 Electricity GHG Emissions Intensity by ZIP Code, Well-to-Wheel*

This comprehensive approach allows us to capture the impact of PEVs on emissions reduction, considering both regional variations and the influence of renewable energy sources on the electricity grid.

## 3. RESULTS AND DISCUSSION

### 3.1 ZIP-Level Fuel Savings Results

At this fine resolution, the analysis affirms the overarching trend that larger vehicles consistently demonstrate a higher potential for fuel cost savings when electrified, as shown in Figure 5. Although CUVs are in general larger than cars, the findings show that they yield slightly lower fuel cost savings. This discrepancy is primarily attributed to the difference in average model year of representative CUV and cars. Areas with more CUVs tend to also have newer vehicles, with an average model year of 2016, resulting in higher average vehicle efficiencies. In comparison, representative cars have an average model year of 2011. The newer CUVs tend to have higher average fuel efficiencies than older cars as was shown in Figure 2. Therefore, the higher fuel efficiencies of these newer ICE CUVs contribute to smaller fuel cost savings when transitioning to PEVs as shown in Table 4. This result again underscores the importance of considering not only vehicle size but also factors such as model year and fuel efficiency in assessing the potential economic benefits of PEV adoption within specific regional contexts.

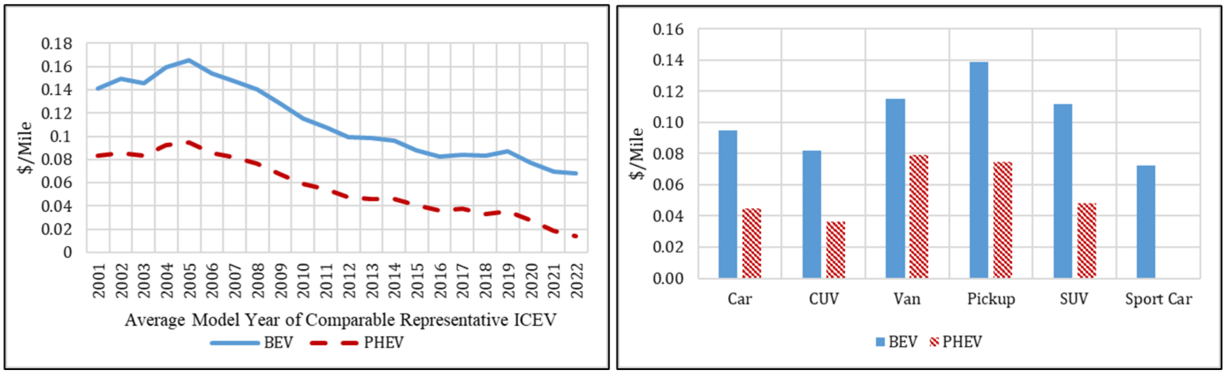


*Figure 5 Fuel Cost Savings per Mile by Model Year (left) and Vehicle Size at the ZIP Code Level (right)*
*(PHEV sports car have very little savings, which is not visible in the chart)*

Table 2 illustrates a wider variance in fuel savings at the ZIP code level than at the state level. Fuel switching to a BEV yields net fuel savings throughout the U.S. This higher resolution analysis reveals that switching from an ICEV to a PHEV would yield net fuel cost savings in over 99.9% of ZIP codes. In fewer than 0.1% of ZIP codes, transitioning from an ICEV to a PHEV would result in increased fuel costs (Figure 6). To better examine the geographic differences in fuel cost savings, several states/regions were selected for detailed comparisons using annual fuel savings realized when driving a BEV as an example, as illustrated more broadly nationwide in Figure 7.

*Table 2 ZIP-Code-Level Fuel Cost Savings: Mean, Minimum, and Maximum Savings per Mile, per Tank, and Annually*

| | **Savings per Mile ($)** | | **Savings per Tank ($)** | | **Annual Savings ($)** | |
|---|---|---|---|---|---|---|
| | **BEV** | **PHEV** | **BEV** | **PHEV** | **BEV** | **PHEV** |
| **Minimum** | 0.016 | -0.040 | 6.97 | -17.5 | 112 | -283 |
| **Maximum** | 0.269 | 0.193 | 75.3 | 58.0 | 2190 | 1540 |
| **Mean** | 0.095 | 0.064 | 27.8 | 18.6 | 669 | 448 |
| **Median** | 0.107 | 0.072 | 31.0 | 20.7 | 723 | 490 |

*Rounded to 3 significant figures.

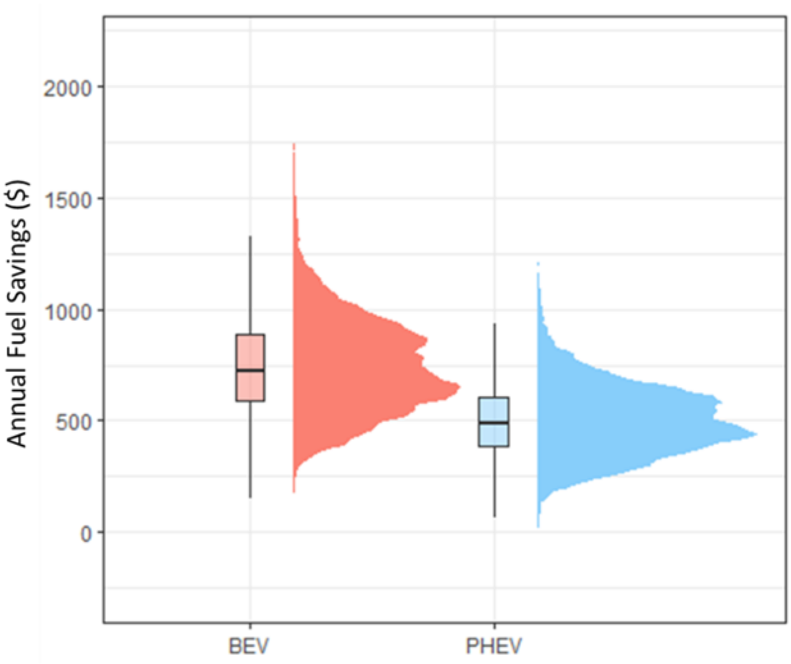


*Figure 6 ZIP-code-level Annual Fuel Savings of Driving a BEV or PHEV.*

(Note: this figure contains a distribution chart and a box and whisker plot for BEV and PHEV, respectively. The top and bottom of each boxplot bar represent the anticipated 75th and 25th percentile of annual fuel savings among all ZIP codes, respectively. The line in the middle indicates the median. The top and bottom whiskers represent the maximum and minimum annual fuel savings among all ZIP codes).

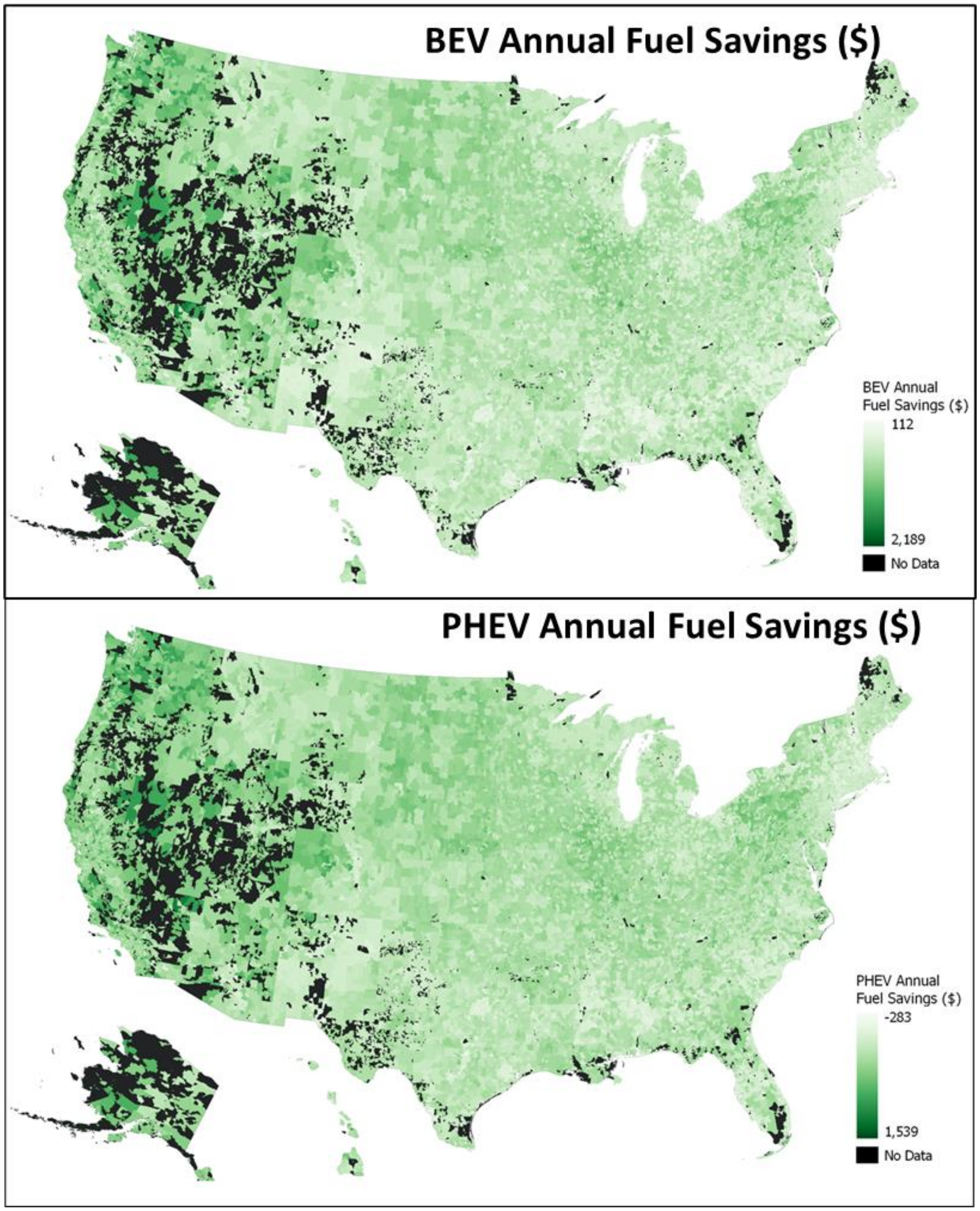
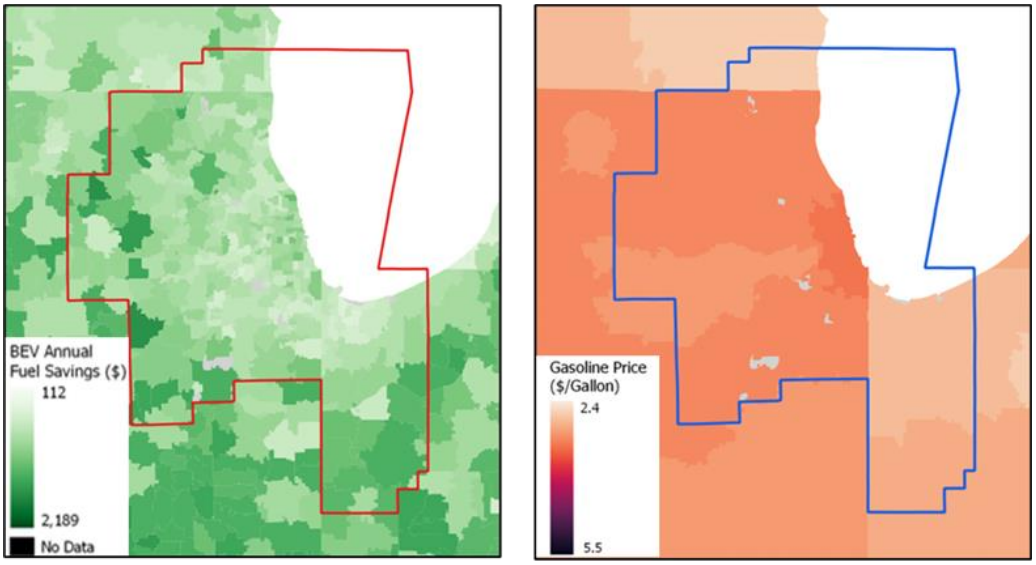
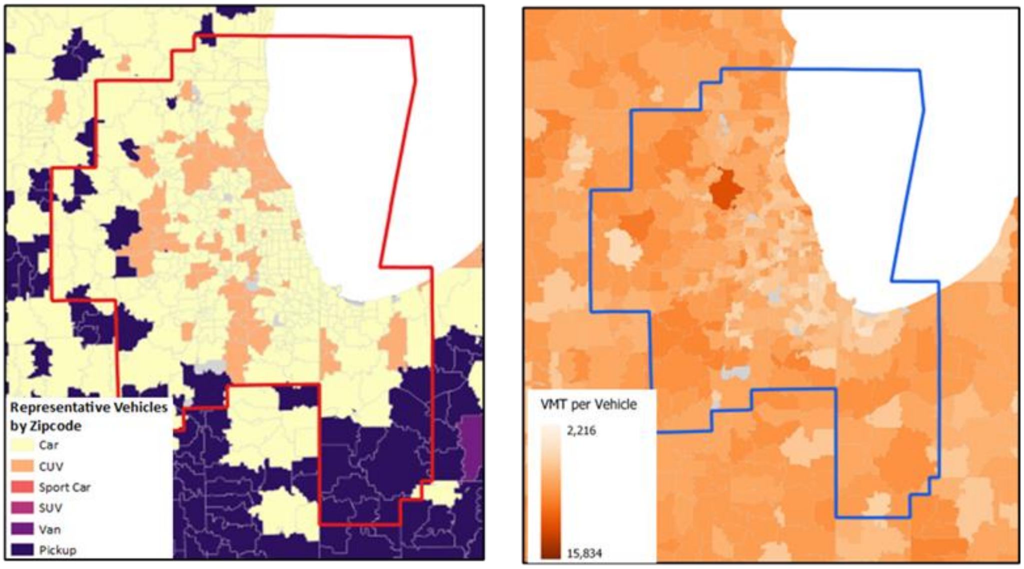


*Figure 7 Annual Fuel Savings when Driving a BEV (top) or PHEV (bottom) by ZIP Code*

The U.S. Census Bureau's metropolitan statistical area (MSA) of Chicago–Naperville–Elgin was chosen as one example as it covers areas in three states: Illinois, Indiana, and Wisconsin. Overall, this metro area has relatively high gasoline prices, with the highest prices in Illinois, followed by Indiana and Wisconsin (Figure 8b). Fuel cost savings within Chicago's city boundary are lower than that of suburban areas (Figure 8a). In general, residents of this metro area drive newer (Zhou et al., 2020) and smaller vehicles such as cars/sedans (Figure 8c), which could be attributed to the well-developed public transport system, higher household income, and the dense urban development in Chicago. About two-thirds of the regular transit commuters live within the Chicago city boundary, and only 50% of the commuters choose solo driving as their commuting mode (CMAP, 2016). Following the MSA further out to the suburban areas, larger vehicles such as CUVs and pickup trucks have become more popular, a finding that is consistent with the trend of increasing vehicle ownership and driving intensities in those areas (CMAP, 2016).



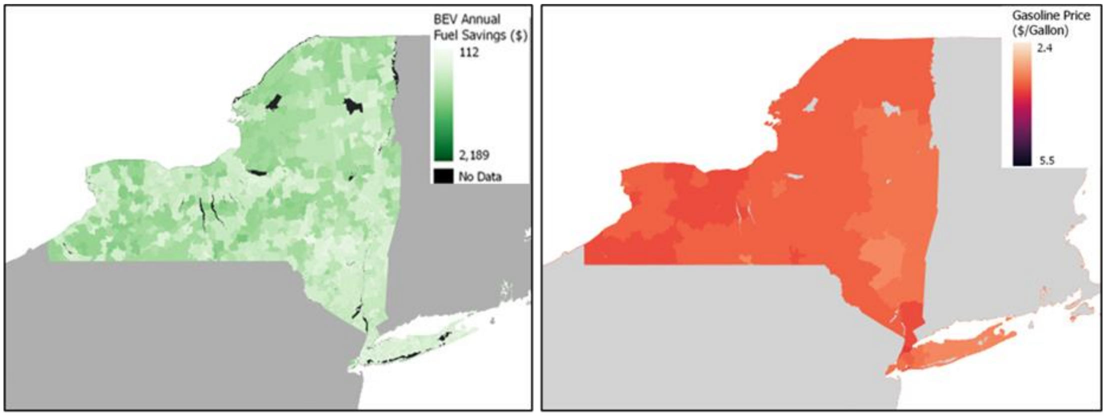
**a. BEV Annual Fuel Savings ($)**  **b. Gasoline Prices ($)**



**c. Representative Vehicles**  **d. Annual VMT**

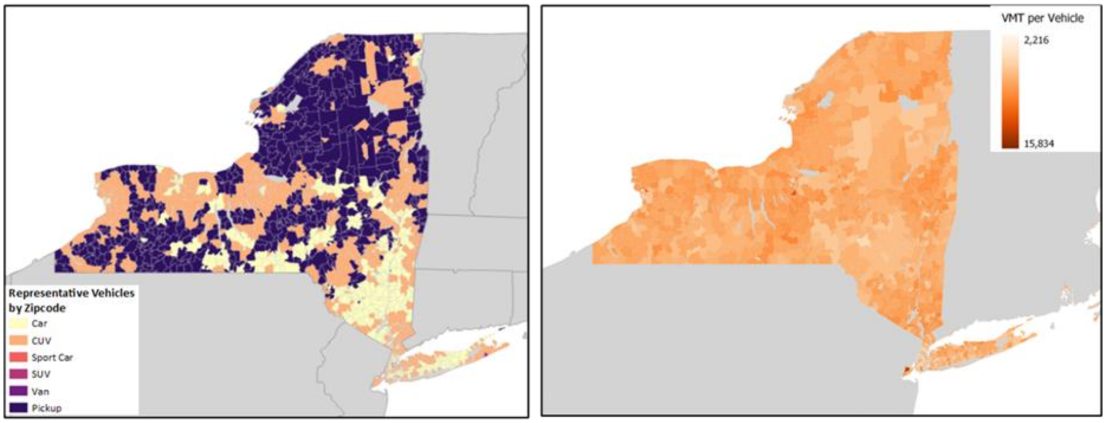
*Figure 8 Case Study: The Chicago–Naperville–Elgin Area (IL–IN–WI)*

In the state of New York, a discernible disparity in fuel cost savings is evident between upstate and downstate regions (Figure 9a). Given its current driving intensity levels and the prevalence of larger vehicles, Upstate New York exhibits more substantial fuel cost savings compared to downstate when switching from an ICEV to a BEV. This difference may stem from the historically extensive use of public transit and efforts to curtail automobile travel in downstate New York, particularly in New York City, where over half of residents rely on public transportation for regular commuting. The dense urban design and well-established public transportation system in downstate New York may have led to the preference for smaller vehicles and low VMT (Figure 9c). In contrast, Upstate New York has witnessed a decline in transit ridership over several decades. The less dense urban layout in Upstate New York results in higher VMT and a preference for larger vehicles, such as CUVs and pickup trucks (Madison Jr., 2006).



a. BEV Annual Fuel Savings ($)

b. Gasoline Prices ($)

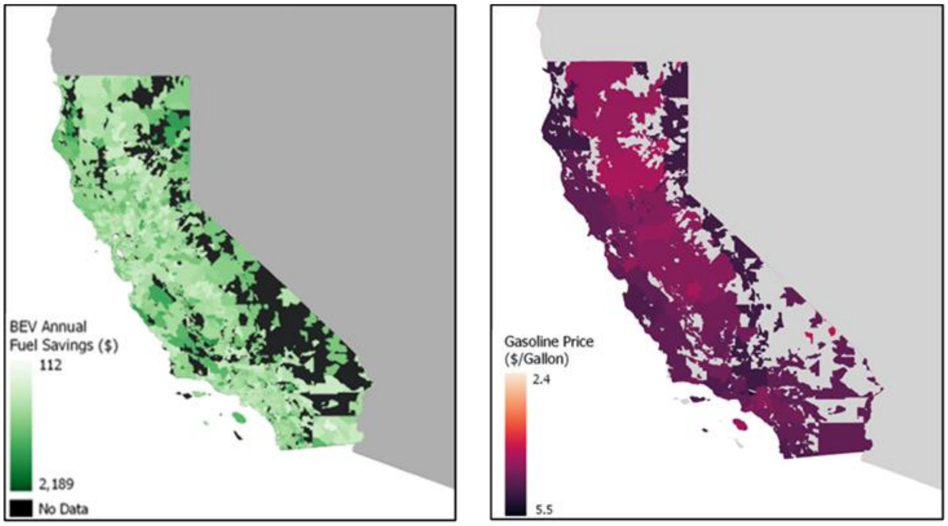


c. Representative Vehicles

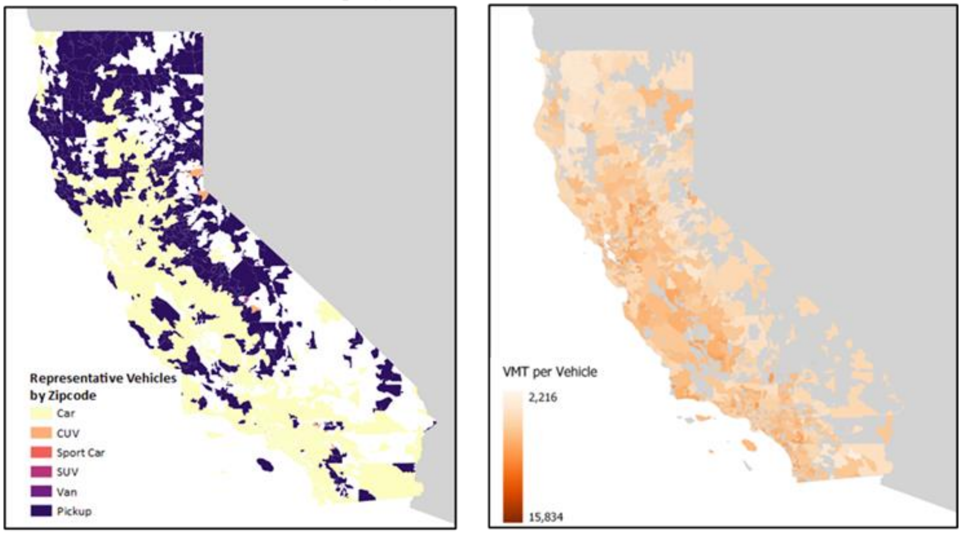
d. Annual VMT

*Figure 9 Case Study: The State of New York*

California is a leading state in decarbonizing its transportation systems aiming to achieve an 80% reduction in greenhouse gas (GHG) emissions by 2050 relative to the 1990 level. This commitment includes regulations targeting 100% of vehicle sales being zero-emissions by the model year 2035. Figure 10b shows California has high gasoline prices prevalent across the state. Representative vehicles differ between urban and rural California. In metro areas such as Los Angeles and San Francisco, there is a preference for smaller vehicles such as cars/sedans, whereas pickup trucks dominate exurban and rural areas (Figure 10c). Similar to urban Chicago and downstate New York, the results show a preference for smaller vehicles in urban areas in California, possibility due to dense urban design and relatively developed public transportation systems. Despite vehicle classes with smaller sizes, large metro areas along the California coastline exhibit higher VMT per vehicle compared to rural and exurban areas (Figure 10d). Taking into consideration these varied factors and regional trends, the findings suggest that transitioning to BEVs will yield moderate levels of fuel cost savings across the state (Figure 10a), aligning with the trend presented in Table 4.



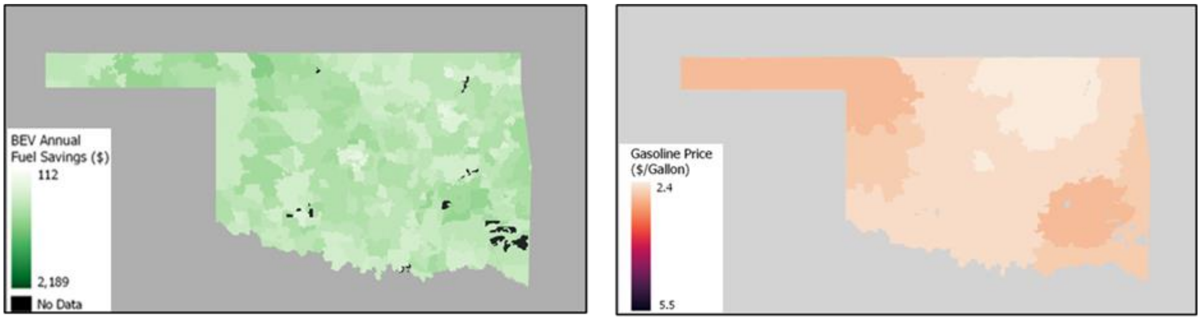
**a. BEV Annual Fuel Savings ($)** **b. Gasoline Prices ($)**



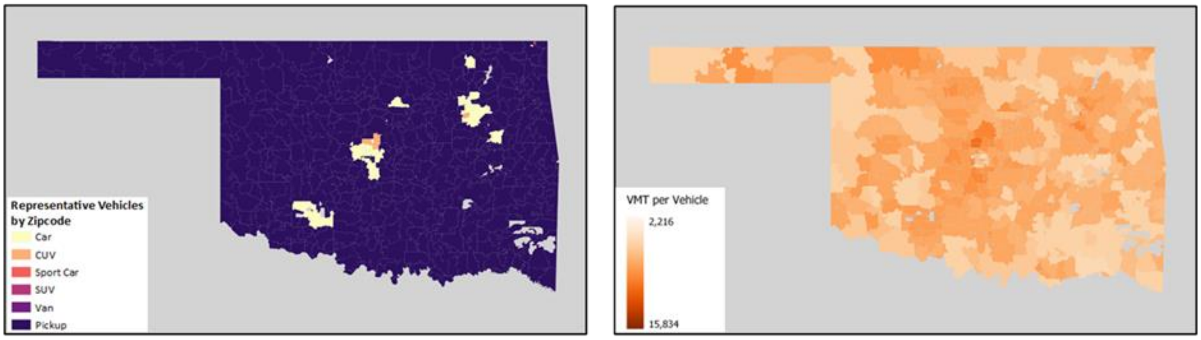
**c. Representative Vehicles** **d. Annual VMT**

*Figure 10 Case Study: The State of California*

Compared to New York and California, Oklahoma has significantly lower gasoline prices (Figure 11b). The prevailing choice of vehicle class across the state leans heavily towards pickup trucks, except in urban centers like Oklahoma City and Tulsa, where cars and CUVs are more popular (Figure 11c). These metro areas also tend to have low VMT per vehicle, and the suburban areas adjacent to them have much higher VMT (Figure 11d). The distribution of fuel cost savings shows a similar pattern to the distribution of vehicle size preferences and VMT (Figure 11a). Large metro areas have relatively small fuel cost savings due to smaller vehicle sizes and low VMT, whereas areas dominated by pickup trucks with high VMT will experience higher fuel cost savings.



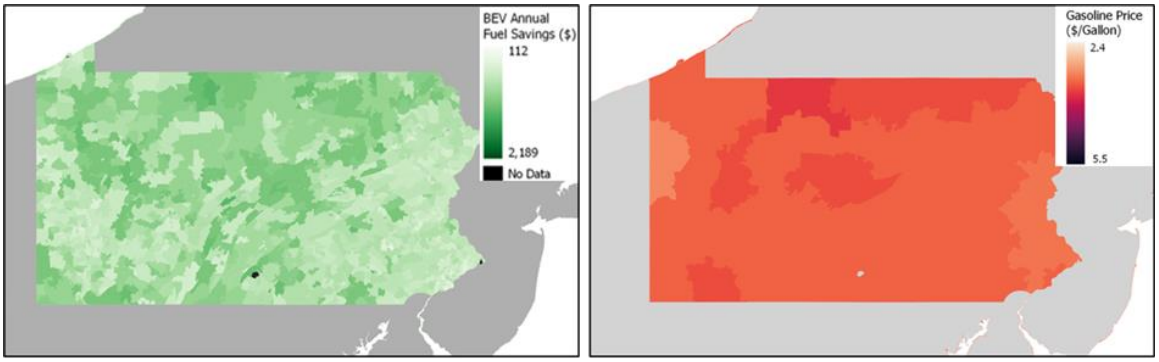
**a. BEV Annual Fuel Savings ($)** **b. Gasoline Prices ($)**



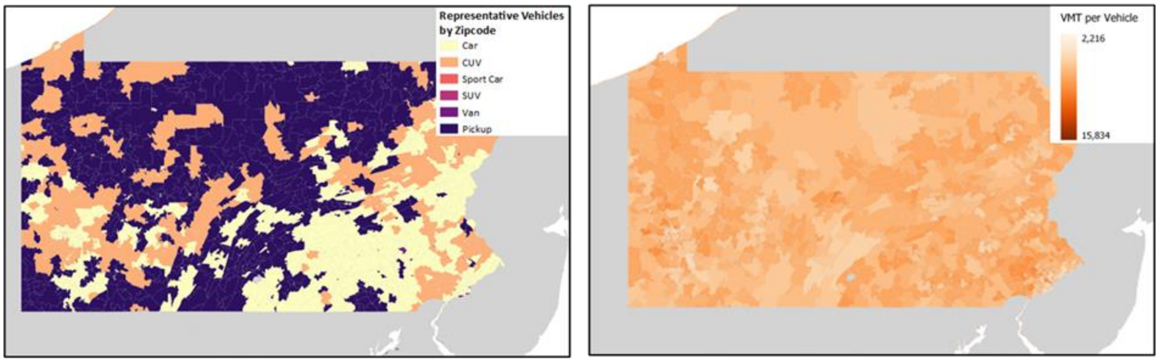
**c. Representative Vehicles** **d. Annual VMT**

*Figure 11 Case Study: The State of Oklahoma*

Similar to the New York and Chicago metro areas, Pennsylvania also has a relatively high gasoline price (Figure 12b). The distribution of representative vehicle class shows a variation between major urban areas and the rest of the state. Metro areas of Philadelphia and Pittsburgh prefer smaller vehicles such as cars and CUVs, whereas residents of the most rural areas prefer larger vehicles like pickup trucks. The distribution of VMT roughly follows a similar pattern with high mileage in the two major urban areas and their adjacent regions (Figure 12d). The amount of fuel savings in Pennsylvania seems to follow the same pattern as representative vehicle sizes: areas dominated by smaller vehicles save less in fuel cost when switching to PEVs than do areas with larger vehicles (Figure 12a).



a. BEV Annual Fuel Savings ($)    b. Gasoline Prices ($)



c. Representative Vehicles    d. Annual VMT

*Figure 12 Case Study: The State of Pennsylvania*

### 3.2 State-Level Fuel Savings Results

Study findings indicate that, across all states nationwide, there are varying levels of fuel savings when transitioning from an ICEV to a PEV, as summarized in Table 3. On average, after weighting by vehicle population and ZIP codes, driving a BEV yields savings of $0.09 per mile, $26.4 per tank, and $626 annually compared to driving an ICEV. For PHEVs, a utility factor of 62% was assumed based on the weighted average PHEV range. Driving a PHEV results in somewhat lower savings with $0.066 savings per mile, $18.4 savings per tank, and $436 savings annually.

*Table 3 State-Level Fuel Cost Savings: Minimum, Maximum, Mean, and Median Savings per Mile, per Tank, and Annually*

| | **Savings per Mile ($)** | | **Savings per Tank ($)** | | **Annual Savings ($)** | |
|---|---|---|---|---|---|---|
| | **BEV** | **PHEV** | **BEV** | **PHEV** | **BEV** | **PHEV** |
| **Minimum** | 0.059 | 0.018 | 18.2 | 6.56 | 393 | 123 |
| **Maximum** | 0.171 | 0.121 | 47.4 | 33.7 | 1020 | 753 |
| **Mean** | 0.094 | 0.066 | 26.4 | 18.4 | 626 | 436 |
| **Median** | 0.086 | 0.060 | 24.5 | 17 | 587 | 407 |

*Rounded to 3 significant figures.

Pickup trucks emerge with the highest fuel cost savings compared to other vehicle sizes, as shown in Figure 13. The analysis also highlights that older ICEVs, being less fuel-efficient on average, exhibit larger fuel cost savings when replaced with PEVs, as depicted in Figure 13. This emphasizes the potential for significant economic and environmental benefits associated with transitioning from older, less efficient ICE vehicles to newer, more efficient alternatives.

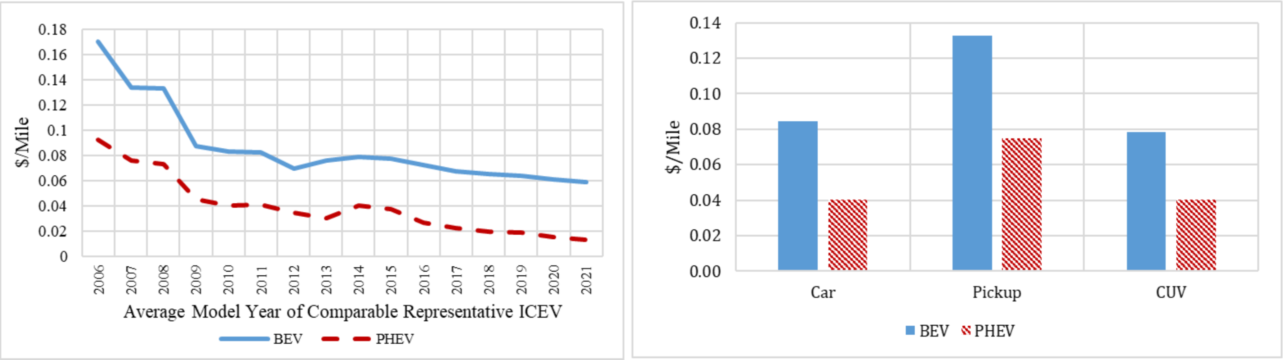


*Figure 13 Savings per Mile by ICEV Model Year (left) and Representative Vehicle Class at the State Level (right)*

The distribution of fuel cost savings reveals a discernible geographic pattern, as exemplified by the annual fuel cost savings for BEVs, depicted in Table 4. In this table, state-level metrics lower than the national average are shaded in orange, whereas metrics higher than the national average are shaded in green[2]. Overall, the magnitude of savings appears more substantial in western states such as Idaho and Wyoming, potentially due to a combination of factors including high gasoline prices, low electricity prices, and low fuel efficiency (due to the preference for larger vehicles) in these states. Some states in the Midwest, such as North Dakota, South Dakota, and Montana, also exhibit notable large fuel savings due to switching from less fuel-efficient conventional pickup trucks to comparable PEVs. Arkansas, Louisiana, and West Virginia also show substantial potential for fuel savings due to the similar preference for large vehicles. These results emphasize the significance of vehicle class preferences and the importance of other local factors in evaluating the potential benefits of PEV adoption across diverse geographic contexts.

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[2] The national average was weighted based on state-level vehicle registration.

*Table 4 BEV Fuel Savings and Key Factors by State (Orange = lower savings, rounded to 3 significant figures)*

| State | Average Model Year of Representative ICEV | Annual VMT | Gasoline Price ($/Gallon) | Electricity Prices (cents/kWh) | Average Fuel Efficiencies of Representative ICEV | BEV Fuel Savings per Mile |
|---|---|---|---|---|---|---|
| Alabama | 2010 | 6650 | 2.71 | 14.3 | 22.0 | 0.071 |
| Alaska | 2008 | 7070 | 3.65 | 23.1 | 14.1 | 0.141 |
| Arizona | 2010 | 6120 | 3.20 | 13.0 | 22.0 | 0.097 |
| Arkansas | 2008 | 6990 | 2.64 | 12.1 | 14.1 | 0.112 |
| California | 2008 | 6190 | 4.59 | 25.8 | 20.2 | 0.147 |
| Colorado | 2012 | 6400 | 2.72 | 14.2 | 19.8 | 0.079 |
| Connecticut | 2010 | 7370 | 3.21 | 24.6 | 22.0 | 0.069 |
| Delaware | 2010 | 6960 | 2.96 | 13.7 | 22.0 | 0.084 |
| District of Columbia | 2011 | 6170 | 3.06 | 14.2 | 21.6 | 0.090 |
| Florida | 2011 | 6480 | 2.85 | 13.9 | 21.6 | 0.081 |
| Georgia | 2010 | 6940 | 2.96 | 13.8 | 22.0 | 0.084 |
| Hawaii | 2010 | 6270 | 4.63 | 43.0 | 22.0 | 0.090 |
| Idaho | 2006 | 5800 | 3.33 | 10.4 | 13.9 | 0.171 |
| Illinois | 2010 | 6930 | 3.16 | 15.7 | 22.0 | 0.088 |
| Indiana | 2009 | 6860 | 2.76 | 14.6 | 21.3 | 0.077 |
| Iowa | 2008 | 7010 | 2.79 | 13.2 | 20.2 | 0.089 |
| Kansas | 2009 | 6820 | 2.76 | 14.0 | 21.3 | 0.079 |
| Kentucky | 2009 | 7060 | 2.73 | 12.9 | 21.3 | 0.080 |
| Louisiana | 2009 | 6960 | 2.62 | 12.9 | 14.4 | 0.103 |
| Maine | 2014 | 7310 | 3.24 | 22.4 | 20.8 | 0.075 |
| Maryland | 2011 | 7210 | 3.10 | 14.5 | 21.6 | 0.091 |
| Massachusetts | 2010 | 7420 | 3.26 | 26.0 | 22.0 | 0.068 |
| Michigan | 2014 | 6780 | 2.97 | 17.9 | 20.8 | 0.074 |
| Minnesota | 2009 | 7310 | 2.89 | 14.3 | 21.3 | 0.084 |
| Mississippi | 2010 | 6760 | 2.58 | 12.4 | 22.0 | 0.070 |
| Missouri | 2009 | 6760 | 2.66 | 11.7 | 21.3 | 0.079 |
| Montana | 2009 | 5820 | 2.96 | 11.3 | 14.4 | 0.133 |
| Nebraska | 2007 | 6920 | 2.85 | 10.8 | 13.8 | 0.135 |
| Nevada | 2010 | 6070 | 3.95 | 13.8 | 22.0 | 0.129 |
| New Hampshire | 2010 | 7690 | 3.15 | 25.5 | 22.0 | 0.064 |
| New Jersey | 2011 | 7220 | 3.11 | 16.7 | 21.6 | 0.086 |
| New Mexico | 2007 | 5650 | 2.84 | 13.8 | 13.8 | 0.122 |
| New York | 2015 | 6750 | 3.40 | 22.1 | 21.5 | 0.078 |
| North Carolina | 2010 | 6720 | 2.89 | 11.6 | 22.0 | 0.086 |
| North Dakota | 2008 | 6900 | 2.87 | 10.9 | 14.1 | 0.133 |
| Ohio | 2010 | 6630 | 2.71 | 13.9 | 22.0 | 0.073 |
| Oklahoma | 2012 | 7090 | 2.50 | 12.4 | 23.3 | 0.060 |
| Oregon | 2008 | 6050 | 3.85 | 11.4 | 20.2 | 0.145 |
| Pennsylvania | 2010 | 6680 | 3.44 | 15.9 | 22.0 | 0.101 |
| Rhode Island | 2010 | 6950 | 3.16 | 23.2 | 22.0 | 0.070 |
| South Carolina | 2009 | 6620 | 2.74 | 13.6 | 21.3 | 0.079 |
| South Dakota | 2007 | 6890 | 2.94 | 12.1 | 13.8 | 0.137 |
| Tennessee | 2009 | 6920 | 2.76 | 12.3 | 21.3 | 0.083 |
| Texas | 2011 | 6950 | 2.49 | 13.8 | 21.6 | 0.065 |
| Utah | 2009 | 6590 | 2.93 | 10.8 | 21.3 | 0.094 |
| Vermont | 2014 | 7600 | 3.36 | 19.9 | 20.8 | 0.088 |
| Virginia | 2010 | 6910 | 2.97 | 13.3 | 22.0 | 0.086 |
| Washington | 2008 | 6240 | 4.16 | 10.3 | 20.2 | 0.163 |
| West Virginia | 2008 | 6460 | 3.02 | 13.2 | 14.1 | 0.134 |
| Wisconsin | 2009 | 7210 | 2.73 | 15.6 | 21.3 | 0.073 |
| Wyoming | 2007 | 6120 | 2.94 | 11.1 | 13.8 | 0.141 |
| | | | | | | |
| USA Average | 2010 | 6710 | 3.17 | 16.2 | 20.9 | 0.094 |

In comparison, states in southern and northeastern regions exhibit lower fuel cost savings potential. Several states in New England, as well as the east/north central regions experience this trend due to higher electricity prices. Examples of such states include New York, and Michigan. Some southern states also have a relatively lower potential for fuel savings due to lower gasoline prices (e.g., Texas and Mississippi). The relatively high regional electricity prices and low gasoline costs in these areas diminish the overall economic advantage of transitioning to plug-in electric vehicles (PEVs). By considering this regional variation, a more comprehensive understanding emerges which enables targeted strategies for promoting PEV adoption in diverse geographic contexts.

### 3.3 Emissions Reduction from PEV Adoption

Nationwide, driving a PEV consistently leads to substantially lower greenhouse gas (GHG) emissions. Upon averaging the results based on ZIP code-level vehicle population, the analysis results show that driving a BEV saves 400 grams of $CO_2e$ per mile, while driving a PHEV saves 200 grams of $CO_2e$ per mile, when compared to an ICEV of the same class (see Figure 14). By this metric BEV adoption is twice as effective at reducing GHG emissions as PHEV adoption. A tiny portion of ZIP codes (less than 0.1%) experience higher GHG emissions with PHEVs than comparable ICEVs, mainly due to relatively higher carbon intensity of the electrical grids in those areas. Approximately half of the population resides in ZIP codes where driving a BEV or PHEV results in savings of approximately 380 and 180 grams of CO2e per mile, respectively, as shown in Figure 15 and Figure 16. The geographic distribution of emissions reductions is affected by the emissions intensities of the local grid and the prevalent vehicle class in each region. In general, regions with clean grids, as observed in the western part of the country, have a relatively large potential for GHG reduction through PEV adoption. Moreover, rural and suburban areas also show larger emissions reductions than urban areas where smaller vehicles are more popular (see Figure 17). The findings highlight the potential for PEVs to play an important role in reducing GHG emissions, especially in regions with cleaner energy sources and in areas where larger vehicles are predominant. Nevertheless, in regions with less clean energy and with smaller vehicles on average, adopting PEVs can still result in net savings, especially when accounting for the improving efficiency and diminishing carbon intensity of the power sector, including from impacts of the Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Law (BIL) (Steinberg et al., 2023).

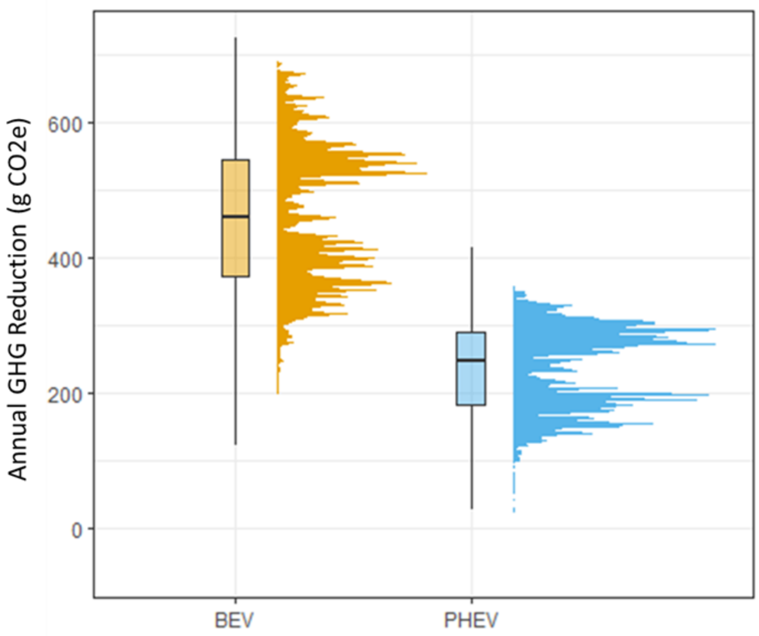

*Figure 14 ZIP-code-level Emissions Reduction of Driving a BEV or PHEV.*

(Note: this figure contains a distribution chart and a boxplot for BEV and PHEV, respectively. The top and bottom of each boxplot bar represent the anticipated 75th and 25th percentile of annual GHG reduction among all ZIP codes, respectively. The line in the middle indicates the median. The top and bottom whiskers represent the maximum and minimum annual GHG reduction among all ZIP codes).

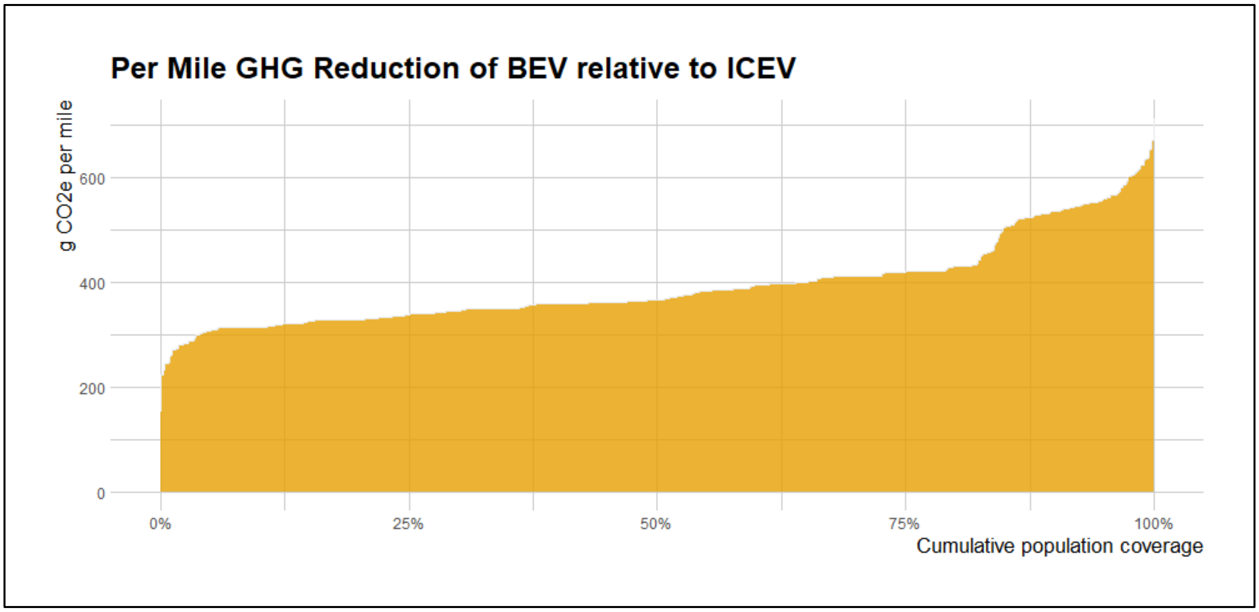

*Figure 15 BEV Per Mile GHG Reduction by Cumulative Population*

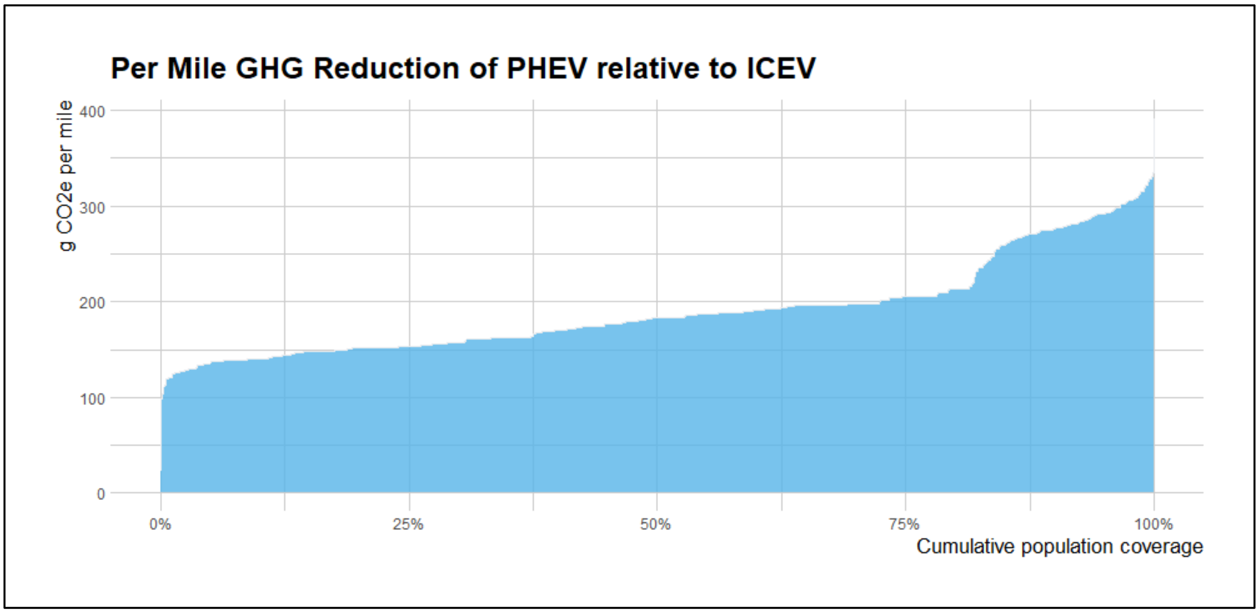

*Figure 16 PHEV Per Mile GHG Reduction by Cumulative Population*

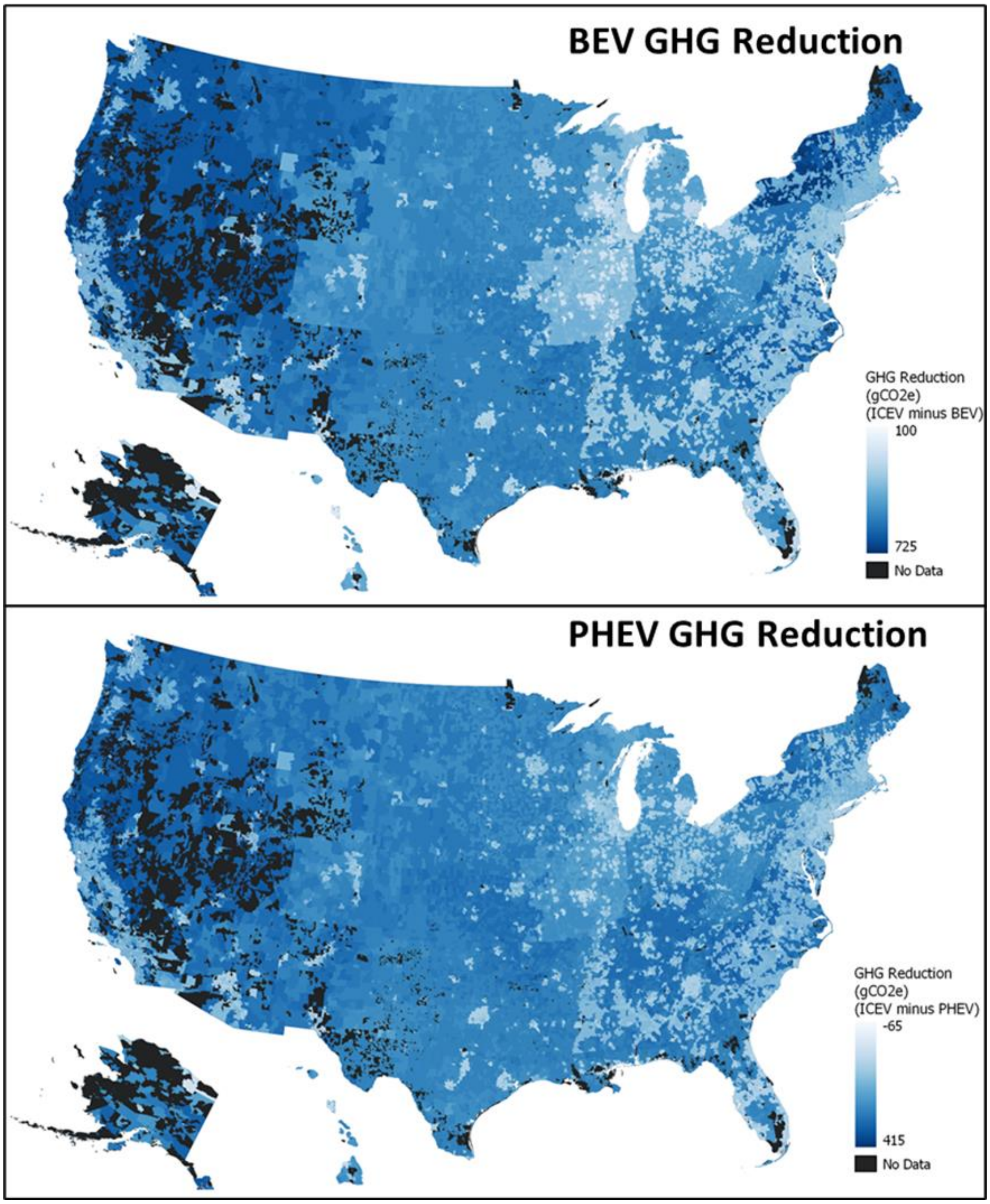

*Figure 17 GHG Reduction per Mile (gram of $CO_2$ Equivalent) by ZIP Code (ICEV minus BEV(top) and PHEV (bottom))*

## 4. CONCLUSION

This study examines the regional savings in fuel costs and GHG emissions of PEVs in comparison to representative ICEVs by ZIP code, considering factors such as fuel prices, electrical grid makeup, electricity prices, vehicle class preferences, and average vehicle age. The nationwide analysis reveals that, despite regional variations, PEVs consistently offer lower fuel costs and GHG emissions compared to ICEVs. At the ZIP-code level, this study finds that driving a BEV results in an average fuel cost savings of $0.09/mile (up to a maximum of $0.27/mile), while a PHEV saves on average $0.06/mile (up to a maximum of $0.19/mile), in fuel costs, when compared to a representative ICEV. The representative vehicle varies based on vehicle class and age. Annually, the potential savings can reach up to $2,200 for BEVs and $1,500 for PHEVs. Moreover, PEVs demonstrate significant emissions benefits across the U.S., saving 400 grams of CO2e per mile for BEVs and 200 grams for PHEVs when compared to ICEVs. Assuming the BEV or PHEV is driven as a new vehicle with higher annual miles than an representative vehicle, the annual savings and emissions reduction would be even more significant.

The study enhances the existing body of research by incorporating a nuanced understanding of local contexts. Compared with previous research, this analysis considers the local context concerning the geographic variability of fuel prices, driving intensities, preferences for vehicle class, and average model year, when evaluating the benefits of PEV adoption. The research findings highlight that region with high gasoline prices, low electricity prices, a preference for larger vehicles, and high driving intensities tend to experience more substantial fuel savings. Similarly, emissions reductions are more pronounced in areas with clean grids and a preference for larger vehicles. In more than 99% of U.S. ZIP codes, PEVs result in net savings in fuel and GHG emissions. This comprehensive understanding enables more targeted strategies for promoting PEV adoption in diverse geographic contexts.

For future research, potential areas of exploration include a more detailed differentiation of public charging prices and the percentage of home versus public charging by region over an increasing population of drivers over time. Investigating the ZIP code-level impact of charging times throughout the day and differences in charging behaviors between BEVs and PHEVs could also enhance the understanding of cost savings. Additionally, future research could further explore the heterogeneity in PHEV utility factors due to VMT and vehicle sizes as well as the geographic variation of home vs. public charging ratios and reductions to grid carbon intensity. It is also worth noting that this study only looks at PEVs' savings in fuel costs and does not account for PEVs' advantages in low maintenance cost (Burnham et al., 2021). Expanding the scope of research in these areas would contribute to a more comprehensive understanding of the benefits of PEV adoption and how these benefits could vary.

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**Energy Systems and Infrastructure Analysis Division**

Argonne National Laboratory
9700 South Cass Avenue
Lemont, IL 60439

www.anl.gov