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RESEARCH ARTICLE

# Electric and gasoline vehicle total cost of ownership across US cities

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## Abstract

Vehicle electrification can significantly decarbonize the transportation sector. Widespread adoption of electric vehicles (EVs) depends on their cost relative to conventional alternatives. Here we compare the total cost of ownership (TCO) of gasoline, hybrid, and electric vehicles. First, we review previous TCO studies, showing that the components (e.g., purchase price, financing, taxes, fees, insurance, refueling, maintenance, repair, and home charging equipment for EVs), parameters (e.g., vehicle miles traveled, discount rate, and lifetime), and methods differ greatly. Then, we develop a comprehensive TCO model comparing across five vehicle classes, three powertrains, and three EV ranges. Using 14 cities in the United States and multiple charging scenarios, we investigate TCO variability based on location and use pattern. We include adjustments for local gasoline prices, electricity rate plans, home charging access, and the impact of local temperatures and drive cycles on fuel economy, among other factors. We show that for a 300-mile range midsize electric SUV, TCO varies by \$52,000, or nearly 40%, across locations. Home charging access reduces the lifetime cost by approximately \$10,000 on average, and up to \$26,000. EVs are more competitive in cities with high gasoline prices, low electricity prices, moderate climates, and direct purchase incentives, and for users with home charging access, time-of-use electricity pricing, and high annual mileage. In general, we find that small and low-range EVs are less expensive than gasoline vehicles. Larger, long-range EVs are currently more expensive than their gasoline counterparts. And midsize EVs can reach cost parity in some cities if incentives are applied.

**KEYWORDS**
breakeven time, cost parity, electric vehicle, industrial ecology, total cost of ownership, transportation decarbonization

## 1 | INTRODUCTION

The transportation sector is currently undergoing a rapid transformation (Muratori et al., 2021). In the United States, the battery electric vehicle (BEV) sales share for light-duty vehicles (LDVs) increased from roughly 2% in 2020, to 4% in 2021, to 8% through May 2023 (Argonne National Laboratory, 2023). This transition to electrified vehicles is a critical strategy for decarbonizing the transportation sector (Bistline, Abhyankar et al., 2022; DOE, 2023). Transportation is the highest emitting sector of the US economy, representing 28% of greenhouse gas (GHG) emissions in 2021, with the majority (57%) from LDVs (EPA, 2022).

To reduce these emissions, the United States has set a goal to make 50% of LDV sales electric by 2030 (The White House, 2021), with many states targeting 100% by 2035 (CARB, 2022). Vehicle manufacturers likewise have set electrification goals, including GM (100% by 2035) (General Motors, 2021), Ford (100% of cars and vans by 2040) (Ford Motor Company, 2022), and Volkswagen (70% in Europe, 50% in China, and North America by 2030) (Volkswagen AG, 2022). The US government has supported these goals through subsidies. For example, the Inflation Reduction Act provides tax credits of up to $7500 for new BEVs and $4000 for used BEVs (H.R. 5376 117th Congress, 2022).

Fleet models have demonstrated the urgency of electrifying LDVs, showing that rapid electrification is essential (though by itself insufficient) to meet US climate targets (Alarfaj et al., 2020; Milovanoff et al., 2020; Woody et al., 2023; Zhu et al., 2021). Therefore, increasing consumer adoption of BEVs has become an important area of study and a priority for climate action and public policy. The most common barriers to consumer adoption are concerns about charging infrastructure, vehicle range, and the cost of BEVs (Kumar & Alok, 2020). Cost is particularly important as vehicle ownership and associated transportation costs are already a substantial proportion of household expenditures in the United States (16%), higher than food and healthcare, and second only to housing (Davis & Boundy, 2022). Previous research has established that BEVs have higher upfront costs; however, it is less expensive to operate a BEV because of lower costs for maintenance, repair, and refueling. Currently, wealthier households generally purchase more fuel-efficient vehicles, while lower income households, with less fuel-efficient vehicles, spend a higher proportion of their income on transportation energy costs (Zhou et al., 2021).

To comprehensively compare the costs of internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), and BEVs, total cost of ownership (TCO) studies aim to quantify all the expenses required to own, maintain, and operate a vehicle over its lifetime. This includes initial or upfront costs (e.g., purchase of the vehicle, taxes, and fees), recurring costs (e.g., gasoline or electricity, repairs, and insurance) and end-of-life (EOL) costs (e.g., resale or scrapping). Previous studies have suggested that consumers underestimate the total cost of car ownership by as much as 50% (Andor et al., 2020), that consumers primarily consider the upfront cost when purchasing a vehicle, and that providing consumers with TCO data might increase the adoption of BEVs (Dumortier et al., 2015; Ji & Gan, 2022).

In this study, we estimate TCO for a range of vehicle classes and vehicle powertrains. We pay particular attention to the impact of location, by comparing costs between 14 cities in the United States, and use patterns, by testing multiple charging scenarios. Our results show significant variability based on location, use, and vehicle size, with important implications for consumers, manufacturers, and policy makers.

## 2 | LITERATURE REVIEW

Roosen et al.'s (2015) review of comparative TCO studies showed substantial variation in methods and results. They found that many studies excluded costs beyond the purchase price and fuel, nearly half did not include a discount rate, most did not include charging infrastructure costs, and a wide range of assumptions were used for annual vehicle miles traveled (VMT), vehicle lifetime, and gasoline and electricity prices. In our review of 30 comparative TCO studies published between 2017 and 2022 (Supplemental Note 1 and Tables S1-S8 of Supporting Information S1) we found substantial improvement, with more attention paid to the full range of components included in a comprehensive TCO model, the myriad factors on which those components depend, and the significant influence of different modeling parameters. However, there remains no uniform, agreed upon list of components that are included in TCO (van Velzen et al., 2019), and relatively few studies have explored variability based on specific location and user factors.

### 2.1 | Components

Total costs are typically divided into initial costs (costs paid at the time of purchase), recurring costs (costs that take place over a vehicle's lifetime), and EOL costs.

### 2.1.1 | Initial costs

Initial costs include the down payment or purchase price of the vehicle, taxes, and fees. Government incentives may be included and have been shown to make BEVs cost competitive in some markets (Lévay et al., 2017). Home charging equipment and installation are usually excluded from the initial cost.

Two main methods are used to estimate the cost of vehicles: using real vehicle data (manufacturer's suggested retail price [MSRP] and rated fuel economy) for specific vehicles, and using modeled vehicles. A common approach is selecting the best-selling vehicles for each segment and powertrain. For example, Breetz and Salon (2018) compared a Toyota Corolla, a Toyota Prius, and a Nissan Leaf, and Franzò et al. (2022) compared a Volkswagen Tiguan, a Toyota Rav4, and a Tesla Model 3 as these were the best-selling ICEV, HEV, and BEV options in the United States in 2011 and in Italy in 2020, respectively. However, the best-selling vehicles, even from the same vehicle class, may have significant differences beyond their powertrains, complicating comparisons. To address this, some studies compare vehicles from the same automaker. Parker et al. (2021) compared ICEVs and BEVs using a Chevrolet Trax and Bolt, a Nissan Versa Note and Leaf, and a Volkswagen Golf and e-Golf.

The other main approach is using physics-based models that construct hypothetical vehicles, with similar performance parameters, of different powertrains. Using this method, TCO is based on differences inherent to the powertrains, rather than other features that may or may not be included in the vehicles. While less common, this approach is used by Argonne National Laboratory's BEAN model (Burnham et al., 2021a) and others (Cox et al., 2020; Hamza et al., 2021; Liu et al., 2021).

### 2.1.2 | Recurring costs

The most prominent recurring cost is fuel—gasoline (or diesel) for an ICEV and electricity for a BEV. Typically, studies use average gasoline or electricity prices in the specific study location. Methods vary, with studies using average annual prices from the previous 1 year (Mitropoulos et al., 2017), 5 years (Breetz & Salon, 2018), or 10 years (Miotti et al., 2016). Weldon et al. (2018) accounted for increasing fuel costs over time by using 0%, 5%, and 10% annual increases over a baseline price for electricity and gasoline. However, historically gasoline prices have risen more significantly, and with greater year-to-year variability, than electricity prices (BLS, 2022a, 2022b).

Additional recurring costs include maintenance, repairs, insurance, annual fees, and financing. Maintenance and repair costs are typically based on vehicle manufacturer's maintenance schedules (e.g., Burnham et al., 2021a), or based on assumed lower maintenance costs for BEVs (e.g., 35% less than ICEVs in Danielis et al., 2018; de Clerck et al., 2018). Insurance estimates are sourced from companies (e.g., Baek et al., 2021), or based on regressions from collected data (e.g., Parker et al., 2021). Interestingly, most studies do not include financing, instead assuming the vehicle's full cost is paid at the time of purchase—despite 80% of new vehicle purchases being financed (Zabritski, 2023).

Some recurring costs are rarely included, such as the time value of recharging or refueling (Hao et al., 2020). Mitropoulos et al. (2017) also included the value of time spent on maintenance and repairs. Other studies include the cost of alternative transportation (e.g., if a BEV could not complete a planned route due to range or charging time limitations) (Hao et al., 2020; Liu et al., 2021; Ouyang et al., 2021). For BEVs there may be additional monetary benefits from vehicle to grid capabilities (Huber et al., 2021).

Finally, some costs inherent to vehicle ownership are typically excluded from comparative TCO studies, as they may not vary between vehicles. These include parking costs (at home or away from home), and on-road tolls. While these costs may be excluded from the perspective of a consumer deciding between vehicles, they may be important if a consumer is considering whether or not to purchase a vehicle in the first place.

### 2.1.3 | End-of-life costs

End-of-life costs depend greatly on the ownership period. Typical new vehicle ownership periods are approximately 7 years (Carlier, 2021) and thus TCO may include the resale value of the vehicle. Over the entire lifetime of the vehicle, EOL cost would simply be the scrappage value of the vehicle. For BEVs there may be additional value in battery resale after retirement of the vehicle for second use or second life applications (Letmathe & Suares, 2017).

### 2.1.4 | Social costs

In addition to the aforementioned private costs, social costs can be included in TCO (Mitropoulos et al., 2017). These externalities, sometimes called "Total Cost for Society" include GHG emissions, other air pollutants, infrastructure costs, road congestion, road safety, road damage, and noise pollution (de Clerck et al., 2016, 2018). Job loss or job creation, at a local level, and energy security, at a national level, may also be considered social costs (Lopez et al., 2021). For the most commonly cited social costs—GHG emissions and the impact of air pollution on human health—BEVs offer significant improvements over ICEVs (Bistline, Blanford et al., 2022). In some locations, the value of human health co-benefits may be greater than the climate benefits (Liang et al., 2019). While these costs may or may not factor in an individual's purchasing decisions, they are important for crafting vehicle and transportation policies.

## 2.2 | Parameters

The parameters used in TCO models also vary widely between studies. This includes annual VMT, vehicle lifetimes (in miles or years), and discount and depreciation rates. Generally, BEVs are favored when there is a higher annual VMT, a longer vehicle lifetime or ownership period, and a lower discount rate.

The vast majority of TCO studies have focused on privately owned LDVs, as these make up the majority of vehicle sales and have been the first vehicles to electrify. But TCO comparisons for commercial fleets (Lebeau et al., 2019; Scorrano et al., 2021), two- and three-wheeled vehicles (Kumar & Chakrabarty, 2020), and medium-duty and heavy-duty (MDHD) vehicles (Noll et al., 2022; Tong et al., 2017) are increasing as electrification becomes a viable option for these vehicles. These alternative ownership models and vehicle classes may have different parameters than privately owned LDVs.

## 2.3 | Dependent factors

While many TCO components and parameters are well understood, the factors on which these components depend upon are much less studied (Delucchi, 2021). We have identified five dependencies affecting each TCO component. First is the vehicle powertrain. As most studies of vehicle TCO make comparing between powertrains their explicit goal, this dependency is well studied. Next is vehicle class. While the majority of vehicle TCO studies have focused on sedans, Burnham et al. (2021a) compared across powertrain and vehicle class (five LDV classes and six MDHD vehicle classes). Three less studied dependencies are the location of the vehicle (Baek et al., 2021; Breetz & Salon, 2018), the vehicle's user and use patterns (Hao et al., 2020; Parker et al., 2021), and how cost components of the vehicle will change over time (Grube et al., 2021).

### 2.3.1 | Location dependency

Most studies investigate vehicle TCO at a national level, with recent studies covering China (Ouyang et al., 2021), France (Desreveaux et al., 2020), Ireland (Guo et al., 2022), Italy (Franzò et al., 2022; Scorrano et al., 2020), Korea (Moon & Lee, 2019), Malaysia (Mustapa et al., 2020), New Zealand (Hasan et al., 2021), Norway (Figenbaum, 2022), Poland (Ewelina & Grysa, 2021), and Thailand (Suttakul et al., 2022). Some studies compare across countries (Baek et al., 2021; Palmer et al., 2018). Others compare different sub-national regions, such as provinces in Canada (Abotalebi et al., 2019), cities in the United States (Breetz & Salon, 2018) or China (Li et al., 2021), and neighborhoods within a city (Parker et al., 2021). Vega-Perkins et al. (2023) mapped county level cost differences in the United States, but only considered operating costs.

Factors that vary based on location include taxes and fees, fuel costs, and insurance costs. Additional components may have some degree of location dependency that is difficult to include in models due to data limitations. For example, maintenance costs may vary based on the vehicle's local climate. Social costs also vary spatially, as GHG and air pollution damages depend on factors including the local electricity grid mix, population density, and wind speed and direction (Tong & Azevedo, 2020).

One factor not found in comparative TCO studies is the impact of local temperatures on fuel economy, and therefore fuel expenditures. While more significant for BEVs, both high and low temperatures will reduce the fuel economy of vehicles of all powertrains (Wu et al., 2019). This temperature dependency has become common in comparative life cycle assessments between vehicles (Archsmith et al., 2015; Burnham et al., 2021b; Gan et al., 2021; Miller et al., 2020; Needell et al., 2016; Woody et al., 2022a, 2022b; Wu et al., 2019; Yang et al., 2021, 2018; Yuksel & Michalek, 2015; Yuksel et al., 2016), but has yet to be included in any TCO studies. Notably, Hao et al. (2020) and Scorrano et al. (2020) include some temperature effects, though only for BEVs.

### 2.3.2 | Use and user dependency

In addition to location-based differences, the user of the vehicle will impact the cost (Guo et al., 2022). Some factors are beyond the user's control. For example, financing terms will be partially determined by credit scores and insurance costs by driving records (as well as age, gender, and address) (Hagman et al., 2016). For other parameters the user has varying degrees of control (e.g., annual VMT). Most studies focus on personal use, though Taiebat et al. (2022) conducted a comparison for ride-hailing drivers.

Abotalebi et al. (2019) used annual mileage, ownership period, and preferred vehicle class survey data to compare vehicle TCO for specific households in Canada, finding 18% of households economically well suited for BEVs. Parker et al. (2021) obtained similar results, finding that a BEV would save money for 17% of households in Los Angeles County, based on different user profiles by neighborhood.

Vehicle owners can also impact their cost of driving through charging patterns. This includes the amount of charging at home, at work, and at public charging stations (which are more expensive), and the timing of charging (to take advantage of time-of-use electricity pricing).

#### 2.3.3 | Time dependency

Many recurring costs change over time. TCO studies typically offer a snapshot at a particular point in time, though there are also predictions of future costs (Grube et al., 2021) and retrospective analyses (Figenbaum, 2022). Maintenance and repair costs are somewhat predictable from vehicle manufacturer maintenance schedules and user reported repair costs. Fuel costs are more difficult to project, with gasoline being less predictable than electricity. Annual VMT is an important parameter impacting many other costs. Most studies use a constant annual VMT; however, on average vehicles drive fewer annual miles as they age (Davis & Boundy, 2022). Santos and Rembalski (2021) used projections for income and fuel costs, along with the elasticity of VMT in response to those projections, to calculate annual VMT. The lifetime of the vehicle, or the ownership period, is also a key parameter. Vehicle lifetimes have been increasing in the United States, with the average vehicle lasting over 15 years (Bento et al., 2018; Greene & Leard, 2022). However, purchasers of new vehicles only own the vehicle for 7 years on average (Carlier, 2021). Finally, the level of political support for new technologies changes, often becoming more controversial, as the technology matures (Stokes & Breetz, 2018). This would impact any recurring incentives, as well as upfront incentives for future purchases.

### 2.4 | Literature gaps

From our review we identified a list of factors that are often excluded from TCO studies. Key factors we incorporate into our study include:

- Diverse vehicle models from compact cars through pickup trucks with multiple range options
- Financing rather than paying the full MSRP at the time of purchase
- A 25-year ownership period, approaching the maximum vehicle lifetime (approximately 250,000 miles or 400,000 km), rather than an average vehicle lifetime (15 years) or first ownership period (3–10 years)
- Accounting for decreasing VMT as the vehicle ages, rather than a constant annual VMT
- Adjusting fuel economies based on temperature for all powertrains
- Using time-of-use prices from utilities in each city rather than annual average electricity costs
- Including the cost of home charging infrastructure
- Testing different charging behavior scenarios, depending on charging timing and home versus public charging

By including these factors, our model provides insight into the significant differences in TCO for gasoline and electric vehicles, and how costs may change depending on specific location and use conditions.

## 3 | METHODS AND DATA

### 3.1 | Goals and scope

We calculate the TCO for a range of vehicle classes and vehicle powertrains (Figure 1a). Vehicle parameters are for model year 2020 from Argonne National Laboratory's Autonomie Model (Supplemental Note 2 of Supporting Information S1) (Islam et al., 2021). We investigate the impact of location on TCO by comprehensively comparing costs between 14 US cities (Figure 1b). These cities, first compared by Breetz and Salon (2018), represent a wide range of climates, electricity markets, gasoline prices, and levels of political and economic support for vehicle electrification.

We consider the TCO over the vehicle's lifetime, which includes initial costs, paid at the time of purchase, recurring costs, paid throughout vehicle's lifetime, and EOL costs, paid in order to retire the vehicle:

$$\text{Total cost of ownership} = \text{Upfront cost} + \text{Recurring cost} + \text{EOL cost}$$

A full summary of our TCO model, including the components, parameters, and the factors on which they depend, is shown in Table 1.

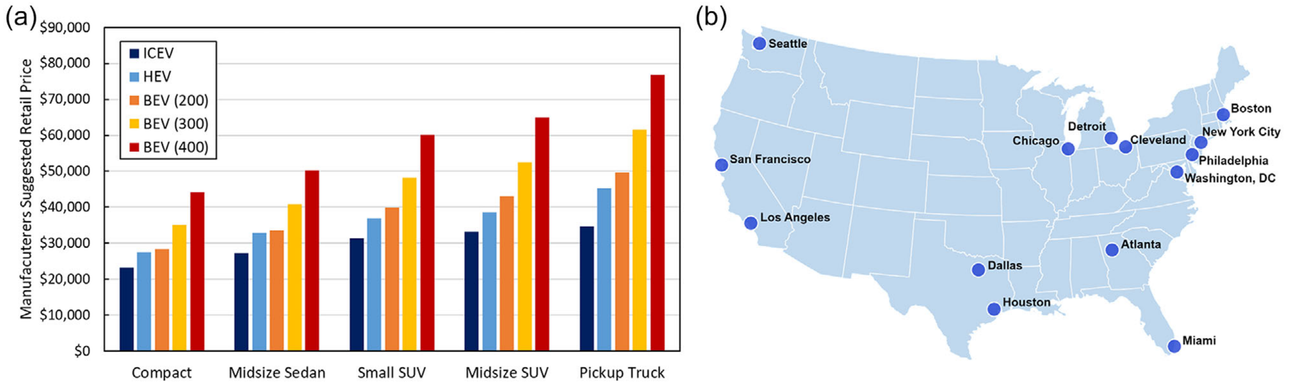


**FIGURE 1** (a) The manufacturer's suggested retail price (MSRP) of the 25 different combinations of vehicle class (compact, midsize sedan, small SUV, midsize SUV, and pickup truck) and vehicle powertrain (internal combustion engine vehicle, hybrid electric vehicle, 200-mile, 300-mile, and 400-mile range battery electric vehicle) used in this study. (b) The 14 cities investigated in this study. Figure source data available in Supporting Information S2.

## 3.2 | Initial costs

The primary factor in the initial cost is the down payment, including taxes and fees (Supplemental Note 3 of Supporting Information S1). We also include charger installation costs and subtract any monetary incentives:

$$\text{Upfront cost} = \text{Down payment} + \text{Fees} + \text{Charger} - \text{Incentives}$$

### 3.2.1 | Purchase price

The down payment is determined by the manufacturer's MSRP, the relevant sales tax, and the percentage of the total cost required at the time of purchase. We use a 10% down payment, which is the most commonly required down payment for new vehicles. The sales tax varies from 3% to 10% among the 14 cities.

### 3.2.2 | Fees

Like sales taxes, fees vary city to city. We include title fees and registration fees. Seven cities also include a specific fee for BEVs. Washington, DC is unique as its sales tax and fees depend on the vehicle's weight as well as the vehicle's powertrain.

### 3.2.3 | Incentives

Purchase incentives include both rebates and tax credits. We include national BEV tax credits and state and local incentives (Alternative Fuels Data Center, 2023). There are incentives for which all BEVs or purchasers qualify, and incentives with additional qualification requirements (e.g., state incentives with income thresholds and federal incentives with domestic production or material sourcing requirements) (Ju et al., 2020). In our base model, we include incentives that apply broadly, adding incentives with specific qualification requirements (most notably the $7500 federal tax credit) in the sensitivity analysis.

### 3.2.4 | Charger costs

Charger costs are the sum of equipment, installation, and permitting costs, and any federal, state, or utility incentives for home charger installation. We use equipment and installation costs from Borlaug et al. (2020), with our own adjustments for the local cost of labor, permitting, and incentives (Supplemental Note 4 of Supporting Information S1).

**TABLE 1** Components, dependencies, and data sources included in our total cost of ownership model. Rows contain components and parameters, while the columns contain the factors that the components and parameters may depend on. Green squares indicate that the dependency is included in our base model. Yellow squares indicate that the dependency is included in a sensitivity case. Red squares indicate that the dependency does or could exist but is not factored into our model. Grey squares indicate that the dependency is not applicable or does not exist.

| | | | Location | Vehicle class | Vehicle powertrain | Vehicle user | Time dependency | Data source |
|---|---|---|---|---|---|---|---|---|
| **Initial costs** | *Vehicle purchase* | MSRP | Red | Green | Green | Grey | Grey | BEAN model—Burnham et al. (2021a) |
| | | Taxes | Green | Green | Green | Red | Grey | State and local data |
| | | Registration fees | Green | Green | Green | Grey | Grey | State and local data |
| | | Incentives | Yellow | Yellow | Yellow | Grey | Grey | AFDC (2023) |
| | *Charging infrastructure* | Equipment | Red | Grey | Green | Grey | Grey | Borlaug et al. (2020) |
| | | Installation | Green | Grey | Green | Grey | Grey | Borlaug et al. (2020) (modified) |
| | | Incentives | Green | Grey | Green | Grey | Grey | AFDC (2023) |
| **Recurring costs** | *Fuel costs* | Gasoline price | Green | Grey | Grey | Grey | Green | BLS (2023) |
| | | Electricity prices | Green | Grey | Grey | Grey | Green | OpenEI (n.d.); BLS (2023) |
| | *Other annual costs* | Financing | Grey | Green | Green | Red | Grey | Own model |
| | | Maintenance | Red | Green | Green | Red | Green | BEAN model—Burnham et al. (2021a) |
| | | Repairs | Red | Green | Green | Red | Green | BEAN model—Burnham et al. (2021a) |
| | | Insurance | Green | Green | Green | Red | Green | Liu et al. (2021) (modified) |
| | | Annual fees | Green | Green | Green | Grey | Grey | State and local data |
| | | Parking | Red | Red | Red | Grey | Grey | N/A |
| | | Tolls | Red | Red | Red | Grey | Grey | N/A |
| | | Alternative transport | Yellow | Grey | Yellow | Red | Grey | Liu et al. (2021) |
| | *Time-value costs* | Refueling | Yellow | Yellow | Yellow | Red | Grey | Mitropoulos et al. (2017) |
| | | Maintenance and repair | Yellow | Grey | Yellow | Red | Grey | Mitropoulos et al. (2017) |
| **Parameters** | *Vehicle parameters* | Annual VMT | Red | Green | Red | Red | Green | Zhu et al. (2021) |
| | | Vehicle lifetime | Red | Green | Red | Red | Grey | N/A |
| | | Fuel economy | Grey | Green | Green | Red | Grey | Autonomie—Islam et al. (2021) |
| | *Location parameters* | Ambient temperature | Green | Grey | Grey | Grey | Grey | NOAA (2021) |
| | | Drive cycle | Green | Grey | Grey | Grey | Grey | FHWA (2014) |

(Continues)

**TABLE 1** (Continued)

| | | Location | Vehicle class | Vehicle powertrain | Vehicle user | Time dependency | Data source |
|---|---|---|---|---|---|---|---|
| | Temperature and drive cycle impact on fuel economy | | | | | | Wu et al. (2019) |
| *Other parameters* | Discount rate | | | | | | N/A |
| | Depreciation rate | | | | | | N/A |
| | Charging behavior | | | | | | Borlaug et al. (2020) (modified) |

## 3.3 | Recurring costs

Recurring costs include payments for the financed vehicle, annual fees, insurance, maintenance, repairs, and fuel. We apply a discount rate, *d*, to all costs taking place in future years, *n*, to estimate the net present value:

$$\text{Recurring cost} = \sum_{n=1}^{N}\left(\frac{\text{Financing}_n + \text{Annual fees}_n + \text{Insurance}_n + \text{Maintenence}_n + \text{Repairs}_n + \text{Fuel}_n}{(1+d)^n}\right)$$

### 3.3.1 | Financing

The financing of a vehicle depends on personal factors (e.g., the purchaser's credit score). We use average US new vehicle loan terms: a 10% down payment, a 6-year loan, and a 5% annual interest rate (Zabritski, 2023) (Supplemental Note 5 of Supporting Information S1).

### 3.3.2 | Fuel costs

The fuel cost in each year, *n*, is the sum of the fuel cost for each month. This is the product of VMT, fuel economy, and fuel price, each of which vary by the month, *m*.

$$\text{Fue l cost}_n = \sum_{m=1}^{12} \text{VMT}_{m,n} \times \text{Fuel economy}_m \times \text{Fuel price}_{m,n}$$

with fuel economy given in gallons/mile for gasoline vehicles and Wh/mile for electric vehicles. We use an estimated average annual VMT schedule from Zhu et al. (2021), which accounts for decreasing annual mileage throughout the vehicle's lifetime, and different annual VMT for sedans, SUVs, and pickup trucks (Supplemental Note 6 of Supporting Information S1). For gasoline prices we use data from the Bureau of Labor Statistics (BLS) for each city (Supplemental Note 7) (BLS, 2023). For electricity prices we compare two methods. Our base case uses real rate plans from electric utilities in each city, along with reported public charging costs (Supplemental Note 8). Rate plans are found using the United States Utility Rate Data Base (OpenEI, n.d.) and verified with documents from utilities. Where possible, rate plans designed for BEV owners were selected. Some rate plans include time-of-use pricing, with varying definitions of seasons and peak hours. We compare this with the more common method of using historic average electricity prices (BLS, 2023, 2018) (Supplemental Note 9). We assume a 5% annual increase in gasoline prices and a 2.5% annual increase in electricity prices in our base case, based on historic data, and conduct sensitivity analysis (BLS, 2022a, 2022b).

### 3.3.3 | Maintenance and repairs

Maintenance costs are estimated from Argonne National Laboratory's BEAN model (Burnham et al., 2021a), which was developed from service schedules recommended in vehicle owner's manuals (Supplemental Note 10 of Supporting Information S1). We apply these service schedules and values to our annual VMT schedule. Li-ion battery replacement is not included in our base case but is shown in the sensitivity analysis.

Repair cost (also from the BEAN model) consists of a time-dependent repair cost coefficient, which is applied to the vehicle's MSRP and adjusted based on powertrain and class (Supplemental Note 11).

### 3.3.4 | Insurance costs

Like financing, insurance costs depend on individual factors including age, gender, and driving history. We developed a formula based on Liu et al. (2021), with the base price dependent on the vehicle's MSRP and powertrain. We modify these equations with adjustment factors based on annual mileage from Parker et al. (2021), and location (Bankrate, 2023) (Supplemental Note 12 of Supporting Information S1).

## 3.4 | End-of-life costs

EOL costs are occasionally included in TCO models focusing on shorter ownership periods of 3—10 years, in the form of resale values. Our model does not include resale values, as we are interested in costs over the vehicle's entire lifetime. Additionally, the difference in depreciation rates between powertrains is inconclusive in the literature.

## 3.5 | Other costs

Time value costs are calculated for refueling, maintenance, and repairs. Refueling time is calculated based on vehicle range and mileage requirements. For maintenance and repairs we use 2 h of time spent for every 7500 miles (12,100 km) driven (for ICEVs and HEVs) or 15,000 miles (24,200 km) driven (for BEVs), roughly in line with the values used by Mitropoulos et al. (2017). The total cost is then determined by multiplying the time spent on refueling, maintenance, and repairs by the median hourly income in each state (Supplemental Note 13 of Supporting Information S1).

Alternative transportation costs are costs incurred for a replacement vehicle that is needed due to BEV range limitations. We use the formula established used by Liu et al. (2021), which uses utility factors from Bradley and Quinn (2010), updated with our own ICEV cost values and vehicle ranges (Supplemental Note 14). Time value costs and alternative transportation costs are excluded from our base case but included in sensitivity analyses. Other private costs (e.g., parking and tolls) are not included in our model.

Social costs (e.g., GHG emissions, local air pollution, noise, traffic congestion, and safety) are outside the scope of our analysis but are highly relevant for policy making. We also do not monetize or include perceived instrumental (e.g., anxiety due to range limitations), hedonic (e.g., how enjoyable each car is to drive), or symbolic (e.g., pride associated with a pro-environmental identity) attributes of car ownership (Schuitema et al., 2013).

## 3.6 | Parameters

### 3.6.1 | Fuel economy, discount rate, and VMT

The fuel economy for each vehicle, gasoline or electric, depends on the location and the month. Temperature and drive cycle adjustment factors are applied to each vehicle based on Wu et al. (2019), with temperature data from the National Oceanic and Atmospheric Administration (2021) and the percentage of city driving from the Federal Highway Administration (2014) (Supplemental Note 15 of Supporting Information S1).

In our base case we use a 5% discount rate, with sensitivity analyses using 0% and 10%. The VMT varies by vehicle class and year, but not by vehicle powertrain, user, or location, in order to perform a fair comparison across powertrains. We include sensitivity analyses with a 25% increase or decrease in annual VMT.

### 3.6.2 | Charging behavior

Based on Borlaug et al. (2020), our base case consumer charges at home 80% of the time and at public charging stations 20% of the time. The home charging is split evenly between on-peak and off-peak hours, and the public charging is split between 75% level 2 charging and 25% DC fast charging (Borlaug et al., 2020). Like residential charging, public charging costs vary spatially (Muratori et al., 2019). We include two additional charging archetypes: a cost-conscious consumer, and a consumer with no home charging access (Table 2).

**TABLE 2** Charging scenarios for different consumer types.

| | | | | | |
|---|---|---|---|---|---|
| **Base case (average consumer)** | **Home charging** | | | **Public charging** | |
| | 80% | | | 20% | |
| | On-peak | Part-peak | Off-peak | Level 2 | DC fast charging |
| | 25% | 25% | 50% | 75% | 25% |
| **Consumer without home charging access** | **Home charging** | | | **Public charging** | |
| | 0% | | | 100% | |
| | On-peak | Part-peak | Off-peak | Level 2 | DC fast charging |
| | - | - | - | 75% | 25% |
| **Cost saving consumer** | **Home Charging** | | | **Public Charging** | |
| | 90% | | | 10% | |
| | On-peak | Part-peak | Off-peak | Level 2 | DC fast charging |
| | 0% | 0% | 100% | 75% | 25% |

# 4 | RESULTS

## 4.1 | Cost of ownership

Across all vehicle classes and powertrains, there is significant cost variability depending on where a vehicle is located (Figure 2). For an example, the 25-year TCO for a midsize SUV varies from $114,000 to $160,000 (ICEV, MSRP $33,000); $108,000 to $156,000 (HEV, MSRP $39,000); and $111,000 to $163,000 (BEV-300, MSRP $52,000). Over 25 years, and across all vehicle classes, the range in TCO across cities meets (99% for BEVs) or exceeds (127% for HEVs, 143% for BEVs) the vehicle's MSRP. Therefore, range in total cost, based on location, is of the same magnitude as the purchase price of the vehicle itself.

The variation in cost, in absolute terms, is greater for larger and longer-range vehicles. However, the range expressed as a percentage of the average TCO across the cities is roughly the same across powertrains and vehicle classes, ranging from 34%—42%. The most expensive city across all classes and powertrains is New York City, while the least expensive city depends on class and powertrain. Cleveland is the least expensive for BEVs. Boston or DC are the least expensive for HEVs, and Cleveland least expensive for ICEVs, except for pickup trucks (Houston).

### 4.1.1 | Initial costs

Initial costs include a down payment for the vehicle (10% of MSRP), sales tax, various fees, and the cost of a home charger (Figure 3). In each of these categories, the BEV is more expensive. The higher MSRP is primarily due to the cost of the battery, which is expected to decline over time (Crabtree, 2019). Because of the higher MSRP, the down payment and sales tax are greater. The exception is Washington, DC, which includes a lower sales tax rate for HEVs and BEVs. Registration and title fees are relatively constant across powertrains, though they vary by city. Home charger costs vary by city due to different labor costs, permitting costs, and incentives from utilities.

### 4.1.2 | Recurring costs

Recurring costs include financing, annual fees, insurance, maintenance, repairs, and fuel costs. Like upfront costs, recurring costs and their relative proportions of the total cost vary city to city (Figure 4). For example, New York City and Detroit have particularly high insurance costs. Some cities (Atlanta, Chicago, Cleveland, Detroit, Los Angeles, San Francisco, and Seattle) include annual fees for BEVs than can add up to several thousand dollars over the vehicle's lifetime. And fuel costs vary by city with the prices of gasoline and electricity. Refueling costs for ICEVs are highest in San Francisco and Los Angeles, and lowest in Houston and Dallas. Refueling costs for BEVs are highest in Boston, San Francisco, and Los Angeles, and lowest in Atlanta, Chicago, and Cleveland. In general, BEVs have higher costs for financing (due to higher MSRP), insurance (due to higher MSRP), and fees (as states apply fees specifically to BEVs); however, BEVs generally have lower costs for maintenance, repairs, and fuel costs. The net impact is that BEVs have generally lower recurring costs than ICEVs.

The costs in Figure 4 are cumulative over the vehicle's lifetime, but the recurring costs vary significantly each year. For example, the financing costs are all in the vehicle's first 6 years, while maintenance and repairs costs are low for the vehicle's first several years and then increase.

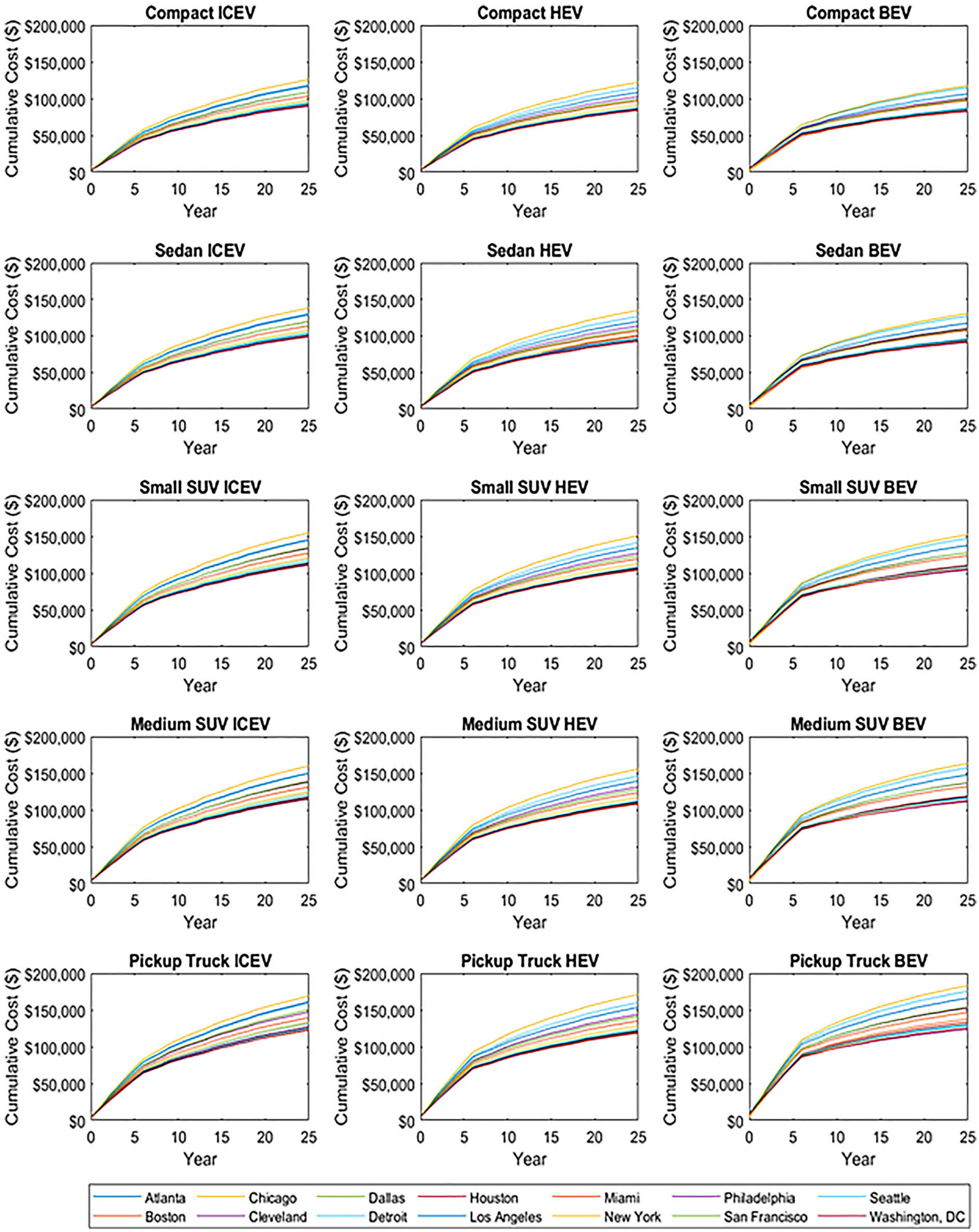


**FIGURE 2** Cumulative costs across vehicle classes (compact, midsize sedan, small SUV, midsize SUV, and pickup trucks), powertrains (internal combustion engine vehicle, hybrid electric vehicle, and 300-mile range battery electric vehicle) in each city. Figure source data available in Supporting Information S2.

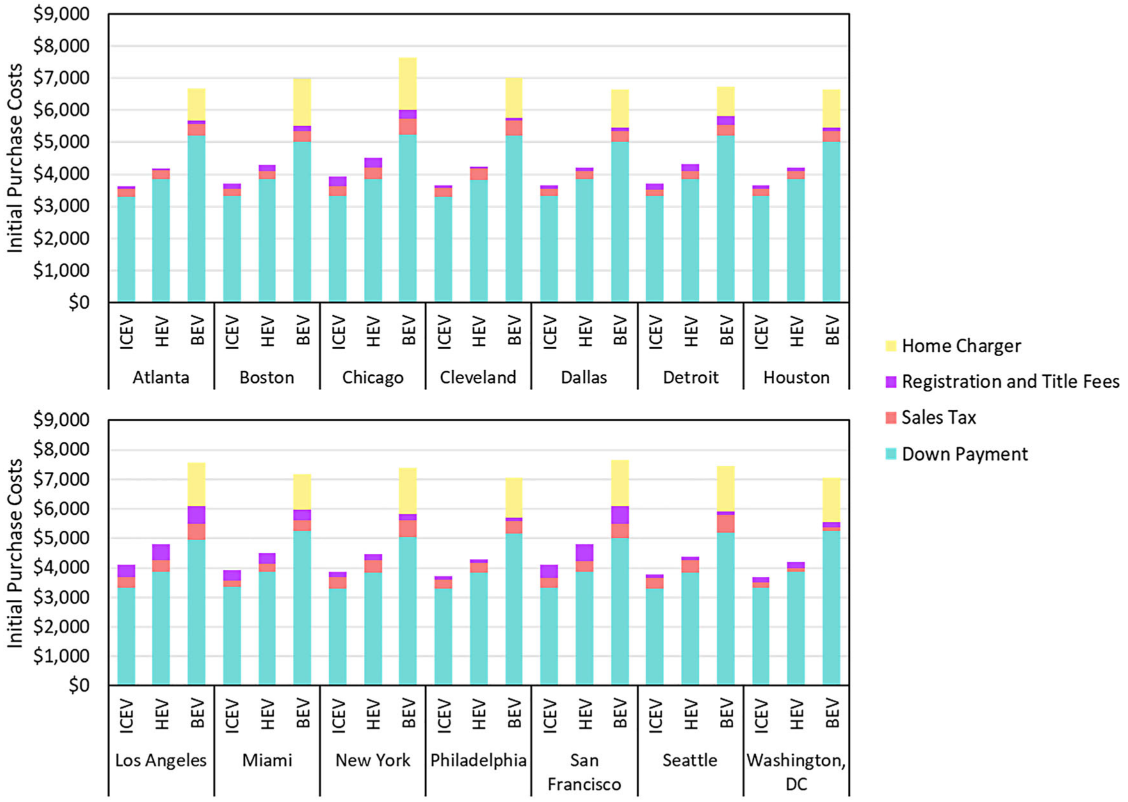


**FIGURE 3** Upfront costs for internal combustion engine vehicle, hybrid electric vehicle, and 300-mile range battery electric vehicle midsize SUV in each city (with a down payment of 20% of the manufacturer's suggested retail price). Figure source data available in Supporting Information S2.

### 4.1.3 | Breakeven analysis

ICEVs are typically less expensive upfront (Figure 3), while BEVs may have lower recurring costs (Figure 4). This results in BEVs breaking even with ICEVs after some amount of use. The breakeven time varies across cities, vehicle classes, and BEV range. Generally, smaller vehicles and shorter-range vehicles break even more quickly, with 200-mile range compact and midsize sedans breaking even in 3–7 years, and 300-mile range compact and midsize sedans breaking even in 9–20 years (Figure 5a,b). For larger vehicles (e.g., 300-mile range SUVs and pickups) BEVs only break even with ICEVs in some cities (Figure 5c–e). And for almost all 400-mile range BEVs the breakeven time exceeds 25 years.

For cities with purchase incentives (e.g., Boston and Chicago 200-mile compact and midsize sedans) the breakeven time is zero years (i.e., purchasing the BEV is less expensive upfront and remains less expensive over its lifetime). Federal incentives are not included here and would increase the number of vehicle classes and cities for which the BEV breaks even with the ICEV, while also reducing the breakeven time.

## 4.2 | Location and user factors

### 4.2.1 | Charging scenarios

The impact of charging patterns depends on the rate structure of the local electric utility, and the difference between residential electricity prices and public charging prices. Using home charging generally lowers costs (Figure 6a). This effect is particularly noticeable for electricity rate plans that include time-of-use pricing (e.g., New York City and Chicago). When vehicle owners charge during off-peak hours and avoid public charging, the cost is further reduced. For BEV owners without access to a home charger, the cost of charging is on average 1.85 times more expensive, and up to 3.20 times more expensive (Cleveland) than charging at home in our base scenario. When the no home charging scenario is compared with the home charging cost saving option, then the cost of charging is on average 2.68 times more expensive, and up to 6.23 times more expensive than

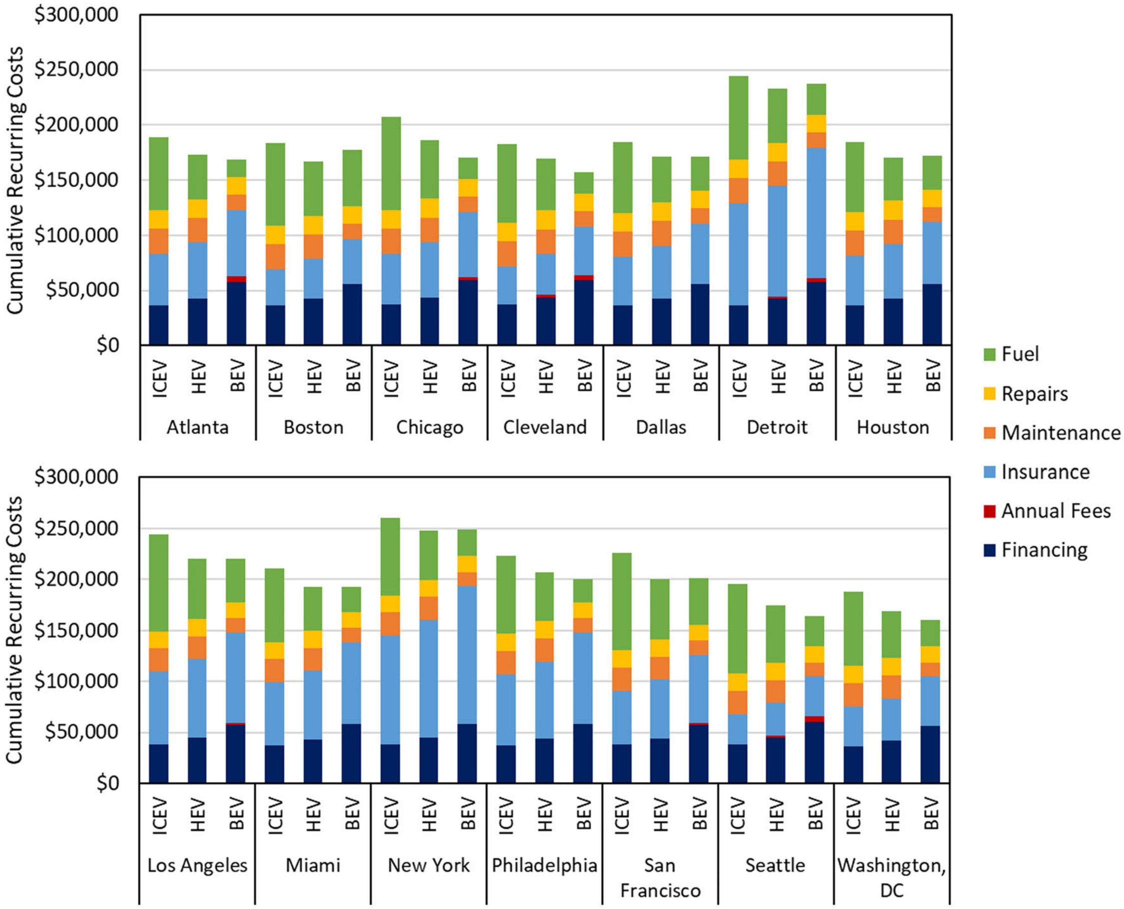


**FIGURE 4** Cumulative recurring costs (not discounted) for an internal combustion engine vehicle, hybrid electric vehicle, and 300-mile range battery electric vehicle midsize SUV in each city over a 25-year vehicle lifetime. Figure source data available in Supporting Information S2.

home charging. This difference in charging cost over the lifetime of the vehicle can make a BEV more or less expensive than its ICEV counterpart. For a 300-mile range midsize SUV, access to a home charger reduces the 25-year TCO by approximately $10,000 on average, and up to $26,000. This flips the lifetime TCO in favor of the BEV in 8 of the 14 cities investigated, even when accounting for the additional cost of home charging infrastructure (Figure 6b).

#### 4.2.2 | Utility rates versus average state electricity rates

Most studies use historic average electricity prices for a city, state, or country. These prices do not reflect specific rate plans offered by electric utilities, which often have hourly, daily, and seasonal variation. Nor do they account for how users may time their charging in response to different rate plans. Here we compare the charging costs using the reported average electricity price in each city with the home charging cost of our base scenario (50% off-peak, 25% part-peak, 25% peak, using the local utility rate plan). Public charging is excluded from this comparison.

We show that using average electricity prices can lead to charging cost estimates that are more than 40% lower or over 80% higher than estimates from coupling rate plans from the electric utility with a realistic charging scenario (Figure 7). Cities in which the estimation methods are particularly far apart tend to be cities with large time-of-use price differences, leading to an average cost that overestimates what a consumer would likely pay (e.g., Chicago and New York City). However, in our limited sample there are similar numbers of cities in which using an average electricity price may underestimate (eight cities) or overestimate (six cities) the charging cost. As shown in Figure 6, individual charging patterns also play a large role in charging costs.

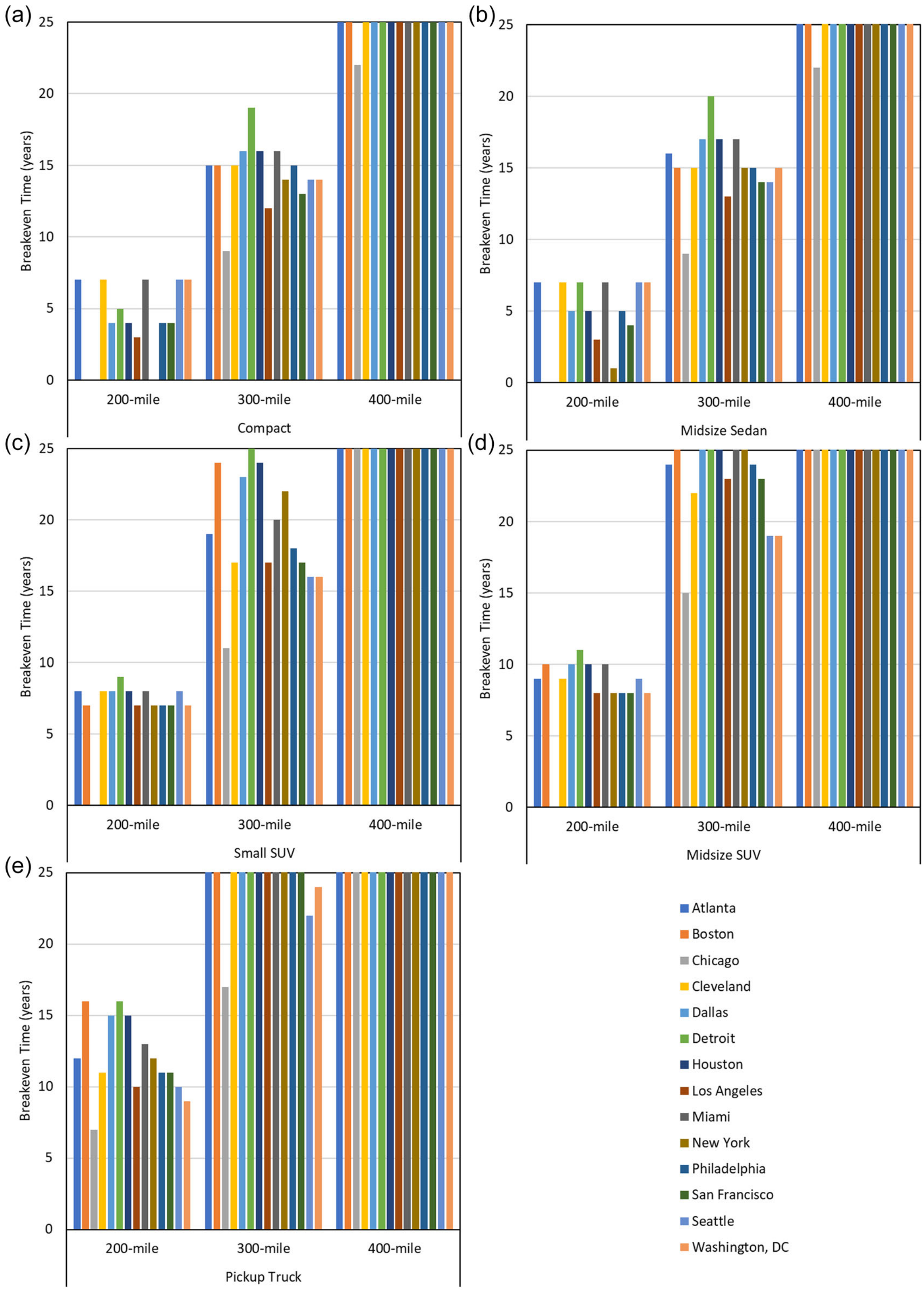


**FIGURE 5** Breakeven times between 200-mile, 300-mile, and 400-mile range battery electric vehicles when compared to the internal combustion engine vehicle of the same vehicle class in each city for (a) compact vehicles, (b) midsize sedans, (c) small SUVs, (d) midsize SUVs, and (e) pickup trucks. Figure source data available in Supporting Information S2.

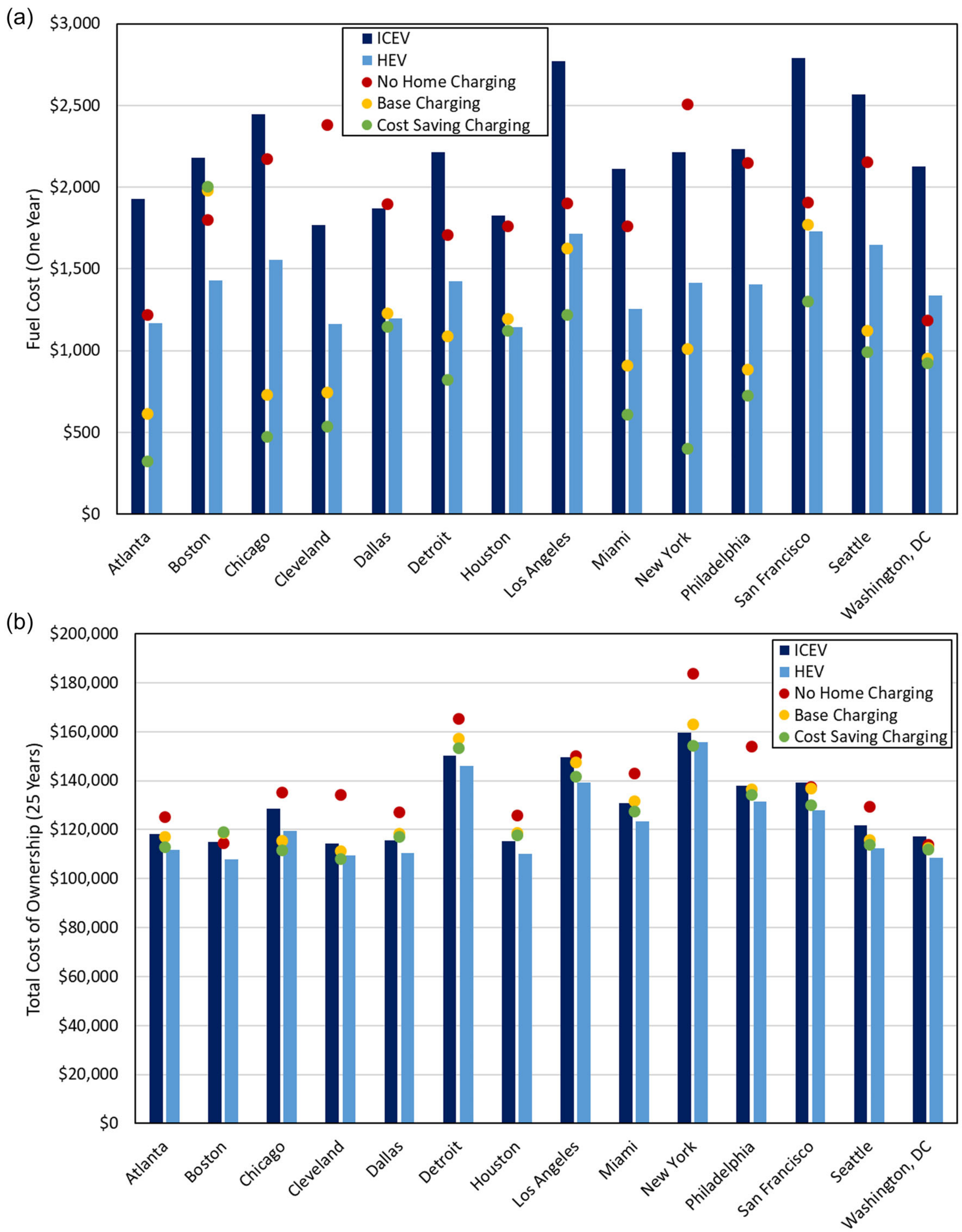


**FIGURE 6** For internal combustion engine vehicle, hybrid electric vehicle, and 300-mile range battery electric vehicle (BEV) midsize SUVs, (a) the refueling costs, with three different charging scenarios for the BEVs (indicated by dots), (b) the total cost of ownership over the vehicle's 25-year lifetime, with three different charging scenarios for the BEVs (indicated by dots), in each city. Figure source data available in Supporting Information S2.

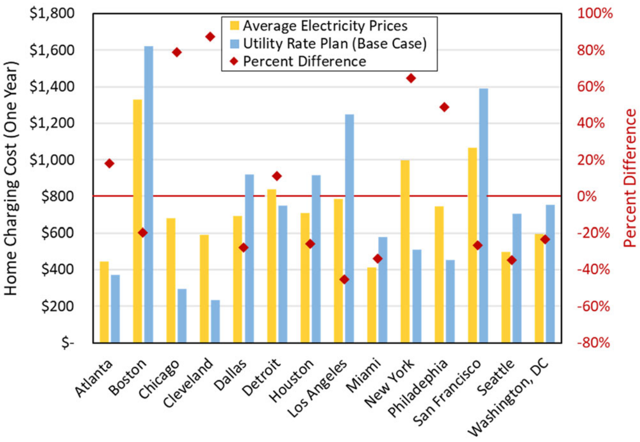


**FIGURE 7** Comparison of one year of home charging costs using average electricity prices from Bureau of Labor Statistics and local electric utility rate plans with our base charging scenario in each city. Columns show the value in dollars and red diamonds show the percent difference between the two options. Figure source data available in Supporting Information S2.

## 4.3 | Sensitivity analyses

### 4.3.1 | Purchase incentives

Our base model includes broadly applied incentives but does not include incentives with additional qualifications. Here we include these incentives, most notably the $7500 federal tax credit. When these are included, BEVs break even with ICEVs more quickly and in more cities. For 200-mile range BEVs, the breakeven time is under 2 years for compact vehicles and sedans, and under 5 years for small and midsize SUVs in each city. Small 300-mile range vehicles break even in under 10 years in each city, and larger 300-mile range vehicles break even in under 10 years in many cities. Without incentives, the 400-mile range BEVs never broke even with their ICEV counterparts. However, when incentives are included, there are a few cities in which 400-mile BEV compact and midsize sedans will break even with ICEV counterparts after 15—20 years (Supplemental Note 16 of Supporting Information S1).

### 4.3.2 | Temperature adjustment factor

Adjusting fuel economy to account for local temperatures and drive cycles has not been included in previous TCO studies. Here we compare our base case results (which include these adjustments) with the counterfactual scenario in which the adjustments are not applied (Supplemental Note 17 of Supporting Information S1).

For ICEVs and HEVs, the difference in annual refueling cost is under 5%, approximately $100 and $70, respectively. For BEVs, the difference in annual refueling cost is 13% on average ($150) with a maximum of 25% difference in Boston and Detroit ($500 and $280, respectively). Other cities with large percentage differences include Chicago and Cleveland, while the cities with the smallest difference are Atlanta, Los Angeles, Miami, and San Francisco. In each case, adjusting for temperature results in a higher refueling cost for BEVs, showing that traditional TCO methods may underestimate the cost, particularly in cities with cold climates. As a percentage of the total cost, this temperature adjustment makes less than a 3% difference in all cities but one (6% in Boston). But this does amount to several thousand dollars over the lifetime of a vehicle, which may be important for some users given the relatively close TCO margins for many vehicle classes.

### 4.3.3 | Expanded TCO

Here we expand our definition of TCO to encompass time value (to the owner) and alternative transportation costs (Supplemental Note 18 of Supporting Information S1). Time value costs vary by city due to the local median wage. For maintenance and repair, the average time cost for ICEVs and HEVs is $93 annually, and for BEVs is $44 annually. This results in a savings of approximately $1000 for the BEV over a 25-year lifetime (undiscounted). For refueling the average time cost is $103 annually for ICEVs, $52 for HEVs, and $64, $67, and $74 for 200-, 300-, and 400-mile range BEVs. This means that over a 25-year lifetime the BEV is several hundred dollars less than the ICEV, but several hundred dollars more than the HEV. These results are for one charging scenario (our base case) and would be highly dependent on individual charging patterns and income level.

Alternative transportation costs represent costs incurred by BEV owners when they are unable to complete a route due to range limitations and must rent an ICEV instead. On average, the annual costs are $390, $160, and $80, for 200-mile range, 300-mile range, and 400-mile range BEVs, respectively.

Combining time value and alternative transportation costs, the average annual expanded TCO costs are approximately $200 for ICEVs, $150 for HEVs, and $500, $275, and $200 for 200-mile range, 300-mile range, and 400-mile range BEVs, respectively. Though this represents a substantial cost increase for the 200-mile range BEV, the total cost remains significantly less than the 300-mile range BEV. With average use conditions this expanded TCO definition is unlikely to change the cost parity of BEVs and ICEVs.

#### 4.3.4 | Annual VMT, discount rate, Li-ion battery replacement, and gasoline and electricity price growth

Our base model uses average annual VMT throughout the vehicle's lifetime. Over 10 years of driving a midsize SUV, a 25% increase or 25% reduction in VMT leads to a $3500 change in the refueling cost differential between BEVs and ICEVs, on average (Supplemental Note 19 of Supporting Information S1). This effect is under $2000 in Boston, Dallas, and Houston, where the difference in operating cost is smaller, and approximately $4000 in other cities, with the relative cost of the BEV compared to the ICEV or HEV improving as annual VMT increases.

The choice of discount rate makes a large difference in TCO. In our base case (5% discount rate), the 10-year TCO of a midsize ICEV SUV in Detroit was $96,000. With a 10% discount rate this is $78,000, and with a 0% discount rate this is $120,000 (Supplemental Note 20). Though the discount rate makes a large difference in absolute cost, the relative difference between ICEVs and BEVs (the change in savings from choosing one powertrain over the other) is relatively small, on average under $1000 in the 10-year TCO differential, with a 5% change in discount rate. Because BEVs have higher upfront costs and lower operating costs, using a lower discount rate is more favorable for the BEV.

Some BEVs for some users may require battery replacement, as lithium-ion batteries degrade over time and with use, at rates dependent on specific operating conditions (Woody et al., 2020). In the United States, the minimum BEV battery warranty is 8 years or 100,000 miles (160,000 km), though some companies have warranties lasting up to 175,000 miles (Rivian Automotive, 2023). Within the warranty period, the battery would be replaced at no cost to the vehicle owner. After the warranty period, battery replacement could cost between $3400 and $17,800, depending on battery size and future battery prices (Supplemental Note 21 of Supporting Information S1). While we expect most vehicle owners would not require battery replacement, we conduct a worst-case scenario sensitivity, in which the battery is replaced right after the warranty expires. For 200-mile range vehicles, this increases the breakeven time by 0–6 years (on average 1 year for compacts, 1.5 years for midsize sedans, 3 years for small SUVs, 3.5 years for midsize SUVs, and 4.5 years for pickup trucks). For 300-mile range vehicles, the breakeven times increase by roughly 6 years for compacts and midsize sedans. For SUVs and pickup trucks, many 300-mile range vehicles no longer break even. Most 400-mile range BEVs did not break even with their ICEV counterparts even before including battery replacement.

In our base case we used a 5% annual growth rate for gasoline prices and a 2.5% annual growth rate for electricity prices, based on historic averages (BLS, 2022a, 2022b). Over 10 years, the cumulative fuel cost savings for a 300-mile midsize BEV SUV compared to an ICEV is approximately $14,000, averaged across cities. In a scenario combining low gasoline price growth with high electricity price growth this savings is reduced to $10,000. In the opposite scenario, low electricity price growth and high gasoline price growth, the savings increases to $19,000 (Supplemental Note 22 of Supporting Information S1). In some cities the growth rate of gasoline and electricity prices may determine which powertrain has the lower TCO.

## 5 | DISCUSSION

### 5.1 | Limitations and future work

The locations used in this study are all large urban centers. Future studies should compare costs in rural and suburban locations. This study relies on projected vehicle MSRP, which may differ from prices at a dealership. This study focuses on new vehicle sales; however, the majority of vehicles sold in the United States each year are used vehicles (Bureau of Transportation Statistics, 2023). Finally, this study uses an historic battery pack price of $170/kWh. BEVs will become less expensive as battery prices continue to decrease, with BloombergNEF projecting that the $100/kWh threshold will be reached by 2027 (Stoikou, 2023). While we attempted to be comprehensive in our treatment of the different costs, there are some costs that were not modeled (e.g., parking), including any social costs. Future research should include social costs and study the impact on transportation equity and justice. Comparisons between gasoline and electric vehicles are also complicated by issues of vehicle equivalency (i.e., different capabilities that may have monetary value to users, like the towing and hauling ability of ICEVs, or the option to power a home during a power outage using a BEV). Finally, there is inherently a large degree of uncertainty when modeling future costs, particularly for gasoline prices, electricity prices, and policy incentives.

### 5.2 | Importance of local conditions and use patterns

To accurately reflect the cost a consumer would pay over a vehicle's lifetime, TCO tools need to include location specific data. Breetz and Salon (2018) found that ownership costs in the most costly US cities were nearly 20% higher than the least costly cities. In our evaluation of the same cities, we found this to be nearly 40% (over \$52,000). Cities that are particularly friendly for BEVs have several things in common, including a low cost of electricity (or at least time-of-use pricing that includes an option with low prices), high gasoline prices, moderate climates, and direct purchase incentives. Several of these factors (e.g., temperature effects and specific utility rate structures) are not well understood by consumers, and additional research is needed in this area.

Likewise, there are use conditions and use patterns for which a BEV is particularly beneficial. These include high annual mileage, strategic use of time-of-use pricing where possible, and the ability to install a home charger. We found that home charging access reduces the lifetime cost by approximately \$10,000 on average, and up to \$26,000.

### 5.3 | Policy implications

Our results have significant implications for policy makers at the city, state, and federal levels, as well as for automakers and consumers. At the city level, officials should identify barriers to BEV cost competitiveness (e.g., high electricity rates without time-of-use pricing in Boston) and focus on policies that address the specific barriers in their city. Cities and states should work with electric utility companies to ensure there are affordable charging plans. At the federal level, our results show that incentives are currently still needed to make BEVs cost competitive in many locations and for many vehicle classes. Beyond incentives, the long-standing goal of reducing battery cost remains an important method of reducing BEV cost (Delucchi & Lipman, 2001; Vehicle Technologies Office, n.d.), and battery prices are projected to decline in the future (Crabtree, 2019).

There should be an increased focus on making home charging accessible. Our results show that without home charging access, a BEV will typically not achieve cost parity. Bringing home charging to renters and those in multi-family dwellings is essential to ensuring the transition to electrified transportation is equitable.

For automakers, our results show that in addition to having lower emissions (Woody et al., 2022b), smaller BEVs may be more cost competitive with their ICEV counterpart than larger BEVs (Cox et al., 2020; Figenbaum, 2022; Ouyang et al., 2021). Michalek et al. (2011) suggest that smaller battery sizes enable greater social benefits per dollar spent.

To promote BEV purchasing, there should be additional outreach and publicization of vehicle TCO, as consumers generally underestimate the total cost of vehicle ownership (Andor et al., 2020). Hagman et al. (2016) theorize that a lack of understanding of TCO may be slowing BEV adoption. Consumers are more likely to focus on upfront costs but making TCO data more readily available could increase BEV adoption (Dumortier et al., 2015; Ji & Gan, 2022).

Upfront incentives are the primary method of subsidizing BEVs in the United States, but the structure of the incentive matters. Gallagher and Muehlegger (2011) showed that the type of tax is equally important as the monetary value offered, with sales tax waivers being 10 times more impactful than income tax credits. Jenn et al. (2020, 2018) show that non-monetary incentives, like HOV lane access, also contribute to adoption, and that incentives are becoming more important as the BEV market shifts away from early adopters. Nunes et al. (2022) argue that to increase BEV adoption, and decarbonization benefits thereof, the focus of BEV incentives should shift toward used vehicles.

## 6 | CONCLUSIONS

Reducing electric vehicle costs to reach parity with gasoline vehicles has long been an important goal of sustainable transportation advocates and policy makers. Whether or not this goal has been reached has no easy answer, as TCO depends on a wide range of factors. Chief among these are the size and range of the vehicle, local conditions including fuel prices and purchase incentives, and use conditions including annual mileage and charging patterns.

In general, lower-range BEVs (roughly 200-mile range) are more affordable than a comparable gasoline vehicle, even without incentives. Longer-range BEVs (300-mile range) can be comparable to their gasoline vehicle counterparts, especially for smaller vehicle classes (compact, midsize sedans). Larger BEVs (SUVs, pickup trucks) currently require subsidies to become cost competitive. The longest-range models (400-mile range) generally are not yet cost competitive with gasoline vehicles, even with subsidies. Despite these generalizations, the question of BEV cost parity is best answered on a case-by-case basis, as vehicle costs are ultimately unique to each specific location and each individual user.

## AUTHOR CONTRIBUTION

**Maxwell Woody**: Conceptualization; data curation; methodology; formal analysis; visualization; writing—original draft; writing—review and editing; funding acquisition. **Shawn A. Adderly**: Data curation; methodology; formal analysis. **Rushabh Bohra**: Data curation; methodology; formal analysis. **Gregory A. Keoleian**: Conceptualization; methodology; writing—review and editing; funding acquisition; supervision.


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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supporting information of this article.


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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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