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# A technical analysis of private overnight charging access in IZEVA jurisdictions

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ZEV ALLIANCE

The International Zero-Emission Vehicle Alliance is a network of leading national and sub-national governments demonstrating their deep commitment to accelerating the transition to zero-emission vehicles within their markets and globally. Its members include Austria, Baden-Württemberg, British Columbia, California, Canada, Chile, Connecticut, Costa Rica, Germany, Maryland, Massachusetts, the Netherlands, New Jersey, New York, New Zealand, Norway, Oregon, Québec, Rhode Island, the United Kingdom, Vermont, and Washington. The members collaborate through discussion of challenges, lessons learned, and opportunities; hosting events with governments and the private sector; and commissioning research on the most pressing issues in the ZEV transition.

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# Introduction and background

Electric vehicle (EV) sales are ramping up around the world, and an increasing number of governments are announcing targets to phase out internal combustion engines.[1] However, a critical challenge hindering widespread EV adoption is the lack of accessible and available charging infrastructure, especially in apartment buildings.[2]

Without a private garage or driveway, those who live in apartment buildings often do not have a place to charge their car, especially if they park it on the street. Indeed, not all apartment buildings have private parking options; those that do may not have electricity readily available for all parking spaces and may require the installation of additional supporting infrastructure, which generally makes it more expensive to install home charging in apartments than in houses. Additionally, the lack of private charging availability can be exacerbated if the EV owner does not own their dwelling, as they may have less leverage and incentive to install a home charger. Addressing the overnight charging needs of EVs in these settings is thus of paramount importance, as it directly affects the convenience and feasibility of owning an EV for a significant segment of the population.

This study delves into the intricate issue of electric vehicle overnight charging infrastructure in apartments and for EV owners parking on-street, focusing on the member jurisdictions of the International Zero Emission Vehicle Alliance (IZEVA).[3] Through an analysis of EV adoption and charging needs among those living in apartments and a battery electric vehicle (BEV) refueling cost analysis, it provides data-based evidence regarding the influence of dwelling type on the cost of refueling a vehicle. This analysis is part of a two-part series on overnight charging access. The other publication focuses on policies and approaches to maximizing overnight charging in apartments.[4]

This study first presents an analysis which forecasts the share of EV owners living in apartments and houses in each IZEVA jurisdiction up to 2035. This analysis is conducted at the national level for all IZEVA jurisdictions, and an additional deep dive is conducted for three jurisdictions (Germany, the United Kingdom, and Connecticut, United States) to assess the influence of income level on dwelling types. The study then presents a cost analysis to compare the yearly cost of recharging a BEV using a private overnight charger at home, in an apartment, and when no private home charging is possible. These yearly costs are further compared to the cost of refueling an internal combustion engine (ICE) vehicle. Lastly, a charging infrastructure needs analysis is undertaken to assess the share of EV owners forecast to have access to overnight charging based on various scenarios and show the trade-offs between private overnight home charging and public charging.

1 Sandra Wappelhorst, *The End of the Road? An Overview of Combustion-Engine Car Phase-out Announcements across Europe* (Washington, DC: ICCT, 2020), https://theicct.org/publication/the-end-of-the-road-an-overview-of-combustion-engine-car-phase-out-announcements-across-europe/.

2 In this paper, we focus on apartment buildings, as this most accurately reflects the data gathered for the analysis, and use this term for consistency.

3 The International Zero Emission Vehicle Alliance (IZEVA) is composed of nine national governments (Austria, Canada, Chile, Costa Rica, Germany, the Netherlands, New Zealand, Norway, and the United Kingdom) and 13 sub-national governments (Baden-Württemberg, British Columbia, California, Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Québec, Rhode Island, Vermont, and Washington).

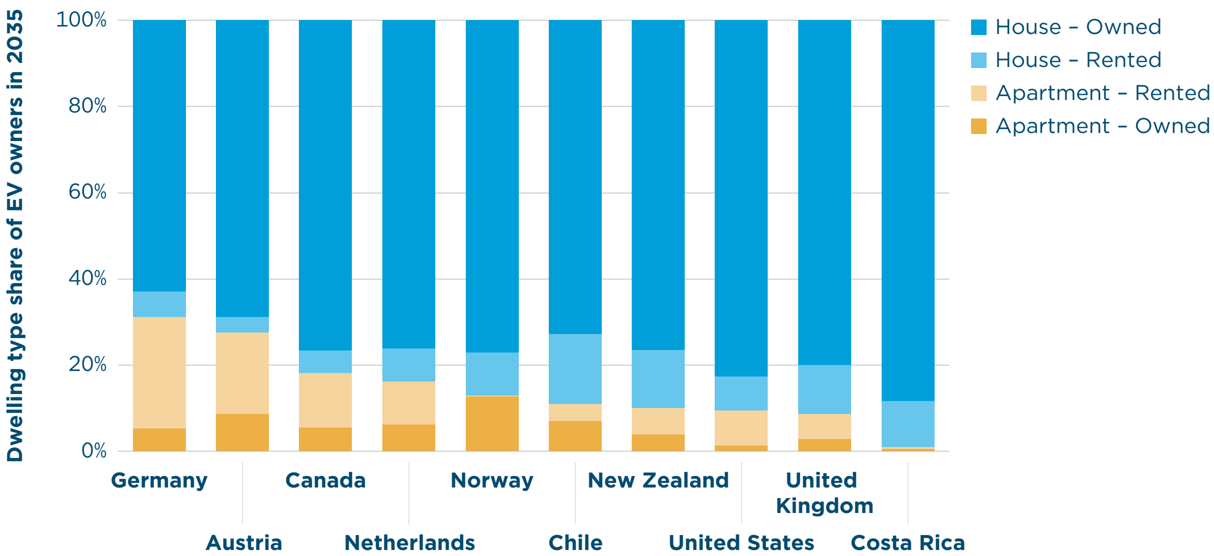
4 Alexander Tankou et al. *Policies and Innovative Approaches for Maximizing Overnight Charging in Multi-Unit Dwellings*, (Washington, DC: ICCT, 2023), theicct.org/publication/izeva-maximizing-overnight-charging-in-multi-unit-dwellings-dec23

## Dwelling types of future EV owners

Based on data from population and housing censuses of every IZEVA jurisdiction, EV driver surveys, and other sources, we derived estimates of the dwelling types and tenure of EV owners up to 2035. These data sources can be found in the appendix. The housing censuses were used to obtain the dwelling types of current vehicle owners (EV and ICE vehicles), and assumptions were made based on surveys of EV owners to reflect early EV adopters' tendency to be higher income and live more in houses that they own rather than in rented apartments. For later EV adopters, dwelling types resemble current dwelling types of all vehicle owners. Additional information on dwelling types and tenure projections can be found in the appendix.

The dwelling types and tenures are split into two dwelling categories: houses (including detached and attached houses) and apartments (in low-, mid-, and high-rise buildings). They are further split into owned and rented units, leading to four housing categories: owned houses, rented houses, owned apartments, and rented apartments. In jurisdictions for which housing censuses split data by the number of dwellings instead of housing type, we categorize buildings with one to two dwellings as houses, and those with three dwellings or more as apartments. Figure 1 displays the forecasted dwelling type shares of EV owners in 2035 for each of these jurisdictions. Jurisdictions are ordered by decreasing share of EV population in apartments, be they owned or rented.

**Figure 1.** Estimated dwelling type shares of EV owners in 2035.




As shown in Figure 1, the share of EV owners forecast to live in apartments in 2035 varies widely between jurisdictions, ranging from 1% in Costa Rica to 31% in Germany. Those forecast to live in rented units (house or apartment) ranges from 11% in Costa Rica to 32% in Germany. Shares of EV owners living in apartments and of EV owners living in rented units are both forecast to increase as EV adoption ramps up and EV owners' dwelling types gradually mimic general vehicle owners' dwelling types (see appendix, Figure A1).

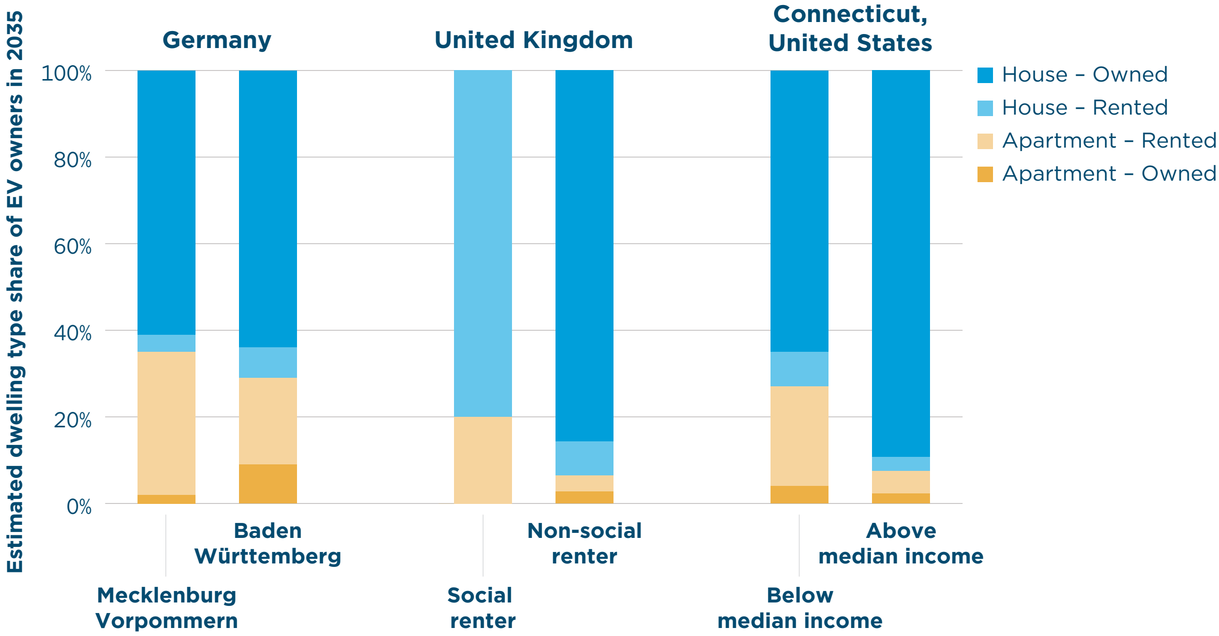
### Deep dive into specific income groups

To assess the equity-related implications of overnight charging access, we conducted case studies of three jurisdictions comparing groups with differing household incomes and housing types. In

Germany, two regions with relatively high and relatively low average net household income were compared: Baden-Württemberg (with an average household net income per capita of €24,900) and Mecklenburg-Vorpommern (€19,470), compared to Germany's average of €22,899.[5] In the United Kingdom, housing types and charging needs of renters in social housing, which is provided by not-for-profit housing associations or local councils at a low cost, were compared with those of non-social renters. In the United States, the authors compared EV owners in the state of Connecticut with net household incomes above and below the U.S. median of $70,000 per year.

Based on the methodology presented above and in the appendix, Figure 2 displays the forecast dwelling types of EV owners for these different groups in 2035.

**Figure 2.** Estimated dwelling type shares of EV owners in 2035.




As shown in Figure 2, projected shares of apartment dwellers and of renters in Germany are both higher in Mecklenburg-Vorpommern than in Baden-Württemberg, by 6 points and 10 points, respectively.[6] Similarly, in the United Kingdom, while 7% of non-social renter EV owners were forecast to live in apartments in 2035, this share jumps to 20% for social renters. In Connecticut, the share of apartment dwellers and the share of renters are likewise higher for households below the U.S. median income compared to those above it: a projected 8% of EV owners in households earning above the median income are forecast to live in rented units in 2035, a share that jumps to 30% for EV owners below the median income.

A significant share of the EV owner population is therefore projected to live in apartments in the coming years. This share is even larger for EV owners in lower income groups. It is thus important

5 Government of Germany, Office of the Federal Returning Officer, "Bundestag election 2021 – Germany," accessed December 1, 2023, https://www.bundeswahlleiterin.de/en/bundestagswahlen/2021/strukturdaten/bund-99.html; Government of Germany, Office of the Federal Returning Officer "Bundestag election 2021 – Baden-Württemberg," accessed December 1, 2023, https://www.bundeswahlleiterin.de/en/bundestagswahlen/2021/strukturdaten/bund-99/land-8.html; Government of Germany, Office of the Federal Returning Officer "Bundestag election 2021 – Mecklenburg-Vorpommern," accessed December 1, 2023, https://www.bundeswahlleiterin.de/en/bundestagswahlen/2021/strukturdaten/bund-99/land-13.html.

6 The projected share of apartment dwellers and renters in Mecklenburg-Vorpommern is 35% and 37%, respectively, and 29% and 27%, respectively, in Baden-Württemberg.

to compare both the potential to install a home charger and the cost of recharging between EV owners living in houses and those living in apartments.

# The influence of dwelling type on battery electric vehicle refueling cost

## Cost to deploy chargers in apartment buildings

The cost of deploying chargers in apartment buildings may vary widely based on the apartment building setting, age, parking type (indoor versus outdoor), and remaining electric capacity, among other considerations. Similarly, the cost of deploying public chargers can vary between and within jurisdictions depending on such factors as the electrical capacity available and the construction work required.

We gathered various real-world examples of charging infrastructure deployment costs, including costs to upgrade building electric systems if needed. Table 1 presents costs shared with the French government by the electricity utility Enedis for the electrification of apartment parking lots.[7]

**Table 1.** Cost of electrifying an indoor and an outdoor apartment parking lot. Data from Enedis, France.

| Indoor parking | | | |
|---|---|---|---|
| Connection power (Pc) | Number of contracts fulfilled by Enedis at this price | Average number of parking spots | Average cost per parking spot |
| 36 kVA < Pc ≤ 60 kVA | 8 | 18 | € 675 |
| 60 kVA < Pc ≤ 120 kVA | 7 | 38 | € 513 |
| 120 kVA < Pc ≤ 240 kVA | 12 | 65 | € 460 |
| Pc > 240 kVA | 7 | 170 | € 388 |
| **Outdoor parking** | | | |
| Connection power | | Average number of parking spots | Average cost per parking spot |
| 36 kVA < Pc ≤ 60 kVA | | 16 | € 1,147 |
| 60 kVA < Pc ≤ 120 kVA | | 30 | € 1,445 |
| 120 kVA < Pc ≤ 240 kVA | | 70 | € 1,667 |
| Pc > 240 kVA | | 165 | € 1,717 |

*Notes:* These costs do not include construction costs outside of the building (e.g., if a new on-street transformer is needed). In France, 40% of utility grid connection cost is covered by the utility itself through electricity ratepayers' money, the cost displayed here is the total cost (including the 40% paid by the utility).

7 Commission de régulation de l'énergie, "Délibération de la CRE du 12 avril 2023 portant proposition sur l'encadrement de la contribution prévue par le décret n° 2022-1249 du 21 septembre 2022 relatif au déploiement d'infrastructures collectives de recharge relevant du réseau public de distribution dans les immeubles collectifs à usage principal d'habitation [CRE deliberation of April 12, 2023 relating to the proposal on the framework of the contribution provided for by Decree No. 2022-1249 of September 21, 2022 relating to the deployment of collective charging infrastructures falling within the public distribution network in collective buildings in main residential use]," accessed August 18, 2023, https://www.cre.fr/documents/Deliberations/Proposition/encadrement-de-la-contribution-prevue-par-le-decret-n-2022-1249-du-21-septembre-2022-relatif-au-deploiement-d-infrastructures-collectives-de-recha.

In the United States, AES Engineering provided cost estimates to make parking in high-rise and mid-rise buildings 100% EV ready (i.e., such that every parking spot has an electric outlet allowing for the installation of a charger). They state that the average cost per EV-ready parking space can be as low as $1,000 when retrofitting all parking spaces to be able to have chargers and integrating EV energy management systems, but closer to $7,000 per Level 2 EV-ready parking space if chargers are incrementally added.[8] The costs associated with metering, transformers, and switchgears account for at least 50% of the total cost, with the remaining being costs associated with installing and connecting the panel and to the outlet. Sizing this infrastructure for less than 100% EV capability will not proportionally reduce initial costs and will instead result in significant future costs when a second upgrade is needed.

Case studies by the Paris Agency for Climate provide additional detail on the cost of deploying chargers in apartment buildings.[9] For example, one project was conducted from 2017 to 2019 in Neuilly-sur-Seine to install 7 chargers in a building built in early 1990 with 68 dwellings and 89 parking spots. The electricity infrastructure for the parking lot cost around €9,000 total (after deducting available grants), equivalent to €100 per co-owner. The individual cost of opening a meter and installing a charger was around €2,000 without financial aid, or around €600 to €1,000—depending on the type of charger installed—with financial aid. Similarly, VELOZ, a Californian nonprofit that promotes EV use, collected 14 case studies of apartment charging infrastructure deployment in existing and new buildings across the state from 2011 to 2016.[10]

## Refueling cost comparison

This section compares the refueling costs for EV owners with and without private home chargers living in a home or an apartment in the three case study areas (Germany, the United Kingdom, and Connecticut). An additional estimate of ICE vehicle refueling costs is provided as reference. Note that this is not a total cost of ownership, only the cost of fuel is considered. The cost of fuel includes the installation and operation of a private home charger for BEV owners who have access to one.

The electricity cost assumptions for the United Kingdom and Germany are derived from the European Alternative Fuel Observatory (EAFO) cost estimates for 2022 for private and public charging. Public charging include prices for those with mobility service provider (MSP) memberships and for ad hoc payment.[11] MSP costs for Europe represent an average of all memberships possible, excluding outliers. For Connecticut, we use an average of 2023 residential electricity costs from electricity service provider Eversource for private charging; an average of station charging prices from PlugShare for AC charging; and an average of EVgo, Electrify America, and Tesla charging costs for DC fast charging.[12] It is important to note that the cost of public recharging with an MSP membership can vary widely, and all MSP memberships are not available to everyone. It is thus important to be careful when comparing results for public ad hoc recharging

8 Brendan McEwen, "Retrofitting EV Chargers into a Multifamily Building: The Merits of a 100-per-Cent EV-Ready Approach-Publications," AES Engineering, March 2, 2021, https://aesengr.com/publications/retrofitting-ev-chargers.

9 Agence Parisienne du Climat, *État Des Lieux et Mobilisation Des Copropriétés à l'installation de Points de Recharge Pour Véhicules Électriques à Paris [Inventory and Mobilization of Condominiums for the Installation of Charging Points for Electric Vehicles in Paris],* (January 2021). https://www.apc-paris.com/sites/www.apc-paris.com/files/file_fields/2021/01/22/etude-irve-apc.pdf.

10 Veloz, "PEVC Documents and Resources," accessed August 18, 2023, https://www.veloz.org/pevc-resources/.

11 European Alternative Fuels Observatory. "Electric Vehicle Recharging Prices," accessed August 18, 2023, https://alternative-fuels-observatory.ec.europa.eu/consumer-portal/electric-vehicle-recharging-prices.

12 PlugShare, accessed August 15, 2023, https://www.plugshare.com.

and public recharging with an MSP membership.[13] Finally, for the ICE vehicle, a fleet mix of diesel and gasoline vehicles is assumed.[14]

For the upfront cost of a home charger, including installation, we assume $1,000 in a house and $2,000 in an apartment amortized over 10 years—assuming that all parking spaces are made EV-ready at once, not incrementally. This is based on stakeholder interviews presented in the accompanying policy report and other research mentioned above.[15] For apartment chargers, we assume a $12/month charge point operator fee. These costs do not account for any subsidy.

**Table 2.** EV charging cost assumptions for BEV owners in different jurisdictions and ICE vehicle refueling cost.

| Country | Cost type[a] | Home - House | Home - Apartment | Public AC, MSP price | Public AC, ad hoc price | Public DC, MSP price | Public DC, ad hoc price | Diesel cost ($/L) | Gasoline cost ($/L) |
|---|---|---|---|---|---|---|---|---|---|
| **Germany** | $/kWh | 0.35 | 0.35 | 0.56 | 0.64 | 0.67 | 0.79 | 1.96 | 2.12 |
| | $/year | 100 | 344 | | 0 | | 0 | | |
| **United Kingdom** | $/kWh | 0.35 | 0.35 | 0.5 | 0.54 | 0.55 | 0.67 | 1.95 | 1.93 |
| | $/year | 100 | 344 | | 0 | | 0 | | |
| **Connecticut, United States** | $/kWh | 0.19 | 0.19 | 0.25 | 0.30 | 0.4 | 0.5 | 1.18 | 1.0 |
| | $/year | 100 | 344 | | 0 | 84 | 0 | | |

*Note:* Conversion rate as of July 27th, 2023: €1 = $1.10.

[a] For public chargers in Germany and the United Kingdom, the price per kWh reflects a weighted average taking into account the extent to which local charge point operators and mobility service providers (MSPs) on average apply an energy price component (kWh fee), a time-based component ($/min or hour), or a fixed session component ($/session). For the MSP price, the average monthly subscription fee is included and transposed into a cost per kWh.

Based on these cost assumptions, we compare the average yearly cost paid by BEV owners with house charging, apartment charging, and without any home charger. We assume the BEV owner does not have access to at-work charging so that workplace charging accessibility does not interfere with the results. The results are presented in Table 3.

13 As an example, the MSP cost per 100 km to recharge a VW ID.3 in Germany at 50 kW can vary between €2.74 and €88.12 per 100 km according to the aforementioned EAFO source.

14 For ICE, the fleet mix of diesel and gasoline comes from ICCT's Roadmap estimates for 2023. The costs come from EU's fuel prices website for Germany (https://www.fuel-prices.eu/Germany/), RAC for the United Kingdom (https://www.rac.co.uk/drive/advice/fuel-watch/), and AAA for Connecticut (https://gasprices.aaa.com/?state=CT). All accessed on August 18, 2023.

15 Tankou et al., *Policies and Innovative Approaches for Maximizing Overnight Charging in Multi-Unit Dwellings*.

**Table 3.** Average cost per year paid by BEV owners with different accessibility to home charging (cost increase in comparison to a home charger in a house in light blue).

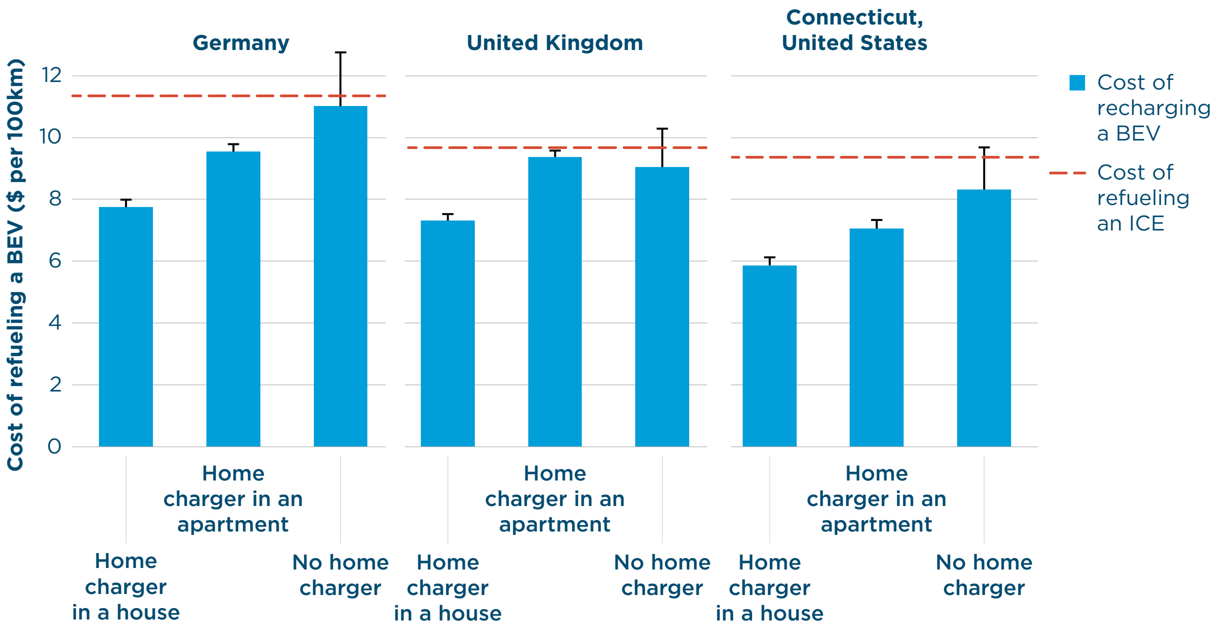
| Jurisdiction | Type of pricing | Average cost per year | | | |
|---|---|---|---|---|---|
| | | Home charger in house | Home charger in apartment | No home charger | Internal combustion engine |
| Germany | MSP membership | $1,055 | $1,300 (+23%) | $1,500 (+42%) | $1,550 |
| | Ad hoc pricing | $1,090 | $1,330 (+22%) | $1,740 (+60%) | |
| United Kingdom | MSP membership | $870 | $1,115 (+28%) | $1,080 (+24%) | $1,155 |
| | Ad hoc pricing | $900 | $1,140 (+27%) | $1,225 (+37%) | |
| Connecticut, United States | MSP membership | $1,195 | $1,440 (+20%) | $1,695 (+42%) | $1,910 |
| | Ad hoc pricing | $1,250 | $1,490 (+20%) | $1,970 (+58%) | |

As shown in Table 3, costs are lower for those living in a house compared to an apartment building. The most expensive option is to have no home charger and always pay ad hoc prices when charging. This price difference could be even larger when higher energy value-added tax is applied for public charging in comparison to residential charging, as is the case in the United Kingdom, for example.

While in most jurisdictions it is cheaper to have an apartment charger than no charger at all, the cost is about the same in the United Kingdom. This is due to the relatively smaller difference between home charging and public charging rates in the United Kingdom, and the fact that UK drivers drive less than in other jurisdictions analyzed (less than 7,000 miles per year). Because they drive fewer miles, the cost of installing and operating an apartment charger ($344/year) represents a relatively higher share of the total recharging cost. Conversely, across all three study areas, when paying ad hoc, it is always cheaper to have a home charger—even in an apartment building—than to always charge at public charging stations.

Figure 3 presents the average costs of refueling a BEV with different overnight charging options across the three study areas. The bars present the cost for a BEV owner, and the black lines represent a sensitivity depending on whether the BEV owner has an MSP membership or not and the type thereof. The top of the blue bar represents the average MSP membership cost and the top of the black line represents the average ad hoc cost. For each jurisdiction, there are three categories: private overnight home charging in a house, private overnight home charging in an apartment, and no private overnight charging option.

**Figure 3.** Average cost per 100 km (in $) paid by BEV owners with different accessibility to a home charging (bars) and by ICE vehicle owners (red dashed line). The black line represents the difference between the average MSP price and the average ad hoc price.




As shown in the graph, it is almost always cheaper to refuel a BEV than an ICE vehicle. Indeed, it can be as much as 25% cheaper in the United States to recharge a BEV in an apartment building when there is an overnight charging option than to refuel an ICE vehicle. However, in some cases—for instance, for EV owners who do not have access to private home charging or an MSP membership, and who therefore pay high ad hoc public recharging prices—it can be more expensive than refueling an ICE vehicle.

# Private home charging access

Home chargers are defined as private chargers typically used overnight, be it in a house or an apartment building; this does not include public chargers in the vicinity of EV owners' homes, where they can potentially park and charge overnight. Using the EV CHARGE model developed by the International Council on Clean Transportation, the projection of future EV owners' dwelling and tenure type presented in the first section of this paper is used to predict private overnight home charging access and public and private charging needs for IZEVA jurisdictions up to 2035.[16] Private home charging needs are calculated based on the number of EV owners having access to home charging, while public charging needs are based on the energy they deliver.

As noted above, home charging access in apartment buildings is usually lower than in houses. Based on a survey conducted by the U.S. National Renewable Energy Laboratory, 72% of detached owned houses can support the installation of a private home charger with their existing electrical access (while potentially requiring a change in parking behavior on the part of the EV owner), a

16 International Council on Clean Transportation, "EV CHARGE Model Documentation," accessed September 21, 2023, https://theicct.github.io/EVCHARGE-doc/.

share that drops to 11% in rented mid-rise buildings.[17] Similarly, a survey conducted by Enedis in France found that while 88% of EV owners living in houses recharge their EV mainly at home, this share drops to 49% for EV owners living in an apartment.[18]

In this section, we analyze the impact of three home charging access scenarios on the overall number and type of chargers needed in 2035. In the three scenarios, we keep charging access in houses constant at 80% for owned houses and 58% for rented ones and vary the apartment charging access share. Home charging access shares are based on a study and survey focused on the United States and conducted by the U.S. National Renewable Energy Laboratory.[19] This variation is displayed in Table 4, which shows home charging access across apartment types for different scenarios. Home charging access (both house and apartment) stays constant for all years, and only the dwelling type of new EV owners changes. Shares are 10% lower in jurisdictions with 110V–120V residential grids (Canada, Costa Rica, and the United States) than in those with 220V–240V residential grids (Chile, European countries, and New Zealand), as Level 1 chargers are not considered to be a home chargers in this analysis.

**Table 4.** Home charging access per apartment type for the three scenarios.

| | Home charging access share in apartments | | | |
|---|---|---|---|---|
| | Owned | | Rented | |
| Scenario[a] | Jurisdictions with a 220V–240V grid | Jurisdictions with a 110V–120V grid | Jurisdictions with a 220V–240V grid | Jurisdictions with a 110V–120V grid |
| **Baseline: Existing electric access without parking behavior change** | 28% | 25% | 10% | 9% |
| **Mid: Existing electric access with parking behavior change** | 40% | 36% | 14% | 13% |
| **High: Enhanced electric access with parking behavior change** | 48% | 43% | 25% | 22% |

[a] Survey questions to derive the different percentages for the 3 scenarios:

**Baseline:** this scenario defines residential charging as available if the vehicle is currently parked near electrical access.

**Mid:** if a vehicle is currently not parked in an area with electrical access but can be moved to a home parking location with electrical access, then residential charging is defined as available.

**High:** this scenario considers residential charging to be available if a vehicle can be moved to a parking location where the respondent believes new electrical access can be installed.

Between the baseline and the high home charging access scenarios, the share of EV owners with access to overnight charging in apartments increases by between 72% (Norway) and 121% (Germany and the United States). However, based on these home access shares and the housing assumptions

17 Yanbo Ge et al. *There's No Place Like Home: Residential Parking, Electrical Access, and Implications for the Future of Electric Vehicle Charging Infrastructure*, (National Renewable Energy Laboratory, October 1, 2021), https://doi.org/10.2172/1825510.

18 Enedis, *Utilisation et Recharge: Enquête Comportementale Auprès Des Possesseurs de Véhicules Électriques [Use and Charging : Behavioral Survey Among Electric Vehicle Owners]*, (October 2022), https://www.enedis.fr/sites/default/files/documents/pdf/utilisation-et-recharge-enquete-comportementale-aupres-des-possesseurs-de-vehicules-electriques-octobre-2022.pdf.

19 Ge et al., *There's No Place Like Home*

presented in the first section, even in the high home charging access scenario, between 26% (Norway) and 37% (Germany and Canada) of EV owners will probably not have access to private overnight home charging in 2035.

## Impact of various home charging access on income groups

As shown in the first section, a larger share of lower-income EV owners live in apartment buildings than live in houses. This is further reflected in the share of EV owners with access to private overnight charging. As an example, based on projections of EV owner dwelling types (Figure 2) and home charging access shares (Table 4), in Connecticut, 68% of EV owners in a household above the median U.S. income are forecast to have access to home charging in 2035, compared to 58% for EV owners in a household earning below the median U.S. income.

If we compare the different home charging access scenarios, increasing home charging access in apartments has a higher beneficial impact on lower-income households. This is shown in Table 5, which displays the increase in the share of EV owners with access to private home charging for differing income groups in 2035 between the three scenarios. For example, in the United Kingdom, between the baseline and the high home charging access scenarios, 150% more EV owners in social housing have access to home charging, compared to a 95% increase for non-socially rented homes.

**Table 5.** Increase in home charging access between the various scenarios for different groups.

| Jurisdiction | Group | Increase in home charging access between the baseline and the mid home charging access scenario | Increase in home charging access between the baseline and the high home charging access scenario |
|---|---|---|---|
| Germany | Baden-Württemberg (higher income) | 42% | 106% |
| | Mecklenburg-Vorpommern (lower income) | 40% | 139% |
| United Kingdom | Non-social renter | 42% | 95% |
| | Social renter | 40% | 150% |
| Connecticut, United States | Above median income | 44% | 104% |
| | Below median income | 44% | 120% |

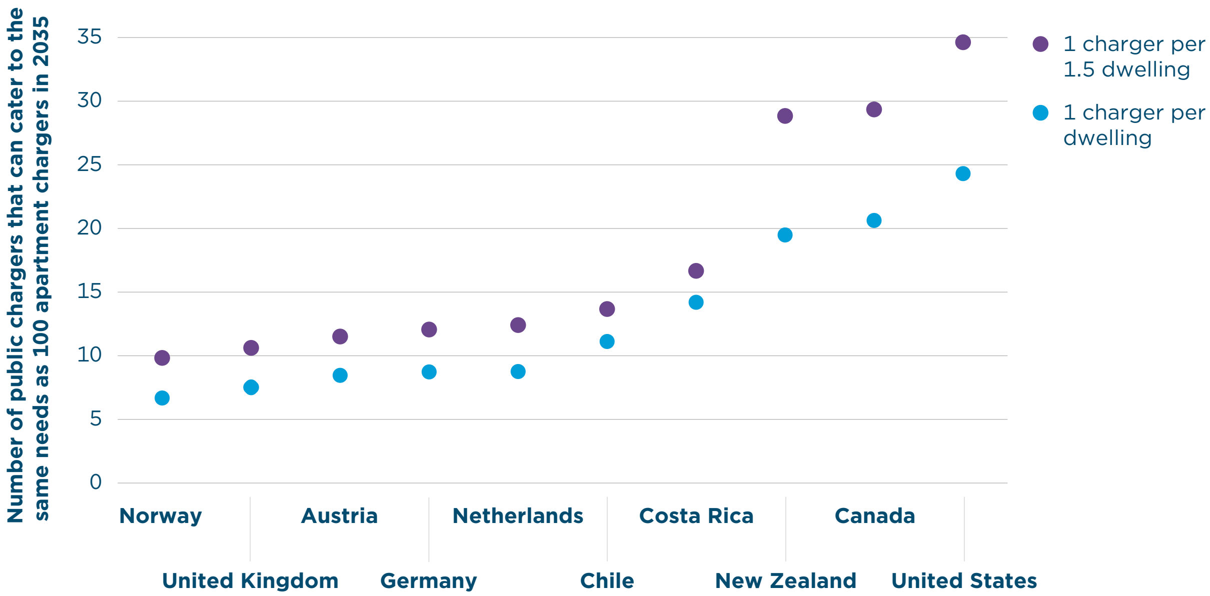
## Impact of various home charging access scenarios on the number of public and private chargers needed

There are trade-offs between public and private charging. More home charging options reduce the demand for public charging; constructing additional chargers in apartment buildings can reduce the number of public chargers needed and, therefore, the pressure on public space. As shown in Table A1 in the appendix, BEV owners with private home charging accessibility only get 10% to 12% of their energy from public charging, while BEV owners without home charging get 40% to 100% of their energy from public charging (with the rest coming from workplace charging). Additional details about the share of energy coming from different charging settings for each EV behavior group can be found in the appendix.

Figure 4 presents the number of public chargers that can cater to the same needs as 100 apartment chargers for all IZEVA national jurisdictions in 2035. The variation across jurisdictions can be explained by EV adoption stage, vehicle efficiency, and vehicle kilometers traveled (VKT). Specifically, for EV adoption stage, we assume that as the market evolves, public chargers will be used more efficiently and thus one public charger will be able to service a greater number of EVs. As for vehicle efficiency and VKT, the lower the efficiency and higher the kilometers traveled, the higher the amount of energy that vehicles will need from public chargers and thus the higher number of public chargers. The amount of energy a car will draw from a private charger will also increase if VKT increases and efficiency decreases, but it does not impact the number of private chargers needed. As explained in the EV CHARGE model documentation, in contrast to public chargers, the number of private chargers is not calculated based on the energy they deliver but rather on the possibility to charge at home.[20] This explains why, in Figure 4, the United States has the highest ratios: U.S. BEV owners have the highest VKT and less efficient vehicles due to their vehicles' size and weight.

Based on our modeling, between 6 and 23 public chargers would cater to the same needs as 100 apartment dwellers in 2035, depending on the jurisdiction and public charging type. For example, in Canada, 20 public chargers would cater to the same needs as 100 chargers deployed in apartment buildings, assuming one charger per dwelling. However, if more dwellings share chargers as the market develops, by the time the EV stock reaches an 80% share, 100 apartment chargers could serve more EV owners and thus substitute for more public chargers. For instance, if each apartment charger in Canada were shared by 1.5 dwellings, then 100 apartment chargers could cater to the same need as 30 public chargers.

**Figure 4.** Number of public chargers that can cater to the same needs as 100 apartment chargers in 2035.




20 International Council on Clean Transportation, "EV CHARGE Model Documentation."

The number of public chargers that can cater to the same needs as 100 apartment chargers decreases as the EV market develops and public chargers are used more efficiently over time, up to a maximum active utilization of 6 hours per day.[21] For example, see the different ratios for Norway and Chile, which have the same average yearly VKT, but between which Norway is at a more advanced EV adoption stage.

Beyond the ratios provided in Figure 4 and the cost aspects showcased in a previous section, it is important to note that private home charging is also more convenient than public charging, increasing users' satisfaction and vehicle owners' willingness to make the switch to electric vehicles. A 2023 survey of 13,425 EV owners by the China Consumer Association showed that 67% of those with a home charger would recommend that others buy an EV, a figure that drops to 56% among those who charge mainly at public chargers.[22] Installing chargers in apartment buildings also decreases the need for public overnight chargers, alleviating competition for public street space.

# Conclusions

Through an analysis of the increase in EV adoption and charging needs among those living in apartments, and a BEV refueling cost analysis, this research provides data-based evidence regarding the influence of dwelling type on the cost of refueling a vehicle. This study illustrates the importance of charging options that specifically target apartment dwellers from the perspective of cost, equity, and magnitude of the population concerned.  Our analysis supports the following conclusions:

**As EV adoption ramps up, a significant share of EV owners in IZEVA jurisdictions is forecast to live in apartment buildings, especially among lower income groups.** In one case (Germany), we estimate that up to 31% of EV owners will live in apartment buildings in 2035; between 10% (Norway) and 32% (Germany) of EV owners will live in rented houses or apartments. These shares are likely to increase over time as EV adoption ramps up and dwelling types of EV owners gradually come to resemble dwelling types of the general vehicle population. As lower-income households tend to live in rented apartment units at higher rates, addressing charging needs at these locations also has equity implications.

**Developing charging solutions for EV owners without private parking options will be important, as not all dwellers will have access to convenient overnight home charging.** Based on our building electrification analysis, in 2035, around 26% (in Norway) to 37% (in Canada and Germany) of EV owners are projected to not have the ability to charge overnight at home. Apartment renters are particularly likely to lack private home charging. It is thus key to provide public charging options for them. These might include on- and off-street public overnight charging points, among others.

**Refueling a battery electric vehicle is generally more expensive without access to private home charging.** In Germany and Connecticut, BEV owners without home chargers pay 42%–60% more to recharge their vehicle than those with home chargers; in the United Kingdom, they pay 24%–37% more. For BEV owners who do not have access to private overnight charging and always recharge at public stations at ad hoc prices, the cost of refueling a BEV can be higher than that of refueling an ICE vehicle.

21 International Council on Clean Transportation, "EV CHARGE Model Documentation."

22 China Consumer Association, *Investigation Report on the Consumption of New Energy Electric Vehicles and the Use of Public Charging Piles* (June 16, 2023), https://www.cca.cn/jmxf/detail/30638.html.

As explained, a significant share of EV owners may need to rely on either private overnight charging in apartments or public charging as their principal source of energy. Additional policies and innovative business models are thus needed to cater to the specific needs of these EV owners. An accompanying report presents these policies in detail, along with interviews with stakeholders to better understand their views, concerns, and insights on possible solutions.[23]

23 Tankou et al., *Policies and Innovative Approaches for Maximizing Overnight Charging in Multi-Unit Dwellings.*

# Appendix

## Methodology description

Based on data from population and housing censuses of every IZEVA jurisdiction, EV driver surveys, and other sources, we derived estimates of the dwelling types and tenure of EV owners up to 2035.[24]

In jurisdictions for which dwelling types of vehicle-owning and non-vehicle-owning populations were not available (Austria, Canada, Chile, Germany, the Netherlands, and Norway), the author had to make assumptions for dwelling types of vehicle owners. They assumed that in European jurisdictions, vehicle owners were 1.19 times more likely to live in a house that they own than in another dwelling type. Of this 19% difference, 64% (12.1 percentage points) is drawn from rented apartments, 12% (2.3 percentage points) from owned apartments, and the remaining 24% (4.6 percentage points) from rented houses. These shares are based on the 2021 UK census.[25] For Canada and Chile, based on 2021 U.S. census data, the author assumed that vehicle owners were 1.0395 times more likely to live in a house they own than in another dwelling type.[26] Of this 3.95% difference, 73% is drawn from rented apartments, 26% from owned apartments, and 1% from rented houses.

It is further assumed that at mass EV adoption (80% EV stock share and above), the dwelling types of EV owners were the same as the dwelling types of vehicle owners generally. In the early stage (below 5% EV stock share), EV owners were assumed to be three times more likely to live in a house they owned than in other dwelling types, based on a 2019 analysis of U.S. Federal Highway Administration survey data.[27] Between the early and mass EV adoption stage, a linear extrapolation based on EV stock share is calculated.

Figure A1 shows the dwelling types of current vehicle owners in blue for houses and yellow for apartments, with darker shades for owned units and lighter shades for rented ones.

24 Austria: Statistics Austria, "Stock of Dwellings," accessed in June 2023, https://www.statistik.at/en/statistics/population-and-society/housing/stock-of-dwellings
Canada: Statistics Canada, "Housing," accessed in June 2023, https://www12.statcan.gc.ca/census-recensement/2021/rt-td/housing-logement-eng.cfm
Chile: Instituto Nacional de Estadísticas, "Population and Housing Census," accessed in June 2023, https://www.ine.gob.cl/statistics/social/population-and-housing-censuses
Costa Rica: INEC Costa Rica, information shared privately, https://inec.cr
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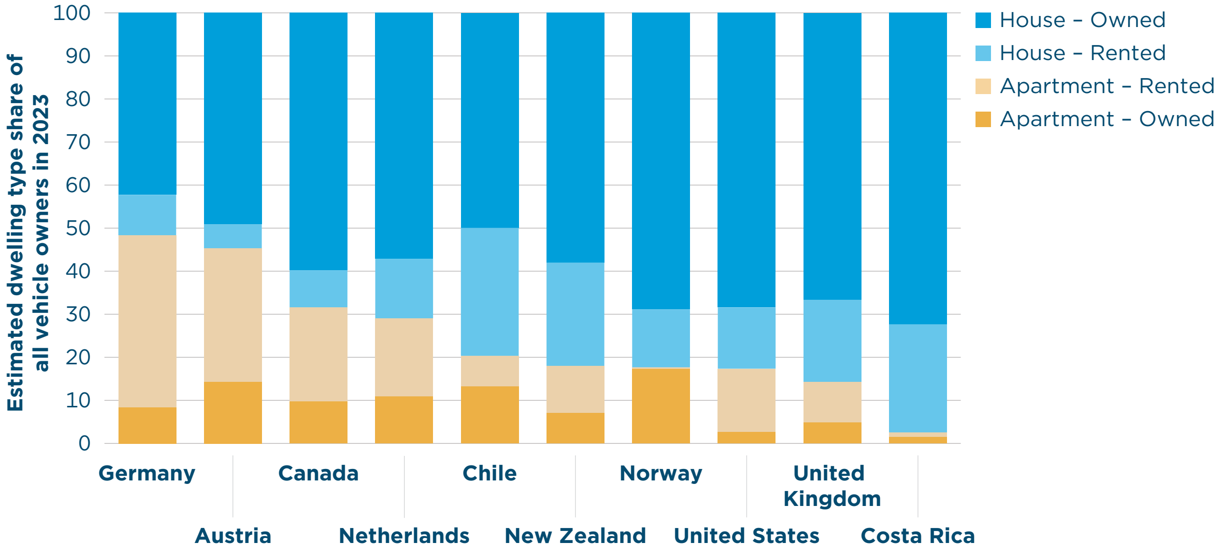
Netherlands: Centraal Bureau voor de Statistiek, "Bijna drie kwart Verenigingen van Eigenaren in Randstad," accessed in June 2023, https://www.cbs.nl/nl-nl/nieuws/2016/20/bijna-drie-kwart-verenigingen-van-eigenaren-in-randstad and Centraal Bureau voor de Statistiek, "The Netherlands in number 2021, How many dwellings in the Netherlands," accessed in September 2023, https://longreads.cbs.nl/the-netherlands-in-numbers-2021/how-many-dwellings-in-the-netherlands/#:~:text=Nearly%206%20in%2010%20Dutch,the%20average%20in%20the%20Netherlands
New Zealand: Stats NZ, "Census," accessed in June 2023, https://www.stats.govt.nz/topics/census
Norway: Statistics Norway, "Building Stock," accessed in June 2023, https://www.ssb.no/en/bygg-bolig-og-eiendom/bygg-og-anlegg/statistikk/bygningsmassen
United Kingdom: UK Office for National Statistics, "Housing Census," accessed in June 2023, https://www.ons.gov.uk/filters/02692304-a4c6-447a-980d-c6c025519b36/dimensions/change?f=search&q=GDHI#dimensions--select
United States: United States Census Bureau, "Housing Census," accessed in June 2023, https://data.census.gov/mdat/#/search?ds=ACSPUMS1Y2021&cv=JWTRNS&rv=HINCP_RC2&nv=YRBLT%28%29,VEH%281,2,3,4,5,6%29,TEN%281,2,3,4%29,BLD%2801,02,03,04,05,06,07,08,09,10%29,ucgid&wt=PWGTP&g=0200000US1,2,3,4&HINCP_RC2=%7B%22S%22%3A%22Household%20income%20%2528past%2012%20months,%20use%20ADJINC%20to%20adjust%20HINCP%20to%20constant%20dollars%2529%20recode%22,%22R%22%3A%22HINCP%22,%22W%22%3A%22WGTP%22,%22V%22%3A%5B%5B%22-59998%3A-1,-60000,-59999,0%22,%22Not%20Elsewhere%20Classified%22,%22X%22%5D,%5B%221%3A70000%22,%22Between%201%20and%2070000%22%5D,%5B%2270001%3A9999999%22,%22Between%2070001%20and%209999999%22%5D%5D%7D.

25 UK Office for National Statistics, "Housing Census," accessed September 21, 2023.

26 United States Census Bureau, "Housing Census," accessed September 21, 2023.

27 Lucas W. Davis, "Evidence of a Homeowner-Renter Gap for Electric Vehicles," *Applied Economics Letters* 26, no. 11 (June 25, 2019): 927–32. https://doi.org/10.1080/13504851.2018.1523611.

**Figure A1.** Estimated dwelling type shares of vehicle owners in 2023.




Related to home charging access, in addition to the home charging access shares presented in Table 4, it is assumed that for EV owners living in an apartment with access to home charging, there is one charger per EV in the early adoption stage and one charger per dwelling at mass EV adoption.

## EV behavior groups and the share of energy they draw from different charging settings

**Table A1.** Share of EV energy coming from different charging settings for all behavior groups.

| Charger location and type behavior group | Home, Level 2 | Work, Level 2 | Public overnight, Level 2 | Public overnight, DCFC (community hub) | Public destination, Level 2 | Public destination, DCFC | Public en-route, DCFC |
|---|---|---|---|---|---|---|---|
| 1 | 70% | 20% | 0% | 0% | 2% | 3% | 5% |
| 2 | 88% | 0% | 0% | 0% | 3% | 4% | 5% |
| 3 | 90% | 0% | 0% | 0% | 2% | 3% | 5% |
| 4 | 0% | 60% | 15% | 5% | 5% | 5% | 10% |
| 5 | 0% | 0% | 50% | 20% | 10% | 10% | 10% |
| 6 | 0% | 0% | 50% | 20% | 10% | 10% | 10% |
| 7 | 75% | 20% | 0% | 0% | 5% | 0% | 0% |
| 8 | 95% | 0% | 0% | 0% | 5% | 0% | 0% |
| 9 | 95% | 0% | 0% | 0% | 5% | 0% | 0% |
| 10 | 0% | 80% | 15% | 0% | 5% | 0% | 0% |
| 11 | 0% | 0% | 70% | 0% | 30% | 0% | 0% |
| 12 | 0% | 0% | 70% | 0% | 30% | 0% | 0% |

As show in Table A1, BEV owners with private home charging accessibility only get 10% to 12% of their energy from public charging, while BEV owners without home charging get 40% to 100% of their energy from public charging (the rest coming from workplace charging). This derives from the assumptions that BEV owners without home charging get most of their energy at work; if not, private overnight home charging is substituted by a mix of alternating current [AC] (Level 2, or greater than 2.5 kW, in this analysis)) overnight charging and direct current [DC] fast charging community hub. These two options are possible as Level 2 AC chargers usually cost less to install and put less pressure on the grid than DC chargers but require a higher number, taking more public space to be installed. Therefore, depending on the local context, cities might opt for a mix of AC and DC public overnight charging options or for full AC overnight charging.

**Table A2.** EV behavior groups definition.

| Behavior group number | Behavior group definition |
|---|---|
| 1 | Battery-Electric Vehicle (BEV) commuter with home and workplace charging |
| 2 | BEV commuter with home and no workplace charging |
| 3 | BEV non-commuter with home charging |
| 4 | BEV commuter without home charging and with workplace charging |
| 5 | BEV commuter without home charging and without workplace charging |
| 6 | BEV non-commuter without home charging |
| 7 | Plug-In Hybrid Electric Vehicle (PHEV) commuter with home and workplace charging |
| 8 | PHEV commuter with home and no workplace charging |
| 9 | PHEV non-commuter with home charging |
| 10 | PHEV commuter without home charging and with workplace charging |
| 11 | PHEV commuter without home charging and without workplace charging |
| 12 | PHEV non-commuter without home charging |

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