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Spain's electric vehicle infrastructure challenge: How many chargers will be required in 2030?

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This working paper assesses the electric vehicle charging infrastructure necessary in Spain by 2030 versus what was installed at the end of 2019. Two vehicle uptake scenarios—50% and 70% of light duty passenger vehicle registrations by 2030—are explored. The focus of the paper is on passenger cars, while light commercial vehicles and heavy-duty vehicles are excluded from the analysis. Results are presented for metropolitan areas and for the remaining nonmetropolitan areas by autonomous community regions. The results show that Spain currently has 10% to 12% of the necessary charging needed by 2025 and 3% to 4% of the charging needed by 2030 under these adoption scenarios.

Introduction

Spain is the fifth largest passenger car market in Europe by stock behind Germany, Italy, France, and the United Kingdom with over 24 million passenger cars on the road at the end of 2019. Yet, there were only 46,000 electric passenger cars in Spain by the end of 2019, representing 0.2% of passenger car stock.[1] The growth of electric vehicles in Spain has been relatively slow compared to other European nations with a 2019 registration share of 1.4% of passenger cars being electric. Yet, some cities such as Madrid and Barcelona have seen higher electric vehicle uptake relative to other parts of Spain at 2.1% and 1.8% of passenger car registrations in 2019, respectively. Spain has set a draft target of 100% new electric passenger car and light commercial vehicle sales by 2040 as part of its draft Law on Climate Change and Energy Transition.[2] The Integrated National Energy and Climate Plan 2021-2030 (PNIEC), which includes measures to meet the European Union's (EU's) energy and climate targets for 2030, states the aim of achieving a fleet of 5 million electric vehicles (cars, vans, buses, and motorcycles) and 500,000

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1 Spanish Association of Automobile and Truck Manufacturers (Anfac), "Informe Annual 2019," 2019, https://anfac.com/wp-content/uploads/2020/07/ANFAC_INFORME_ANUAL_2019_VC.pdf.

2 Legislature of Spain, "Congreso de Los Diputados," Boletin Oficial de las Cortes Generales, July 16, 2019, http://www.congreso.es/public_oficiales/L13/CONG/BOCG/B/BOCG-13-B-48-1.PDF.

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chargers in 2030.[3] This mirrors the current EU's Alternative Fuels Infrastructure Directive which suggests one charger for every 10 vehicles.[4]

New electric vehicles, including battery electric vehicles (BEVs) with no gasoline or diesel engine and plug-in hybrid electric vehicles (PHEVs) which can operate without petroleum but have a backup gasoline engine when exceeding electric range, are being introduced in a wide range of body types and styles. Depending on the range and the availability of a backup engine, the charging infrastructure needs change. The availability of home charging is also changing. Early adopters are more likely to have a plug available to charge at home than those who purchase an electric vehicle in the 2020–2030 time frame, increasing the need for public charging.

This paper examines the current passenger electric car market for trends and charging behavior characteristics for Spain and incorporates a future increase in electric range and charging speed, and the decrease in home charging availability.[5] Results are presented for four charging categories: charging at home, at the workplace, at public locations, and at direct current (DC) fast chargers regardless of location.

Market characterization of vehicles and charging

The growth of the electric passenger car market in Spain is variable across the country but generally uptake is low. The following section describes these developments and provides background information specifically on charging infrastructure in Spain in terms of technical specifications as well as housing stock and home charging access.

Market overview for electric vehicles and charging infrastructure

In 2019, there were more than 18,000 electric passenger cars sold in Spain.[6] Electric vehicles in our analysis include BEVs and plug-in hybrid electric vehicles PHEVs. We consider the new vehicle registration data to be representative of new vehicle sales as a measure of electric vehicle uptake. Electric vehicle registrations as a share of passenger cars in 2019 were variable among metropolitan areas as defined by the European Union's Metropolitan Region definition.[7] In 2019, the electric passenger car stock was made up of 57% BEVs and 43% PHEVs in Spain. The electric passenger car uptake trends are assessed across these metropolitan areas and the remaining nonmetropolitan areas are categorized by autonomous community, corresponding to NUTS 2 regions.

Figure 1 shows electric vehicle sales across Spanish metropolitan areas and nonmetropolitan areas as a percentage of new passenger vehicle sales. There are 23 metropolitan areas outlined in thin black lines with the top 10 by population labeled. The remaining 13 nonmetropolitan areas are separated by autonomous regions delineated by thick gray lines. The nonmetropolitan areas are shown with diagonal lines to differentiate them from metropolitan areas.

3 Government of Spain, "Borrrador Actualizado Del Plan Nacional Integrado de Energia y Clima 2021 - 2030," January 20, 2020, https://www.miteco.gob.es/images/es/pniec_2021-2030_borradoractualizado_tcm30-506491.pdf. https://www.miteco.gob.es/images/es/pnieccompleto_tcm30-508410.pdf

4 European Parliament & the Council of the European Union, "DIRECTIVE 2014/94/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 on the Deployment of Alternative Fuels Infrastructure," *Official Journal of the European Union*, August 22, 2014, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=EN.

5 The geographical scope of this paper covers the Spanish mainland, the Balearic Islands and Canary Islands, and the North African coastal cities of Ceuta and Melilla.

6 IHS Markit Copyright © IHS Markit, 2019. All rights reserved., "Purchased Dataset on Vehicle Registrations by European NUTS 3 Statistical Areas. Data through December 31, 2019," 2020.

7 Eurostat, "Metropolitan Regions," accessed May 5, 2020, https://ec.europa.eu/eurostat/web/metropolitan-regions/background.

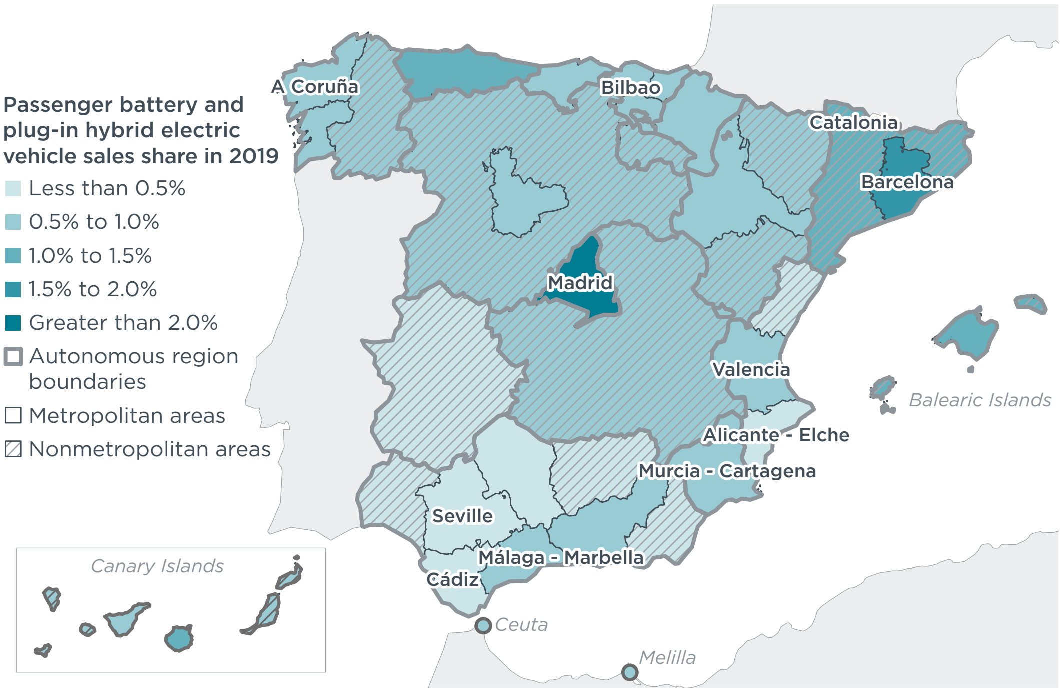

Figure 1. Electric vehicle share including BEVs and PHEVs of new passenger car registrations in 2019.

The map in Figure 1 shows that electric passenger car share was highest in Madrid and Barcelona. The nonmetropolitan Catalonia area surrounding Barcelona also showed high shares. In general, electric vehicle uptake is highest in metropolitan areas and the north of the country and lower in the south.

However, there are some anomalies regarding conventional passenger car registrations. The metropolitan areas of Barcelona, Alicante—Elche, and Las Palmas (Canary Islands) all show more than 125% of the national average for new vehicle registrations. For nonmetropolitan areas of autonomous regions, Castilla—La Mancha, Catalonia, Castile and Leon, Andalusia, and the Community of Valencia show a registration rate of more than 150% of the national average in 2019. These high conventional passenger car registrations could be the result of greater prosperity and a preference for new vehicles, but could equally be the result of auto manufacturing activities with registrations related to this industry. If the registration of conventional vehicles were a reflection of manufacturing activities, the effect would be to depress the electric vehicle sales shares shown in Figure 1. Electric vehicles are produced in Spain by Ford, Nissan, Puegot, Opel, and Citroën,[8] but the exact distribution of manufacturing and its relation to registration is unclear.

Current charger counts are estimated from Electromaps.[9] As of December 31, 2019 there were 8,673 public chargers in Spain excluding standard wall outlets with type C or type F sockets. These chargers range from 3 kW to 22 kW. The extent to which private or semi-private workplace chargers are included in these counts is unknown. Figure 2 shows the number of chargers per million population. This is a measure of how prevalent infrastructure is regardless of how many electric vehicles have been sold. Areas that are relatively high on this metric, such as the eastern coast of Spain, are primed for faster electric vehicle growth.

8 Spanish Association of Automobile and Truck Manufacturers (Anfac), "Informe Annual 2019."

9 Electromaps, "Charging Stations in Spain," accessed January 1, 2020, https://www.electromaps.com/en/charging-stations/espana.

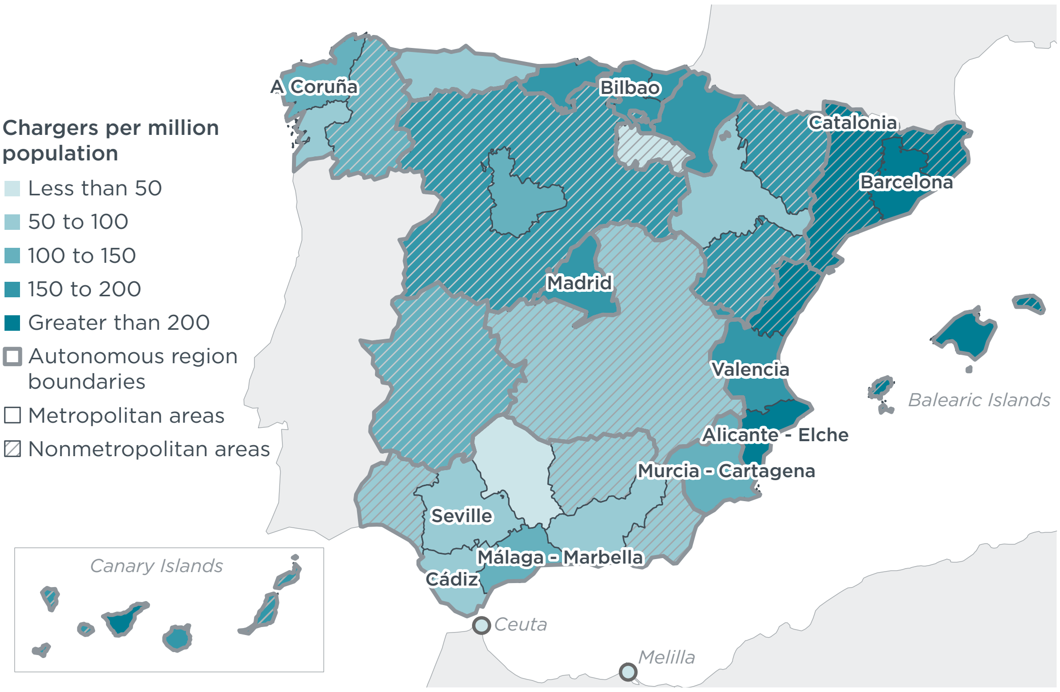

Figure 2. Chargers per million population.

In general, the south of the country lags the north on infrastructure. However, the entire country is quite low in terms of charging access. Barcelona and surrounding Catalonia are the highest with a ratio of 282 and 346 chargers per million people, respectively.

Table 1 shows the charging terminology used in the analysis related to power level, applicable standards, and current type. This report's terminology for normal (less than or equal to 22 kW) and fast (greater than 22 kW) charging is based on the methods applied across different regions in previous ICCT reports.

Table 1. Charger terminology, power level, standards, and current type.

Terminology in this report	Typical power levels	Standards included in this report	Current type
Normal	Approximately 3 kW – 22kW	Chargers with Type 2 connectors	Alternating current
Fast	43 kW – 350 kW	Chargers with Type 2, CHAdeMO, CCS, or Tesla connectors	Alternating current and direct current

Vehicle charging infrastructure scenarios

This section describes the modeling approach for charging infrastructure scenarios in Spain from now till 2030. The modeling incorporates current charging trends and data and adapts parameters to reflect expected changes in range, vehicle technology, home charging availability, and charging speed. We make estimates for normal work charging, normal public charging, and fast charging for each metropolitan and nonmetropolitan area based the characteristics of each area.

Overview of methodology

The methodology employed to estimate charging needs is described more fully in other U.S.- and Germany-based studies, and only a brief review of methods are provided here.

Baseline vehicle registrations are from IHS Automotive[10] and charger counts are from Electromaps.[11]

An important issue concerning fast charging for establishing baselines is double counting. Multi-standard rapid chargers may have up to three outlets, only one of which can be used at a time. In the model, this would only be counted as one charger. This becomes important when interpreting results or comparing to other studies. For Spain, we estimate that for every 100 outlets there are only 70 chargers which can be used at a time for an outlet-to-charger ratio of 1.4-to-1. Comparisons to other studies that use outlets as a basis for measurement will have to have this ratio incorporated.

Results for charging are presented in four categories: home, work, public, and fast charging. The categories are grouped by the activity done while charging, shown in Table 2, which is important when formulating strategies from the results. The activity done while charging is shown in columns along with the category they represent in paratheses. The first row lists representative locations where these categories of charging occur. An "x" denotes a location where an activity is likely to occur.

Table 2 Charging categories grouped by activity and location.

	Activity done while charging			
Location of charging	**Charging while at home / sleeping (home)**	**Charging while working (work)**	**Charging while doing other activities (public)**	**Fast charging is the activity (fast charging)**
Private home garage	x			
Apartment	x			
Private workplace		x		
Curbside	x	x	x	x
Public garage	x	x	x	x
Retail		x	x	x

Of particular interest is charging while working. There is a large potential for workplace charging to be done at public chargers in garages and perhaps at curbside. As more retail workers use electric vehicles, chargers classified as public at retail locations may be used by those employees while working. Likewise, home charging is broadly defined as charging while sleeping. The same public garage or curbside charger could be used by workers, shoppers, and nearby residences. In the Spanish context, many cars are parked in public places suggesting curbside charging or charging in public parking garages could be pursued as strategies to electrify those vehicles along with increasing daytime charging opportunities. The exact amount of sharing between purposes and the definition of exact locations is left for future analyses.

The model incorporating the assumptions above is outlined in Figure 3. The blue rectangles represent each step in the model, while the yellow trapezoids indicate the data and assumptions necessary for each step. Finally, the gray circles explain the steps. The first step on the top left defines the number of vehicles to serve and the bottom right step is the charger estimate by charging category.

10 IHS Markit Copyright © IHS Markit, 2019. All rights reserved., "Purchased Dataset on Vehicle Registrations by European NUTS 3 Statistical Areas. Data through December 31, 2019."

11 Electromaps, "Charging Stations in Spain."

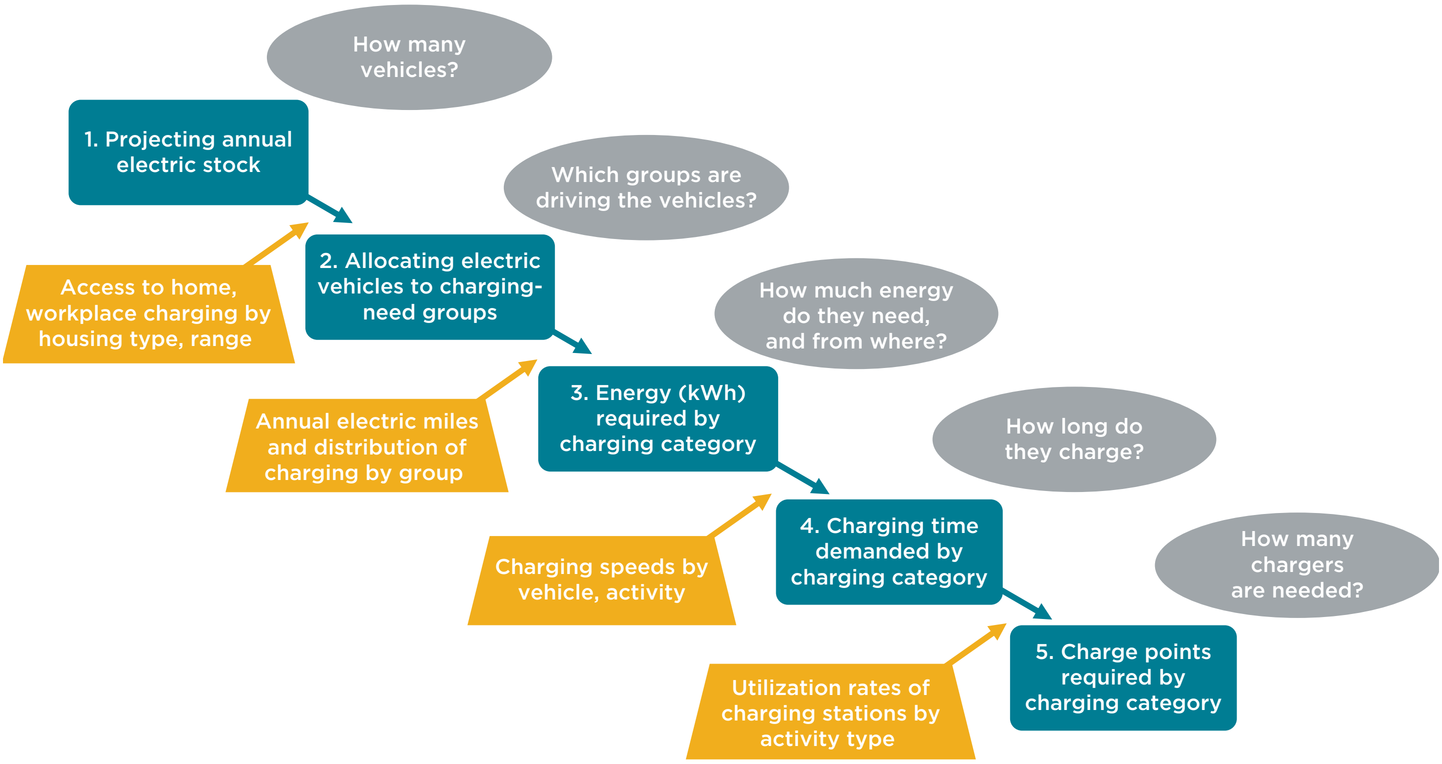

Figure 3. Model to allocate chargers to electric vehicles.

The data inputs shown in the yellow trapezoids are drawn from many sources including commercially available data and other analytical research. Data areas, the variables that depend on these data, and the relevant sources for these data are shown in Table 3.

Table 3. Data sources for key variables.

Data area	Variables	Source
Population	Population by NUTS 3 statistical area and future projections	Eurostat [a]
Housing	Number of dwellings in houses and apartments Population by dwelling type	Eurostat [b] Eurostat [c]
Metropolitan area definitions	Definition of metropolitan areas in Spain	Eurostat [d]
Electric vehicle sales by NUTS 3 area	Registrations of new electric vehicles, including battery electric vehicle (BEVs) and plug-in hybrid electric vehicles (PHEVs)	IHS Markit [e]
Vehicle ownership	Vehicles per capita Vehicle stock by NUTS2	ACEA [f] Eurostat [g]
Commuting	Number of commuters in Spain Commute mode	Eurostat [h] Statistia [i]
Existing charging infrastructure	Counts of charging outlets in Spain	Electromaps [j]
Charging infrastructure to electric vehicle relationships	Ratios of electric vehicles to charge point, based on market size and/or electric share	Nicholas, Hall, and Lutsey [k] Nicholas and Hall [l] Hall and Lutsey [m]
Charging behavior	Observed charging rates of charging for residential, workplace, public, and DC fast chargers	Tal et al. [n] Dodson and Slater [o] Schaufenster Elektromobilität [p]
Vehicle travel	Annual vehicle miles traveled	Odyssee - Mure [q]

Note: NUTS 3 = Nomenclature of territorial units for statistics

[a] Eurostat, "Population on 1 January by Broad Age Group, Sex and NUTS 3 Region," 2019, https://ec.europa.eu/eurostat/web/products-datasets/-/demo_r_pjanaggr3.

[b] Eurostat, "Conventional Dwellings by Occupancy Status, Type of Building and NUTS 3 Region," 2011, https://ec.europa.eu/eurostat/web/products-datasets/-/cens_11dwob_r3.

[c] Eurostat, "Distribution of Population by Degree of Urbanisation, Dwelling Type and Income Group - EU-SILC Survey," 2020, http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_lvho01&lang=en.

[d] Eurostat, "Metropolitan Regions."

[e] IHS Markit Copyright © IHS Markit, 2019. All rights reserved., "Purchased Dataset on Vehicle Registrations by European NUTS 3 Statistical Areas. Data through December 31, 2019."

[f] European Automobile Manufacturers Association, "Vehicles per Capita by Country," accessed June 30, 2020, https://www.acea.be/statistics/tag/category/vehicles-per-capita-by-country.

[g] Eurostat, "Stock of Vehicles by Category and NUTS 2 Regions," 2018, http://ec.europa.eu/eurostat/product?code=tran_r_vehst&language=en&mode=view.

[h] Eurostat, "Employment and Commuting by Sex, Age and NUTS 2 Regions," accessed June 30, 2020, http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfst_r_lfe2ecomm&lang=EN.

[i] Statistia global survey, "Modes of Transportation for Commuting in Spain 2020," n.d., https://www.statista.com/forecasts/1001474/modes-of-transportation-for-commuting-in-spain.

[j] Electromaps, "Charging Stations in Spain."

[k] Michael Nicholas, Dale Hall, and Nic Lutsey, *Quantifying the Electric Vehicle Charging Infrastructure Gap across U.S. Markets*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/charging-gap-US.

[l] Michael Nicholas and Dale Hall, *Lessons Learned on Early Electric Vehicle Fast-Charging Deployments*, (ICCT: Washington, DC, 2018), https://theicct.org/publications/fast-charging-lessons-learned.

[m] Dale Hall and Nic Lutsey, *Emerging Best Practices for Electric Vehicle Charging Infrastructure*, (ICCT: Washington, DC, 2017), https://theicct.org/publications/emerging-best-practices-electric-vehicle-charging-infrastructure.

[n] Gil Tal, Jae Hyun Lee, and Michael Nicholas, "Observed Charging Rates in California," Working Paper (University of California, Davis, 2018), https://itspubs.ucdavis.edu/index.php/research/publications/publication-detail/?pub_id=2993.

[o] Tristan Dodson and Shane Slater, "Electric Vehicle Charging Behaviour Study" (Element Energy, 2019), http://www.element-energy.co.uk/wordpress/wp-content/uploads/2019/04/20190329-NG-EV-CHARGING-BEHAVIOUR-STUDY-FINAL-REPORT-V1-EXTERNAL.pdf.

[p] Schaufenster Elektromobilität, "Abschlussbericht der Begleit- und Wirkungsforschung 2017 [Final Report and Impact of Accompanying Reserarch]," 2017, https://www.bridging-it.de/media/download/ep30_abschlussbericht_2017_der_begleit-_und_wirkungsforschung.pdf.

[q] Odyssee - Mure, "Sectoral Profile - Transport," accessed December 14, 2020, https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/transport-eu.pdf.

Spanish electric vehicle market scenarios

Step one in the model is projecting electric vehicle sales as a percentage of passenger car sales. Although Spain lags other European countries in terms of electric vehicle adoption, our scenario models a new vehicle sales share of 50% to 70% of all new vehicle sales being electric by 2030, labeled scenario 1 and scenario 2, respectively.

Electric and conventional vehicle sales are estimated based on vehicle registrations from IHS Markit which detail registrations at a local level (NUTS 3 resolution).[12] Although Spain's population is expected to grow, we assume new vehicle registrations will remain at 2019 levels through 2030, consistent with broader goals to encourage alternate modes of transport. The number of yearly new registrations that are electric rise from approximately 18,000 in 2019 to 450,000 in 2030 in scenario 1, and to 680,000 in scenario 2. BEVs were 56% of electric vehicle sales in 2019, and our scenarios assume the sales share rises to 75% by 2030 with the remaining electric vehicle sales being PHEVs.

Some areas of Spain have much higher new passenger car registrations than other areas. For example, Valladolid registers only 49% of the country average new vehicle registrations. However, the vehicle stock per capita is 105% of the country average, implying a movement of used or leased cars to Valladolid from other areas of Spain. To account for redistribution of vehicles, new passenger car registration data were compared to vehicle stock data.[13] The differential in the new registration per capita versus the stock per capita allowed the estimation of vehicle flows from areas that tended to register more new vehicles versus areas that tended to receive those vehicles secondhand. These secondhand vehicle movements are assumed to mirror secondhand electric vehicle movements. In 2019, areas for which electric vehicles were relatively more popular remain more popular in 2020. By 2025, these regional popularity differences disappear as electric vehicles become less expensive and more mainstream.

Stock turnover is assumed to follow stock turnover for conventional vehicles. The electric vehicle stock for scenario 1 and scenario 2 is shown in Figure 4. In 2030, cumulative electric vehicles in scenario 1 with a 50% sales share reach 2.7 million (left) and in scenario 2 with a sales share of 70% reach 3.6 million (right).

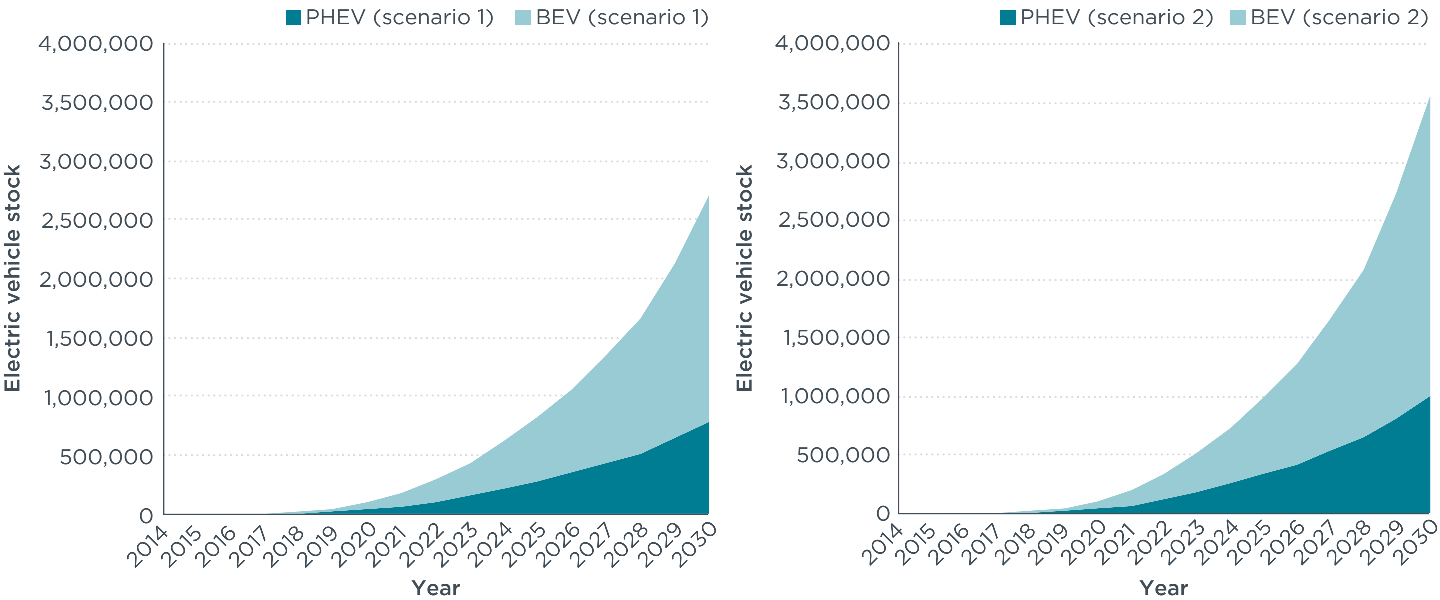

Figure 4. Scenarios for electric vehicle stock in Spain up to 2030.

In contrast to the scenarios above, the government's 5 million electric vehicle target includes motorcycles, vans, and busses, while this analysis only includes passenger electric cars. However, reaching the government target would likely require earlier sustained vehicle uptake across these transportation modes.

12 IHS Markit Copyright © IHS Markit, 2019. All rights reserved., "Purchased Dataset on Vehicle Registrations by European NUTS 3 Statistical Areas. Data through December 31, 2019."

13 Eurostat, "Stock of Vehicles by Category and NUTS 2 Regions."

Allocation of electric vehicles to charging need groups

Step two in the model outlined in Figure 3 is to separate the electric vehicle market into charging need groups that exhibit different charging behavior. There are three factors that are considered: vehicle type (PHEV or BEV), commuting status, and home charging access. This results in eight charging need groups as shown in Table 4.

Table 4 Charging need groups modeled.

Vehicle type	Commuting status	Home charging
BEV	Commuter	Home
BEV	Commuter	No home
BEV	Non-commuter	Home
BEV	Non-commuter	No home
PHEV	Commuter	Home
PHEV	Commuter	No home
PHEV	Non-commuter	Home
PHEV	Non-commuter	No home

Vehicle type is important since BEVs do not have a gasoline backup engine and the battery is larger, both of which prompt more charging than PHEVs. By 2030, 75% of new passenger car registrations are modeled to be BEVs. Commuting status determines whether work charging is used and affects other charging behavior. In Spain 62% of commuters commute by car.[14]

The model uses the type of housing as a proxy for determining if home charging is likely to be available and determines the magnitude of the charging need groups. There are three categories of housing in Spain as defined by Eurostat: single dwelling buildings defined as having a private entrance at ground level, two dwelling structures which may not have a private ground level entrance, and three and more dwelling buildings which include a mix of flats and attached houses.[15] The most recent housing census to provide comprehensive data on the breakdown of households by the dwelling structure type in Spain by NUTS 3 dates from 2011.[16] Table 5 combines occupancy by tenure status[17] and vehicles per capita[18] to estimate the approximate breakdown of vehicles by housing type. Row one shows the percentage of dwellings by type in Spain. Row two shows the vehicle ownership by dwelling type. One dwelling houses have more cars per household, so the share of cars is larger than the share of dwellings. Row three shows the estimate of the distribution of electric vehicles by dwelling type. As there are no current surveys to estimate this metric in Spain, international examples are used and applied to Spain.[19] In row three, the electric vehicle stock approaches that of conventional vehicles by housing type in row two. By 2030, sales match the distribution in row two, but a time lag exists to transition vehicle stock to conventional vehicle distributions.

14 Statistia global survey, "Modes of Transportation for Commuting in Spain 2020."
15 Eurostat, "Conventional Dwellings by Occupancy Status, Type of Building and NUTS 3 Region."
16 Eurostat.
17 Eurostat, "Distribution of Population by Degree of Urbanisation, Dwelling Type and Income Group - EU-SILC Survey."
18 European Automobile Manufacturers Association, "Vehicles per Capita by Country."
19 Schaufenster Elektromobilität, "Abschlussbericht der Begleit- und Wirkungsforschung 2017 [Final Report and Impact of Accompanying Reserarch]."

Table 5. Housing for the general population in Spain.

	One-dwelling buildings	Two-dwelling buildings	Three-or-more-dwelling buildings
Percentage of dwellings	32%	5%	63%
Conventional passenger vehicle stock by dwelling type in 2019	40%	5%	55%
Electric passenger vehicle stock by dwelling type in 2019	60%	5%	35%
Electric passenger vehicle stock by dwelling type in 2030	44%	5%	51%

Housing type is used to estimate home charging availability utilizing international examples[20] and adjusting for Spain context. The availability of home charging by housing type, called the "home charging availability multiplier" is shown in row one (Table 6). That availability is multiplied by the electric vehicle stock in Table 5 in 2019 and 2030 to obtain the charging availability by housing type in rows two and three. The total availability of home charging for each year is listed in the total column.

Table 6. Scenarios for electric vehicle owner housing type and access to home charging.

	EVs in one-dwelling buildings	EVs in two-dwelling buildings	EVs in three-or-more-dwelling buildings	Total
Home charging availability multiplier	92%	83%	48%	-
Percentage of total Spanish electric vehicle stock with home charging available in 2019	55%	4%	17%	76%
Percentage of total Spanish electric vehicle stock with home charging available in 2030	29%	23%	22%	69%

Overall, 69% of electric car owners are assumed to have home charging available in 2030. Although the home charging availability in three or more dwelling buildings is listed as 48%, this represents a continued large investment in home charging as little exists today. This will require funding, utility involvement, and building standards incorporating charging access at or near home.

Energy required by charging category

The third step in the model is to determine the total energy that electric vehicles will need and assign them to chargers at home, work, public and fast chargers. Energy needs for the vehicle stock are apportioned according to breakdowns in Table 7 which approximate the percentages of a 2019 analysis of electric vehicle drivers. However, charging need groups without home charging are expanded to explore the away-from-home charging that is needed to support them. In this respect, our scenario gradually diverges from today's electric vehicle market. The three consumer classifications are listed in the first three columns: vehicle type, commuting status, and home charging. After BEV or PHEV vehicle types, commuting status denotes whether the vehicle is used for commuting purposes and the home charging denotes whether the consumer has

20 Tal, Lee, and Nicholas, "Observed Charging Rates in California;" Dodson and Slater, "Electric Vehicle Charging Behaviour Study;" Schaufenster Elektromobilität, "Abschlussbericht der Begleit- und Wirkungsforschung 2017 [Final Report and Impact of Accompanying Reserarch]."

access to reliable charging at or near home. These classifications result in eight basic charging need groups. The fourth through the seventh columns describe the percent of energy in kilowatt-hours (kWh) by charging location comprised of home, work, public, and fast charging. The annual kilometers are based on the annual kilometers traveled in Spain and this average is disaggregated by commuting status.

Table 7. Energy breakdown by location of charging.

Vehicle type	Commuting status	Home charging	Home energy	Work energy	Public energy	DCFC energy	Vehicle kilometers traveled per year	Percent vehicle kilometers traveled that are electric	Vehicle kilometers traveled per year that are electric	Percent of vehicle stock in 2030
BEV	Commuter	Home	75%	15%	5%	5%	14,900	100%	14,900	29%
BEV	Commuter	No home	0%	55%	20%	25%	14,900	100%	14,900	13%
BEV	Non-commuter	Home	85%	0%	5%	10%	8,300	100%	8,300	20%
BEV	Non-commuter	No home	0%	0%	40%	60%	8,300	100%	8,300	9%
PHEV	Commuter	Home	70%	25%	5%	0%	14,900	70%	10,400	12%
PHEV	Commuter	No home	0%	65%	35%	0%	14,900	40%	6,000	5%
PHEV	Non-commuter	Home	90%	0%	10%	0%	8,300	50%	4,200	8%
PHEV	Non-commuter	No home	0%	0%	100%	0%	8,300	10%	800	4%

Notes: BEV = Battery electric vehicle; PHEV = plug-in hybrid electric vehicle; DCFC = direct current fast charger

The kilometers indicated above are converted into energy needed using efficiency numbers from representative vehicles. BEV and PHEV have efficiencies of 5.5 kilometers per kilowatt-hour and 5.15 kilometers per kilowatt-hour, respectively. Efficiency is assumed to remain constant over the study period as efficiency improvements will be negated by an assumed increase in vehicle size and weight versus today's vehicles.

The charging need group values represent the average behavior within the group, but individual charging behavior and access to charging varies widely. For example, in the case of workplace charging, not everyone has access to a charger and sometimes those with access do not choose to charge at work due to personal preference, pricing, congestion etc. Similarly, not every PHEV owner plugs in. Nevertheless, the average charging behavior of these groups are distinct and are sufficient for analysis and scenario purposes.

Although the driver charging energy breakdowns are constant through time, the relative proportions of the driver groups change. The early market is likely to have a higher prevalence of commuters than the later market. In 2019, the percentage of electric vehicles used for commuting is estimated at 70% and is modeled to reduce to 55% by 2030, which approaches the current percentage of vehicles used for commuting. Electric vehicle stock used for commuting in 2030 is 59% as it is modeled to lag the most current year of sales by three years. This drop in the number of vehicles used for commuting reduces the relative need for workplace charging.

Charging hours and charger power

The fourth step in the model is to estimate the average charger power and the average number of hours that a charger is actively charging per day in each category. We do not use the peak capacity of a charger, but rather the power delivered to the vehicle. For example, if a PHEV is plugged into a 22 kW charger, but only draws 3.4 kW, the 3.4 kW is used in the weighted average of power used to determine charging needs. The average rate of power draw for normal chargers is estimated at 7 kW for BEVs and 3.4 kW for PHEVs. For fast charging, the average rate per charger increases by year starting at 35 kW in 2019 and 80 kW in 2030. Even though much higher power will be used and is available, we limit it to 80 kW to reflect the cost of high power. Today, even though higher power is possible, in practice power sharing, battery management over an entire charge cycle and the lower cost of lower power suggest that on average, speeds will be much lower than the maximum possible.

Charger utilization and number of chargers

The fifth and final step in the charging infrastructure model shown in Figure 3 is to determine the number of chargers. Charger output power in kW and hours of use actively drawing power per day are used to obtain kWh per day and per year possible per charger. The kWh determined above for the entire electric vehicle market was divided by this average utilization to get the number of outlets needed.

The model reflects increasing utilization in hours per day with increasing electric vehicle penetration as shown in other studies.[21] As the market is nascent in Spain, showing no examples of markets with high penetration, other European examples are used to forecast the utilization trend.[22] The average daily utilization in hours of active power draw for normal public charging is estimated by the following equation:

Average daily hours of usage = 0.832 × LN (EV per million population) - 4.902

This equation was derived from the inspection of Spanish charger data and comparison to benchmarked studies elsewhere[23]. Using a natural log (LN) function bounds the utilization at higher electric vehicle penetrations. For example, the average hours of usage on a public charger at 6,000 electric vehicles per million population is 2.3 hours, but at 100,000 electric vehicles per million population, the average utilization only rises to 4.7 hours meaning the utilization doubled while the market increased over 16 times. It is important to note that this utilization is an average over an entire metropolitan area and across different days of the week and months of the year. Locational, daily, weekly, and seasonal variation allows for different chargers to be more highly utilized than others across time and locale. The implicit assumption is that public chargers will increase average utilization along with a growing market.

Workplace charging utilization is modeled to remain constant at 6 hours per day throughout the study period as it is tied to routine usage and can expand in a more predictable way. Since chargers are less likely to be used on weekends, the average hours of use per day falls to 4.3 hours.

Fast charging is assumed to follow a similar trend to normal charging such that average usage in hours climbs with market development. Since only BEVs are the primary users of fast charging, the utilization is a function of BEV penetration. There are two equations used for fast chargers, one for metropolitan areas and one for nonmetropolitan areas, which are expected to have lower utilization based on lower population density.[24] The equations used to define this relationship are:

For metropolitan areas,

Average daily hours of usage = 0.593 × LN (BEVs per million population) – 2.733

21 Nicholas, Hall, and Lutsey, *Quantifying the Electric Vehicle Charging Infrastructure Gap across U.S. Markets*; Nicholas and Wappelhorst, *Regional charging infrastructure requirements in Germany through 2030*, (ICCT: Washington, DC, 2020) https://theicct.org/publications/regional-charging-infra-germany-oct2020.

22 Nicholas and Lutsey, *Quantifying the Electric Vehicle Charging Infrastructure Gap in the United Kingdom* (ICCT, Washington, DC, 2020) https://theicct.org/publications/charging-gap-UK-2020.

23 Nicholas, Hall, and Lutsey, *Quantifying the Electric Vehicle Charging Infrastructure Gap across U.S. Markets*.

24 Nicholas and Wappelhorst, *Regional Charging Infrastructure Requirements in Germany through 2030*.

For nonmetropolitan areas,

Average daily hours of usage = 0.483 × LN (BEVBEVs per million population) - 3.021

With 10,000 BEVs per million population, the average estimated hours of power draw would be 2.7 hours per day, and at 100,000 BEV per million the hours of power draw would be 4.1 hours, a number reached in Madrid in 2030. Again, these are averages across the entire year and across a metropolitan region and there will be some chargers with much higher utilization. Additionally, certain days of the week will have higher usage than the average and some lower. Finally, this utilization only represents the hours used by private passenger cars. Other usage by ride-hailing, heavy duty and light commercial vehicles is not reflected.

The number of chargers in the model is determined using the variables of charger power and utilization defined above. The estimated output per charger in a year is equal to the utilization in hours of power draw × charger output (kW) × 365.25 days per year.

Finally, home charging and highway fast chargers are calculated in another way. Home charging depends on the housing type of vehicle owners as described above. Highway fast charger counts rely on outside analyses and are added at a rate of one fast charger for every 1,500 BEVs in metropolitan areas and one fast charger for every 1,000 vehicles in nonmetropolitan areas.[25] These chargers are in addition to the fast chargers detailed above and are assumed to have power available over 150 kW.

Summary of data inputs

The inputs for the future scenarios described above are summarized in Table 8. Each of these inputs affect the number of chargers. As indicated, some inputs shift over time from 2019 to 2030, while others remain constant over the analysis period.

Table 8. Summary of data inputs and assumptions for the charging infrastructure model.

	2019	2030
Electric vehicle stock	45,122	2,700,000 – scenario 1 3,600,000 – scenario 2
Market share of electric new car registrations	1.3%	50% – scenario 1 70% – scenario 2
Portion of BEV and PHEV new car registrations	57% BEV, 43% PHEV	75% BEV, 25% PHEV
Dwelling type of electric car owners	One dwelling = 60% Two dwelling =5% Three or more dwelling = 35%	One dwelling = 44% Two dwelling = 5% Three or more dwelling = 51%
Home charging availability by dwelling type	One dwelling = 92% availability Two dwelling = 83% availability Three or more dwelling = 65% availability	
Commuter share of electric new car registrations	70%	55%
BEV average charging acceptance rate for normal	7 kW	
PHEV average charging acceptance rate	3.4 kW	
Workplace charging daily utilization in hours	6 on weekdays, 0 on weekends	
Public charging daily utilization in hours	Average daily hours = 0.832 * LN (Electric vehicles per million population) – 4.902	

25 Patrick Jochem, Eckhard Szimbac, and Melanie Reuter-Oppermann, "How Many Fast-Charging Stations Do We Need along European Highways?," *Transportation Research Part D*., 2019, 120–29, https://www.sciencedirect.com/science/article/pii/S1361920919300215?via%3Dihub.

	2019	2030
Fast charging daily utilization in hours for metropolitan areas	Average daily hours = 0.593 * LN (BEV per million population) – 2.733	
Fast charging daily utilization in hours for nonmetropolitan areas	Average daily hours = 0.483 * LN (BEV per million population) – 3.021	
Fast charging outlet to charger ratio	1.4:1	—
Fast charging kW acceptance per charger	35 kW	80 kW
BEVs per high power highway fast charger	1,500 in metropolitan areas, 1,000 in nonmetropolitan areas	
Electric vehicle electricity consumption	BEVs 0.182 kWh/km, PHEVs 0.194 kWh/km	
Average vehicle kilometers per year	Commuter 14,000 km, noncommuter 8,300 km	

Note: BEV = Battery electric vehicle; PHEV = plug-in hybrid electric vehicle; DCFC = direct current fast charger; LN = natural log

Evolution of charging over time

The number of vehicles per charger changes from 2019 to 2030 according to the variables shown in Table 8. The overall trend is an increase in the number of electric vehicles supported per charger. Although home charging availability decreases corresponding to an increase in the need for public charging, increasing utilization and increasing power decrease the number of chargers necessary. Figure 5 shows two ratios over time, one for electric vehicles per normal work and public charger in purple and one for BEVs per fast charger shown in red.

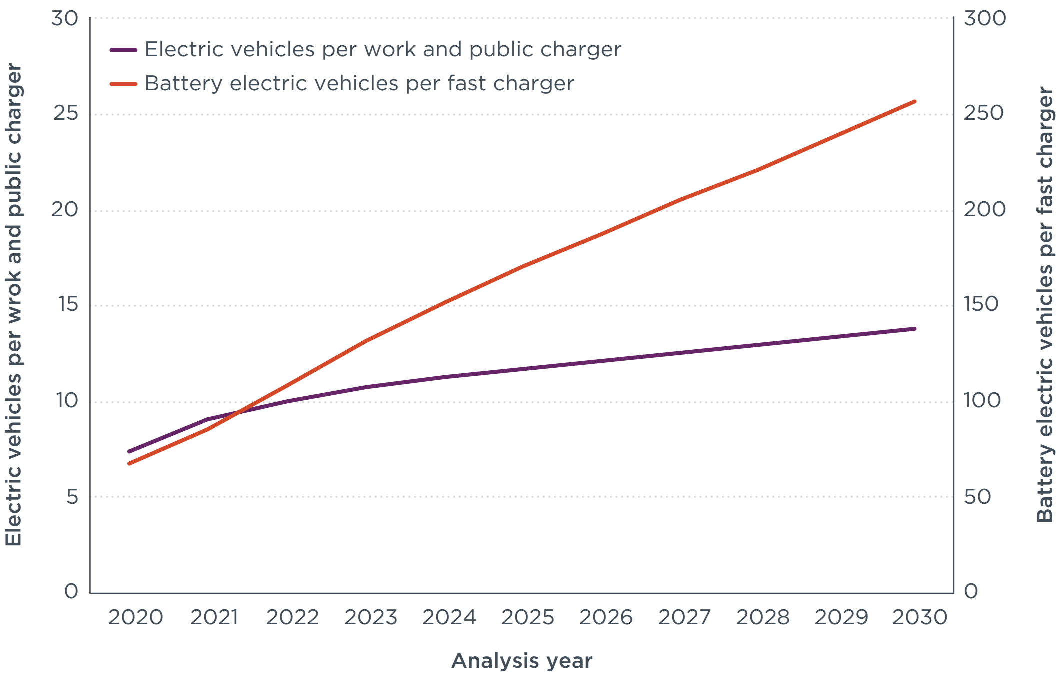

Figure 5. Electric vehicles per work and public charger and battery electric vehicles supported per fast charger.

The figure shows that for normal charging at work and public locations, the electric vehicles per charger increases from 7 in 2020 to 14 in 2030. For fast charging, the BEVs per charger increases from 67 in 2020 to over 250 in 2030. The ratios reflect that in an early market, there is a need for geographic coverage resulting in low utilization, but as coverage is achieved, stations are added in relation to capacity needed to relieve congestion. These ratios vary by metropolitan area. The increasing utilization shows an improving business case for charger installation as the market develops.

Results

By the end of 2019, Spain had installed 4% of the charging it needs in 2030 in scenario 1 and 3% of what it needs in scenario 2. This section describes and discusses the results. Differences between metropolitan areas and nonmetropolitan areas are broadly described, and comparisons are made between metropolitan areas.

Figure 6 depicts the needed electric vehicle charger counts for scenarios 1 and 2 for 2025 and 2030, as compared to total 2019 charger counts for selected regions. Each figure shows charging needs for the 7 metropolitan areas and 3 nonmetropolitan areas by region with the highest population. The number of chargers is shown on the vertical axis. There are four categories of chargers shown. Existing charging by location in 2019 is shown as a hashed section at the base of each bar. Private workplace charging may be underrepresented in this count from public sources. For 2025 and 2030, workplace, public, and fast charger needs are disaggregated. The colored bars represent the number of total chargers needed by city in the designated year.

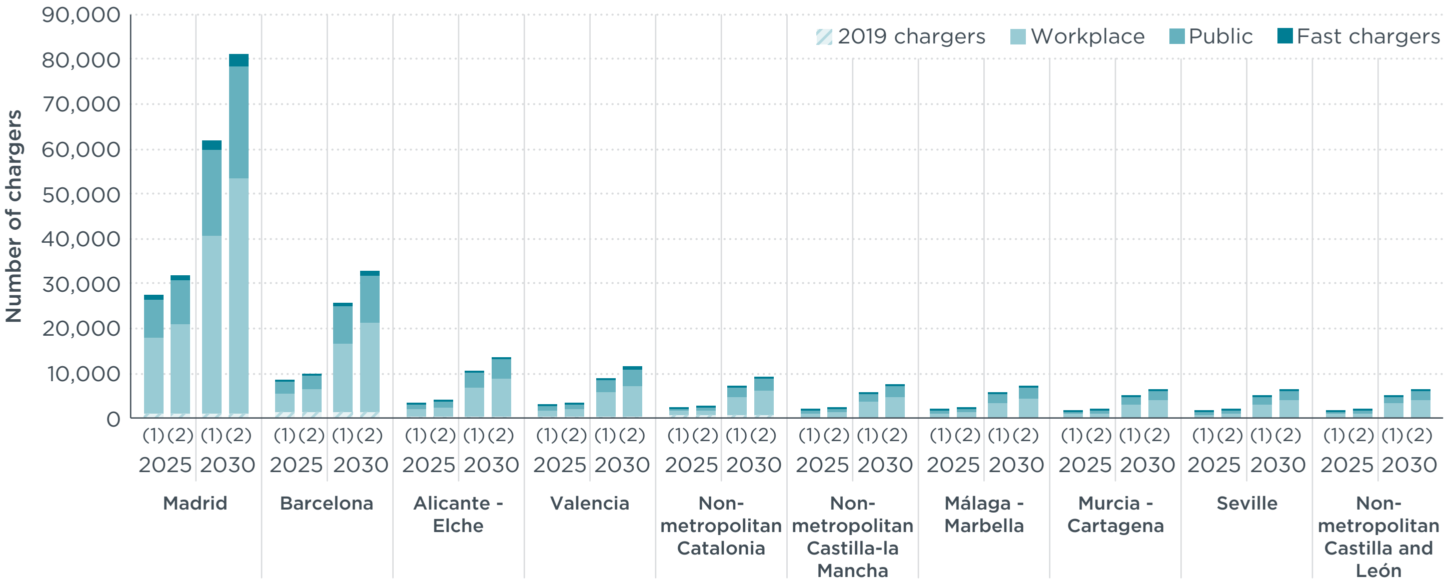

Figure 6 Chargers existing in 2019 versus chargers needed by 2025 and 2030 for selected metropolitan and nonmetropolitan areas.

The Figure represents that, Madrid in 2019 had between 4% and 5% of the public and workplace charging it needs by 2025, and 2% of what it needs by 2030. In 2019, Barcelona had about 16% to 19% of its 2025 charging needs and 5% to 6% of its 2030 charging needs. Nonmetropolitan Catalonia, a relatively small market compared to Barcelona and Madrid, had 26% to 30% of its 2025 needs and 7% to 9% of its 2030 needs. Further comparisons can be derived from numbers in the Appendix. In general, nonmetropolitan areas will need fewer chargers per vehicle. This is primarily due the increased availability of home charging. The number of workplace chargers exceeds the number of public chargers due to higher expected demand for charging at work, showing the importance of charging at or near centers of employment. However, much of the charging done while working may be in public garages or other locations available to the general public, so there will be a sizeable number of publicly available chargers classified as workplace above.

Table 9 summarizes the overall charging infrastructure needs in Spain for 2025 and 2030, including overall results for the metropolitan and nonmetropolitan areas and comparisons versus chargers installed through 2019. This analysis indicates that total chargers in Spain must increase from 8,500 to 73,500 in scenario 1 and to 85,500 in scenario 2 by 2025. To meet the electric vehicle goals through 2030, 205,000 to 263,000 chargers will be needed. This is 9 to 10 times more charging needed in 2025 than exists in 2019, and 24 to 30 times more charging will be needed by 2030. This is still less than would be required for the official 500,000 charger government target. The annual growth rate in charging to reach these targets is from 43% to 46% from 2019 to 2025 or 33% to 36% from 2019 to 2030.

Table 9. Summary of Spain charging infrastructure needs for two scenarios.

	Year	Scenario 1: 50% electric car share in 2030			Scenario 2: 70% electric car share in 2030		
		Metropolitan areas	Nonmetropolitan areas	Spain overall	Metropolitan areas	Nonmetropolitan areas	Spain overall
Total chargers (public, workplace, fast)	2019	6,624	2,049	8,673	6,624	2,049	8,673
	2025	62,406	11,157	73,563	72,653	12,964	85,617
	2030	170,848	34,231	205,080	219,650	43,543	263,194
Electric vehicle stock	2025	693,688	131,111	824,799	820,981	155,788	976,769
	2030	2,231,387	490,558	2,721,945	2,922,311	637,496	3,559,808
Projected future charging compared to 2019	2025	9.4	5.4	8.5	11.0	6.3	9.9
	2030	25.8	16.7	23.6	33.2	21.3	30.3
2019 as percentage of future chargers needed	2025	11%	18%	12%	9%	16%	10%
	2030	4%	6%	4%	3%	5%	3%
Annual increase in chargers from 2019 to meet 2025 and 2030 needs	2025	45%	33%	43%	49%	36%	46%
	2030	34%	29%	33%	37%	32%	36%

Figure 7 depicts the charging infrastructure in place in 2019 as a percentage of the chargers needed by 2025 for scenario 2 with a 70% sales share of electric passenger cars. The national average charging in place in 2019 is 10% of what is needed for 2025, and 3% of what is needed by 2030. As shown in the figure, some areas in 2019 had less than 5% of the needed charging in 2025, while others had over 20% of the needed charging. The colors indicate the charging gap as a percentage of charging installed as of the end of 2019 that will be needed by 2025. For example, if there are 100 chargers installed in 2019 but 1,000 are needed by 2025, then this would be at a 10% level. Darker red colors indicate a larger charging gap than lighter colors.

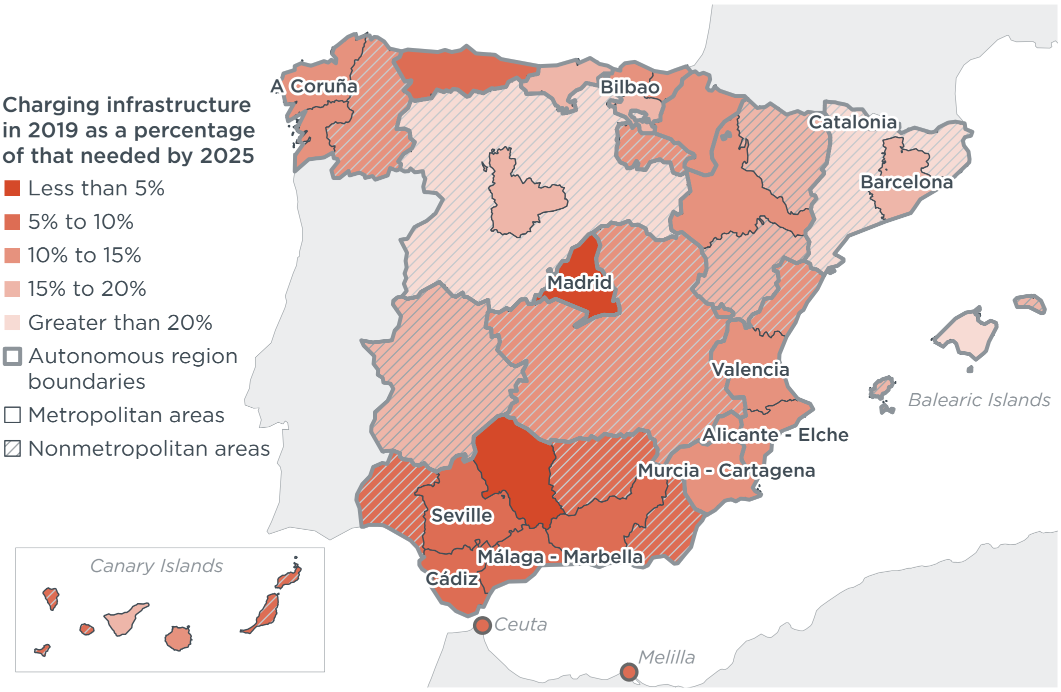

Figure 7. Percent of charging infrastructure installed as of 2019 that will be needed by 2025 for scenario 2.

Figure 7 shows a few broad trends. In general, areas in the south have a larger charging requirement than areas in the north. However, Madrid shows a notable gap with less than 5% of what will be needed by 2025. Metropolitan areas have a larger gap than nonmetropolitan areas. This is partly due to more access to home charging outside of metropolitan areas. Barcelona and the surrounding nonmetropolitan area has a smaller gap, showing good progress on charging infrastructure. The Balearic Islands, as well, have a larger percentage of infrastructure installed versus other regions.

Sensitivity analysis

The assumptions and results presented in the previous section represent our base scenarios. However, the numbers of chargers in these scenarios are sensitive to a few key variables. In order to show the effect that changing these variables would have, a sensitivity analysis was performed. The variables tested are access to home charging, usage of workplace charging, and a combination of both. The effect is shown as a percentage increase or decrease in the number of chargers in that category of charger relative to the number of chargers in scenario 2 (70% sales share in 2030). The categories are home, public/workplace chargers, fast chargers and total nonhome chargers. The six sensitivity cases are shown in Figure 8. Sensitivity cases one and two vary the percentage of customers with home charging access. Sensitivity cases three and four vary the usage of workplace charging, and sensitivity cases five and six vary both home access and workplace usage. The results show that nonhome charger totals can reduce by as much as 66% or increase by as much as 45%.

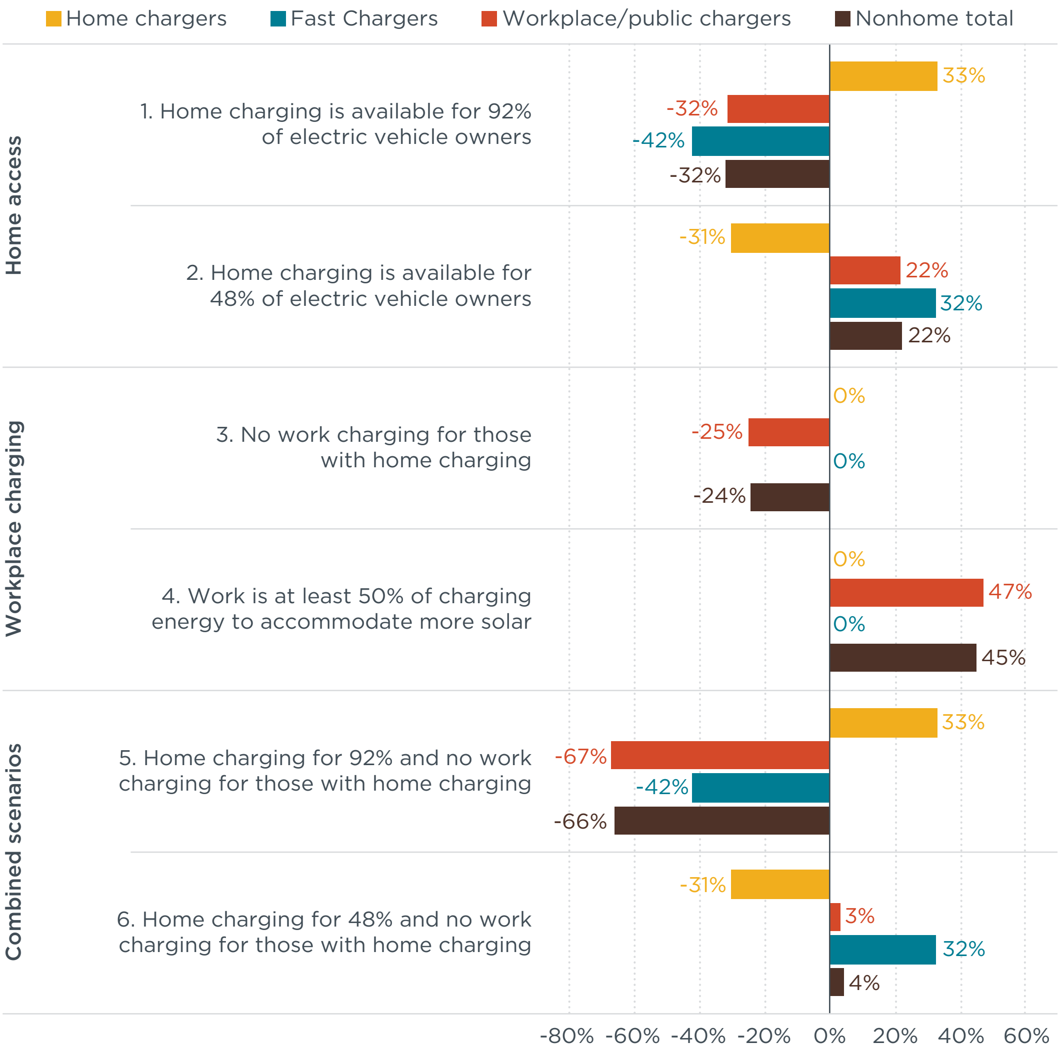

Figure 8. Sensitivity analysis with different home and workplace assumptions.

The base case does allow for some shifting of charging demand to the middle of the day to account for abundant solar energy available in Spain. Sensitivity case four increases the share of charging while working to at least 50% of all energy demand for commuters in order to amplify the shift away from overnight charging in a scenario with large solar generation. This increases the number of chargers by 45%. Home charger numbers remain unchanged, but they are used less often.

The sensitivity cases are meant to be illustrative and highlight the magnitude of effects rather than suggest a future outcome. However, the sensitivity cases show a few important relationships and suggest policy priorities. The extent to which home charging is available has a direct effect on the number of nonhome chargers needed. However, when home charging access was adjusted from 69% of customers to 48% of customers, and more efficient usage of workplace chargers was posited, the effects canceled each other out such that the number of chargers in the base scenario was nearly sufficient to adapt to the less available home charging. However, a scenario which makes heavy use of available solar energy suggests that workplace and public chargers may need to drastically increase from the base scenarios.

Smart chargers that can communicate with electric vehicles to time charging will be a key technology to accommodate more solar on the electricity grid and lower the costs of grid upgrades. Networked chargers with the ability to set prices in response to higher electricity cost could shift usage from public to home chargers, or do the opposite depending on price, ultimately affecting the number of chargers needed. Nevertheless, a focus on smart chargers increases the cost of chargers, and they are not needed in every situation. Choosing the appropriate application for smart charging can optimize for cost and convenience.

Regarding home chargers, a large shift to daytime charging can potentially reduce the need for home charging access, but reducing home access can make vehicles less desirable to own and operate. However, more access to public charging reduces the need for shared home chargers in an apartment or curbside context.

Government programs for public charging infrastructure

Although the previous analysis shows that charging infrastructure must grow rapidly in Spain over the coming decade, other European countries have accomplished similar growth. This section explores the policies and funding which have enabled charging growth in Germany, the Netherlands, and the United Kingdom to demonstrate possible opportunities for Spain.

By the end of 2019, 76% of the public charging infrastructure network in Europe[26] was concentrated in the Netherlands, Germany, France, the United Kingdom, and Norway, while only 45% of the European population live in these countries. The Netherlands has the densest public charging infrastructure network in Europe with almost 3,400 public charging points per million population available (Figure 9). An equally high penetration can be seen in Norway with over 3,000 public charging points per million inhabitants. Despite a comparably less dense network, France, Germany, and the United Kingdom show similar distributions patterns with about 500 charging points per million inhabitants. In contrast, Spain is lagging behind with merely over 100 public charging points per million population. This number was achieved at least five years ealier in the other five markets.[27]

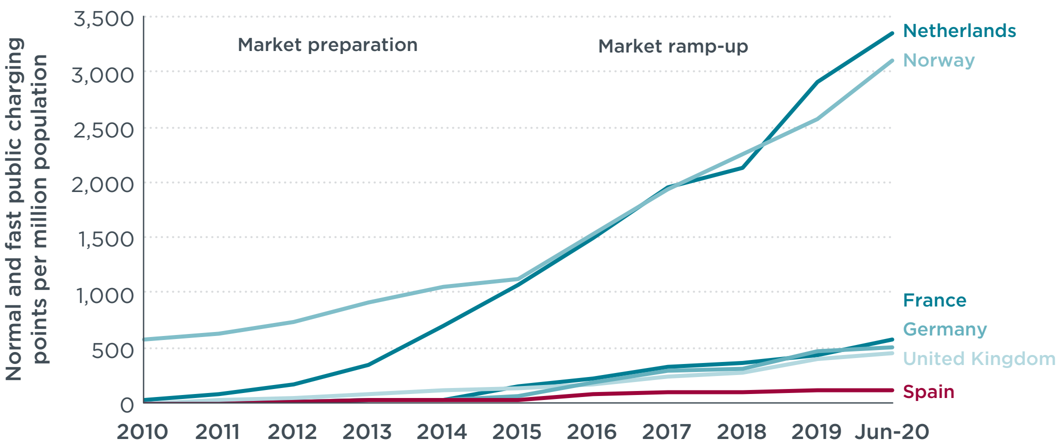

Figure 9. Development of public charging points per million population in select markets between 2010 and June 2020.

In the Netherlands, key success factors for the buildout of the public charging infrastructure network have been a combination of governmental subsidies and collaborations between utilities, municipalities, urban and metropolitan regions, and

26 This includes the 27 Member States of the European Union, the United Kingdom, and the countries of the European Free Trade Association (EFTA) including Iceland, Liechtenstein, Norway and Switzerland.

27 EAFO – European Alternative Fuels Observatory, "Summary," (2020), https://www.eafo.eu/countries/european-union/23640/summary; Eurostat, "Population and population change statistics", (10 July, 2020), https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_and_population_change_statistics

provinces.[28] For example, in 2015 the government initiated the "Publicly Accessible Electric Charging Infrastructure Green Deal," which provided €7.2 million in funding for the installation of public charging stations between 2016 and 2018. Local authorities could request a contribution for each public charging station. To create scale and cost reductions, municipalities worked together in regional associations to issue concessions and tenders.[29] In parallel, the government set up the "Netherlands Knowledge Platform for Charging Infrastructure" to accelerate the roll-out of charging infrastructure and promote collaboration between different stakeholders.[30]

The German government has also secured extensive funding for charging infrastructure. Between 2017 and 2020, the government provided €300 million in funding for public charging facilities as part of the "Funding Guideline for Charging Infrastructure."[31] The government has additionally secured over €3.0 billion to invest in the public electric charging infrastructure network for cars and trucks up to 2023.[32] An additional €500 million will be made available for private charging facilities.[33] To coordinate national activities and support municipalities in the deployment of the charging infrastructure network, the government established a "National Control Center for Charging Infrastructure" in late 2019.[34] In addition, since 2019, the government provides an online tool (StandortTool) helping investors and municipalities to find suitable locations for public charging infrastructure.[35]

The government of the United Kingdom has provided significant investments in charging infrastructure with partial co-financing by the private sector. In its 2017 budget, the government launched a £400 million (€436 million) "Charging Infrastructure Investment Fund" for the extension of the fast charging network between 2018/19 and 2020/21, envisaged to be equally financed by the government and private sector partners.[36] The fund is managed on a commercial basis by a private sector fund manager.[37] In addition, the Office for Low Emission Vehicles provides financial aid for the installation of home chargers and workplace charging points, as well as on-street chargers and chargers for taxis.[38] In its 2020 budget, the government announced another £500 million (€545

28 Ministry of Economic Affairs, "Vision on the Charging Infrastructure for Electric Transport" (The Hague, April 2017), rvo.nl/sites/default/files/2017/05/Vision%20on%20the%20charging%20infrastructure%20for%20electric%20transport.pdf. ; "Laadinfrastructuur voor elektrisch vervoer - EPBD III," Rijksdienst voor Ondernemend Nederland, March 10, 2020, https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels/nieuwbouw/epbd-iii/laadinfrastructuur-elektrisch-vervoer.

29 Green Deal, "Publicly accessible electrical charging infrastructure," accessed December 14, 2020, https://www.greendeals.nl/green-deals/openbaar-toegankelijke-elektrische-laadinfrastructuur

30 NKL - Netherlands Knowledge Platform for Charging Infrastructure, "Independent Knowledge Platform," accessed December 14, 2020, https://www.nklnederland.com/#:~:text=The%20Netherlands%20Knowledge%20Platform%20for,Get%20inspired

31 BMVI - Bundesministerium für Verkehr und digitale Infrastruktur, "Funding guideline for charging infrastructure for electric vehicles in Germany," (2017), https://www.bmvi.de/SharedDocs/DE/Anlage/G/konsolidierte-foerderrichtlinie-lis-29-06-2017.pdf?__blob=publicationFile

32 BMVI – Bundesministerium für Verkehr und digitale Infrastruktur, "We'll soon be charging anywhere and anytime – the charging infrastructure master plan," (2019), https://www.bmvi.de/SharedDocs/DE/Artikel/G/masterplan-ladeinfrastruktur.html

33 BMVI – Bundesministerium für Verkehr und digitale Infrastruktur, "500 million euros in addition for charging infrastructure - 6th funding call completed," (2020), https://www.bmvi.de/SharedDocs/DE/Artikel/G/infopapier-sechster-foerderaufruf-ladeinfrastruktur.html

34 NOW GmbH, "Development of the national control center for charging infrastructure is progressing," (2020), https://www.now-gmbh.de/de/aktuelles/presse/aufbau-der-nationalen-leitstelle-ladeinfrastruktur-kommt-voran

35 BMVI – Bundesministerium für Verkehr und digitale Infrastruktur, "LocationTOOL with a map of the charging infrastructure goes online," (2020), https://www.bmvi.de/SharedDocs/DE/Artikel/G/standorttool-infopapier.html

36 GOV.UK, "Policy paper. Autumn Budget 2017," (22 November, 2017), https://www.gov.uk/government/publications/autumn-budget-2017-documents/autumn-budget-2017

37 GOV.UK, "Policy paper. Charging Infrastructure Investment Fund," (2018), https://www.gov.uk/government/publications/charging-infrastructure-investment-fund

38 GOV.UK, "Collection. Grant schemes for electric vehicle charging infrastructure," (2019), https://www.gov.uk/government/collections/government-grants-for-low-emission-vehicles

million) to facilitate the build-out of charging infrastructure, including a "Rapid Charging Fund" for the roll-out of high-powered charging points across key roads over 5 years.[39]

Like other markets, the Spanish government has also funded the extension of the charging infrastructure network as part of various incentive programs. Currently, under the second iteration of the MOVES Plan, the Spanish government has secured €100 million for charging infrastructure and the acquisition of electric cars, up to 50% of which may be directed to the installation of recharging points. In Spain, the energy providers play a key role in building up charging infrastructure and have—unlike the national government—released individual strategic plans for the roll-out. In mid-2020, Utility provider Endesa received €35 million from the European Investment Bank (EIB) to install 8,500 charging points within four year. Another utility, Iberdrola, envisages the installation of up to 25,000 charging points in Spain before 2021, most of which would be private.

Table 10 summarizes the governmental targets as well as national budgets for key funding schemes and measures for charging infrastructure deployment. The comparison illustrates that the governments of Germany and the United Kingdom have secured significant funding for the extension of the charging infrastructure network. For select national programs, yearly funding amounts per capita range between €0.14 (Netherlands) and €9.0 (Germany). Yet, the programs vary in terms of usage (home, workplace, public charging), charging capacities (normal, fast, rapid charging), support of charging for different vehicle types (cars and vans, buses, heavy duty vehicles), and timeframes, and are therefore only partially comparable. In Spain, the exact budget to be distributed for charging infrastructure has not been announced. Assuming 50% of the funding of the MOVES II plan goes to charging infrastructure deployment and the program runs over a one-year time spam without funding exhausted beforehand, the rate would be €1.1 per person per year. However, national funding programs in Spain have been less stable and partially exhausted in a short period of time in the past, which have hindered faster deployment of charging infrastructure.

Next to funding, national strategies are also crucial to coordinate the extension of the network. Beyond strategies to increase the share of electric passenger cars overall, key policies to secure the continuous expansion of the charging infrastructure network are national strategies with defined targets; financial aids and tax incentives for home, workplace, and public charging; cross-regional collaborations between different stakeholders and public-private partnerships to reduce governmental funding streams; and cooperation platforms to connect the different stakeholders and identify charging requirements.

39 GOV.UK, "Policy paper. Budget 2020", (12 March, 2020), https://www.gov.uk/government/publications/government-vision-for-the-rapid-chargepoint-network-in-england/government-vision-for-the-rapid-chargepoint-network-in-england

Table 10. Select national government's electric vehicle charger promotion actions in select European countries.

	2030 target [per million population]		Government budget for select programs [per capita and year]								Key national strategies					
	Public charging points	Private charging points	2016-2018: €7.2 million Charging Infrastructure Green Deal	2017-2020: €300 million Funding Guideline Charging Infrastructure	2021-2023: €3.3 billion Public charging infrastructure investment [a]	2018/19-2020/2021: €218 million Charging Infrastructure Investment Fund	2020-2025: €545 million Extension charging infrastructure inclusive Rapid Charging Fund	2019-2020: €13.5 to €27 million MOVES program	2020-2021: About €50 million MOVES II program	Charging infrastructure plan	Financial and tax incentives	Inter-municipal collaboration	Public-private funding strategy	National coordination platform	National online tool
Netherlands	57,000	46,000	€0.14	-	-					x	x	x		x	
Germany	12,000	-	-	€0.9	€9.0					x	x			x	x
United Kingdom	-	-				€1.1	€1.4			x	x		x		
Spain	11,000	-						€0.3 to €0.6	Max. €1.1		x				

[a] Includes both trucks and passenger car infrastructure

In comparison, despite continuous investments by the Spanish government in the extension of the charging infrastructure network, key policy actions are missing, such as a national charging infrastructure strategy or a platform coordinating the work of the different stakeholders. Rather than the government like in other European markets, the large energy companies in Spain are currently leading the transition to close the charging gap and have adapted their own plans and strategies in order to benefit from electricity charges.

Conclusions

Although Spain's electric vehicle market is not as developed as some other European countries, the government's goal of 5 million electric vehicles on the road (including busses, vans, and motorcycles which we do not include) by 2030 is even more ambitious than our high scenario of 3.6 million electric passenger cars by that date. However, the home, workplace, public, and fast chargers needed to support these large numbers of vehicles currently do not exist in Spain.

This analysis informs the charging needs on a metropolitan area level as well as the charging needs outside of metropolitan areas depending on vehicle sales, used vehicle redistribution, the availability of home charging, and commuting status. It assumes the market will gradually shift from one in 2019 where home charging is more likely to be available to a market with less access to home charging by 2030. Even though away-from-home charging is critical to achieving a high share of electric vehicles, the scenarios reflect that by 2030, approximately 70% or customers will have some form of home charging accounting for 90% of chargers with more than half of all energy dispensed there. This analysis has five main conclusions:

Spain has experienced slow uptake of electric vehicles and charging through 2019, creating an immense challenge for widespread electrification. By the end of 2019, Spain had 46,000 registered electric vehicles representing 0.2% of the 25 million passenger cars in Spain and 8,000 chargers. To reach a stock of 2.7 to 3.6 million electric vehicles and 50% to 70% of passenger car sales in 2030, 205,000 to 263,000 workplace, public, and fast chargers are needed. This represents an annual growth rate of 33% to 36% in vehicle chargers in Spain.

Metropolitan areas are leading in vehicle adoption. Madrid is by far the largest electric vehicle market with an estimated 26,000 electric passenger car stock and a 2.1% share of passenger car sales in 2019. Barcelona has a 1.8% sales share in 2019 and over 6,000 electric vehicles on the road. Of note as well are the metropolitan areas on Spanish islands, with Las Palmas in the Canary Islands at 1.2% and Palma de Majorca in the Balearic Islands at 1.1% of vehicle sales being electric in 2019. Most other metropolitan and nonmetropolitan areas were below a 1.0% sales share in 2019.

The pace of charger installation will need to be higher in the initial years till 2025. The annual increase in charger installation will need to be 43% to 46% until 2025 to support the scenarios in this paper. Because fewer chargers per vehicle are needed as the market grows, the annual increase will decline from 2025 to 2030. Despite a declining public charger per vehicle ratio, a growing market still requires increasing charger installation till 2030.

Different charging infrastructure outcomes are possible by 2030 depending on national priorities and home charging installation. The sensitivity cases show that different ratios of home and non-home chargers can serve the same number of electric vehicles. Home charging remains primary in almost all scenarios and is where most charging is expected to occur. When workplace charging was reserved exclusively for those with no home charging, perhaps in response to policies to encourage home charging, 24% fewer non-home chargers were needed. When a large shift to daytime charging was tested to simulate large solar generation, total non-home chargers increased by 45% versus the base scenario. A key enabling technology is smart charging that can signal the best time to charge to take advantage of solar and avoid drawing power at times of grid stress.

Leading markets show promising strategies that can be applied in Spain. Germany, the United Kingdom, and the Netherlands point to near-term strategies for market and charging growth. Markets such as Germany and the United Kingdom have secured significant funding for the extension of the charging infrastructure network including public, workplace, and home charging facilities. The governments provide up to €9.9 per capita per year for select programs. Beyond investments by the national governments, nation-wide strategies have proven to be key success factors in the coordinated ramp-up of the charging infrastructure network. These strategies include the collaboration among different stakeholders to reduce and split the financial burden among government and other groups. To guarantee equal access and avoid a solely market-driven ramp-up which might leave out certain population groups, governments like the Netherlands and Germany have also set up coordination platforms and provide information on charging infrastructure needs.

This working paper does not address every charging need in 2030 and restricts the analysis to private passenger cars. Light commercial vehicles and other medium and heavy-duty applications are expected to need additional infrastructure. Taxi, carsharing, or ride-hailing fleets are also expected to require significant infrastructure, but some of the infrastructure identified in this analysis can be shared with these vehicles.[40] Alternative solutions to electromobility such as increased transit are not covered in this analysis although they may affect the magnitude of chargers needed or the locations to which chargers are shifted.

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40 Michael Nicholas, Peter Slowik, and Nic Lutsey, *Charging Infrastructure Requirements to Support Electric Ride-Hailing in U.S. Cities*, (ICCT: Washington, DC, 2020), https://theicct.org/publications/charging-infrastructure-electric-ride-hailing-us-032020.

Appendix

This Appendix provides normal (public and workplace) and fast charging infrastructure results for individual metropolitan areas and nonmetropolitan areas for scenarios 1 and 2.

Table A1. Charging infrastructure needs for electric vehicle scenario 1 (50% electric sales by 2030)

Metropolitan area *(and nonmetropolitan area in italics)*	2019 normal chargers	2019 fast chargers	2025 electric vehicles	2025 normal chargers	2025 fast chargers	2030 electric vehicles	2030 normal chargers	2030 fast chargers
Madrid	1,178	106	308,585	26,547	1,037	793,311	59,993	2,118
Barcelona	1,456	116	89,061	8,117	343	323,927	24,992	893
Valencia	385	28	31,262	2,774	118	116,665	8,699	312
Seville	146	15	18,715	1,516	61	71,366	4,791	166
Alicante - Elche	386	11	38,051	3,151	127	146,170	10,349	356
Málaga - Marbella	175	22	20,216	1,745	73	75,927	5,510	196
Murcia - Cartagena	222	18	19,103	1,498	59	72,558	4,775	163
Cádiz	113	6	13,078	1,099	45	50,173	3,516	124
Bilbao	187	26	13,696	1,418	64	50,703	4,325	162
A Coruña	117	12	10,747	923	38	40,447	2,884	102
Oviedo - Gijón	93	15	12,185	1,089	46	44,891	3,375	122
Zaragoza	90	34	11,428	1,021	43	42,628	3,194	115
Santa Cruz de Tenerife	223	3	14,814	1,214	49	55,135	3,841	133
Vigo	93	2	8,309	701	29	31,054	2,168	77
Palma de Mallorca	449	11	16,753	1,327	53	62,815	4,258	146
Granada	70	10	8,291	675	27	31,435	2,115	74
Las Palmas	256	5	19,181	1,524	60	71,493	4,876	165
Córdoba	27	1	6,742	553	23	25,765	1,741	61
Gipuzkoa	124	3	8,965	925	42	33,688	2,864	107
Pamplona/Iruña	98	8	8,007	678	29	29,742	2,130	76
Santander	92	19	6,488	580	25	24,547	1,836	66
Valladolid	77	14	5,490	471	19	20,236	1,451	51
Vitoria/Gasteiz	62	20	4,520	432	19	16,710	1,336	49
Nonmetropolitan Castilla-La Mancha	173	60	24,567	1,822	123	91,126	5,598	286
Nonmetropolitan Catalonia	571	118	27,625	2,261	166	101,455	7,038	383
Nonmetropolitan Castilla and León	334	94	16,914	1,364	103	63,627	4,227	233
Nonmetropolitan Andalusia	119	20	16,526	1,333	102	63,411	4,213	233
Nonmetropolitan Extremadura	122	26	8,683	663	50	33,124	2,061	111
Nonmetropolitan Galicia	64	5	6,248	485	36	23,357	1,507	81
Nonmetropolitan Valencian Community	122	3	12,310	976	66	47,229	3,207	165
Nonmetropolitan Canary Islands	24	6	6,382	482	33	22,688	1,461	76
Nonmetropolitan Aragón	65	11	4,005	317	23	15,168	1,000	54
Nonmetropolitan La Rioja	31	11	3,162	288	23	11,932	903	53
Nonmetropolitan Balearic Islands	57	1	3,185	265	20	11,809	826	46
Autonomous City of Ceuta	4	1	721	72	6	2,714	221	14
Autonomous City of Melilla	6	1	784	72	6	2,919	222	13
All metropolitan areas	6,119	505	693,688	59,978	2,428	2,231,387	165,016	5,833
All nonmetropolitan areas	1,692	357	131,111	10,399	758	490,558	32,484	1,747
Spain total	7,811	862	824,799	70,377	3,185	2,721,945	197,500	7,580

Table A2. Charging infrastructure needs for electric vehicle scenario 2 (70% electric sales by 2030)

Metropolitan area *(and nonmetropolitan area in italics)*	2019 normal chargers	2019 fast chargers	2025 electric vehicles	2025 normal chargers	2025 fast chargers	2030 electric vehicles	2030 normal chargers	2030 fast chargers
Madrid	1,178	106	363,752	30,914	1,195	1,053,942	78,413	2,726
Barcelona	1,456	116	105,088	9,412	393	420,180	31,815	1,123
Valencia	385	28	37,126	3,231	135	151,584	11,081	392
Seville	146	15	22,322	1,769	70	92,840	6,103	209
Alicante - Elche	386	11	45,449	3,702	147	190,222	13,241	450
Málaga - Marbella	175	22	24,037	2,034	84	98,678	7,020	246
Murcia - Cartagena	222	18	22,765	1,751	68	94,361	6,092	205
Cádiz	113	6	15,617	1,285	52	65,291	4,482	156
Bilbao	187	26	16,240	1,647	74	65,855	5,503	203
A Coruña	117	12	12,784	1,074	44	52,578	3,669	128
Oviedo - Gijón	93	15	14,433	1,265	53	58,275	4,293	152
Zaragoza	90	34	13,569	1,188	50	55,380	4,067	144
Santa Cruz de Tenerife	223	3	17,584	1,416	57	71,627	4,899	168
Vigo	93	2	9,871	814	33	40,352	2,756	96
Palma de Mallorca	449	11	19,908	1,552	61	81,599	5,437	183
Granada	70	10	9,877	786	31	40,875	2,691	92
Las Palmas	256	5	22,766	1,782	69	92,837	6,228	208
Córdoba	27	1	8,045	645	26	33,522	2,217	76
Gipuzkoa	124	3	10,661	1,078	48	43,787	3,647	134
Pamplona/Iruña	98	8	9,500	790	33	38,630	2,714	95
Santander	92	19	7,726	677	28	31,918	2,339	83
Valladolid	77	14	6,504	546	22	26,274	1,845	65
Vitoria/Gasteiz	62	20	5,359	502	21	21,704	1,701	61
Nonmetropolitan Castilla-La Mancha	173	60	29,140	2,119	138	118,355	7,130	354
Nonmetropolitan Catalonia	571	118	32,704	2,630	186	131,695	8,964	473
Nonmetropolitan Castilla and León	334	94	20,119	1,586	116	82,709	5,378	287
Nonmetropolitan Andalusía	119	20	19,735	1,556	115	82,519	5,366	287
Nonmetropolitan Extremadura	122	26	10,358	773	55	43,094	2,624	136
Nonmetropolitan Galicia	64	5	7,422	565	40	30,349	1,918	100
Nonmetropolitan Valencian Community	122	3	14,700	1,147	75	61,459	4,105	205
Nonmetropolitan Canary Islands	24	6	7,514	559	37	29,430	1,862	94
Nonmetropolitan Aragón	65	11	4,770	370	26	19,726	1,275	66
Nonmetropolitan La Rioja	31	11	3,763	336	26	15,513	1,150	65
Nonmetropolitan Balearic Islands	57	1	3,776	308	22	15,330	1,051	56
Autonomous City of Ceuta	4	1	858	83	7	3,528	281	17
Autonomous City of Melilla	6	1	930	83	7	3,792	282	16
All metropolitan areas	6,119	505	820,981	69,859	2,794	2,922,311	212,253	7,397
All nonmetropolitan areas	1,692	357	155,788	12,113	850	637,496	41,386	2,157
Spain total	7,811	862	976,769	81,972	3,645	3,559,808	253,639	9,555