Research Whitepaper

Charging Masterplan

European EV Charging Infrastructure Masterplan

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acea
DRIVING MOBILITY FOR EUROPE

In collaboration with

WindEurope

SolarPower Europe

eurelectric

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List of Exhibits

Executive Summary

		PCs	LCVs, trucks, and buses
EV Charging Masterplan for EU-27	**We developed an EV Charging Masterplan** with input from 8 industry associations	■	■
	The masterplan translates into a synced buildup of EV rollout addressing charging infrastructure, grid, and energy	■	■
	With 55% CO_2 reduction (2021-30) for PCs and LCVs, and 30% (based on HDT regulations) for trucks and buses, **EV sales grow to 6.7 mn, 1.0 mn, and 0.1 mn in 2030, respectively**	■	■
	In total up to €280 bn investments are necessary until 2030 in private (~30%) and public (~30%) charging infrastructure, grid upgrades (~15%), and renewables (~25%)	■	■
	A balance of private and public investments is required to ensure fast build-up of charging infrastructure across Europe, especially for public on-street charging for EV owners without home chargers	■	■
Charging infrastructure	**6.8 mn public charging points are required by 2030** for consumer-driven EV adoption in the PC segment with a high share of AC slow charging, and **€144 bn EVCI investments**	■	☐
	Balanced charger utilization and consumer adoption with a higher share of fast charging requires 2.9 mn public chargers by 2030, and **€104 bn EVCI investments**	■	☐
	On average, up to 14,000 public charging points need to be installed per week, today, only ~2,000 are installed per week, in balanced optimization ~6,000 public chargers are required	■	■
	On the core TEN-T corridors, ~184 charging points will be needed for every 100 km for passenger EVs	■	☐
	Trucks will need ~51 fast chargers every 100 km to charge on the core TEN-T corridors	☐	■
	€11 bn investment will be required for EV public charging infrastructure for LCVs and CVs until 2030	☐	■
Electricity grid upgrades and energy supply	**Grid upgrades due to EVs will cost €41 bn by 2030 –** 11% of total DSO investments into upgrades for electrification of buildings and mobility and the transition to fossil-free electricity generation by 2030	■	■
	Deployment of renewable power will cost €69 bn – 18% of total renewable investments until 2030 to generate the additional electricity needed for EV charging with new green energy capacity	■	■
Key interventions	**Range and charging remain key consumer concerns in the purchase of an EV,** further consumer pain points along the charging experience have been identified and addressed	■	☐
	5 critical interventions are needed to accelerate charging infrastructure rollout: streamline the infrastructure approval process, define EU Member State and cross-country coordination bodies, implement smart incentive programs, facilitate access to financing, and ensure a wide rollout of smart charging	■	■

A. EV Charging Masterplan for EU-27

The EU Commission has set ambitious CO_2 targets for the transport sector. The EU's "Fit for 55 Package" published in July 2021 revealed its plans to reduce emissions by at least 55% by 2030 (compared to 1990 levels), and to be the world's first climate-neutral continent by 2050. All sectors of the economy are expected to contribute to achieving these reductions, transport included. Transport is one of few sectors, where greenhouse gas (GHG) emissions have been rising since 1990, with the sector accounting for almost 20% of total EU GHG emissions.

Understanding the transport sector's significant contribution to GHG emissions, the EU Commission has reviewed the climate and energy legislations for road transport in 2021. By 2030, new passenger cars and trucks have to reduce their CO_2 emissions by 55% compared to 2021.[1] The current truck regulation requires a 30% emissions reduction by 2030 and will be reviewed in 2022. Together, these targets need a significant share of new passenger car (PC) and commercial vehicle (CV) sales to be electric vehicles (EVs) by 2030. The uptake of EVs requires the build-up of an electric vehicle charging infrastructure in Europe.

The automotive industry is of critical importance for the EU: accounting for over 7% of the EU's GDP, providing jobs to 14.6 million Europeans, and currently changing due to such ambitious targets. With high economic and social value at stake, the automotive sector will be empowered to undergo structural shifts to low-emission technologies while maintaining its role as a global leader in clean mobility.

1. Introduction and methodology

The objective of the EV Charging Masterplan is to provide a neutral fact base how the EV infrastructure ecosystem should ramp-up to support the transition to e-mobility. The Masterplan is based on the proposed EU regulatory CO_2 targets for 2030 in the road transport sector, i.e., –55% for passenger cars (PCs) and –30% for trucks. The Masterplan comprises PCs and CVs and focuses on charging stations (both public and private or nonpublic), required electricity grid upgrades, and the build-out of renewable energy to supply EVs with "green" electricity. The underlying vehicle market models consider emission improvements of combustion engine vehicles, hybrids, as well as fuel cell powertrains and provide a technology-neutral outlook of powertrains. Fuel cell electric vehicles, which are considered equally relevant to decarbonize the commercial transport sector, are not in scope of this report. Similarly, the Masterplan acknowledges the potential to decarbonize the existing vehicle parc and use cases that are difficult to electrify through sustainable fuels, yet these are not in scope of the study as well.

The complexity of decarbonizing transport is high, also due to multiple complementary technologies that can be used to achieve zero-emission mobility. While passenger cars will quickly transition to battery electric vehicles (BEVs), with only a minor share of fuel cell electric vehicles (FCEVs) by 2030, the percentage of BEVs and FCEVs for trucks, buses and light commercial vehicles (LCVs) will be more balanced, depending on the segment and use case. BEVs win for shorter distances and along predictable routes with access to charging, while for long-haul trucking also FCEVs play a role, especially for heavy payloads and long daily distances (not part of this report). In addition, sustainable fuels can help decarbonize the existing internal combustion engine (ICE) vehicle parc for PC and CV and replace fossil fuels for commercial use cases that are difficult to electrify in the long term.

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[1] The overarching target of the EU "Fit for 55" proposal is to reduce net CO_2 emissions by 55% compared to 1990. Concerning the transportation sector, the proposal includes reducing average yearly emissions of all newly registered vehicles by 55% compared to 2021.

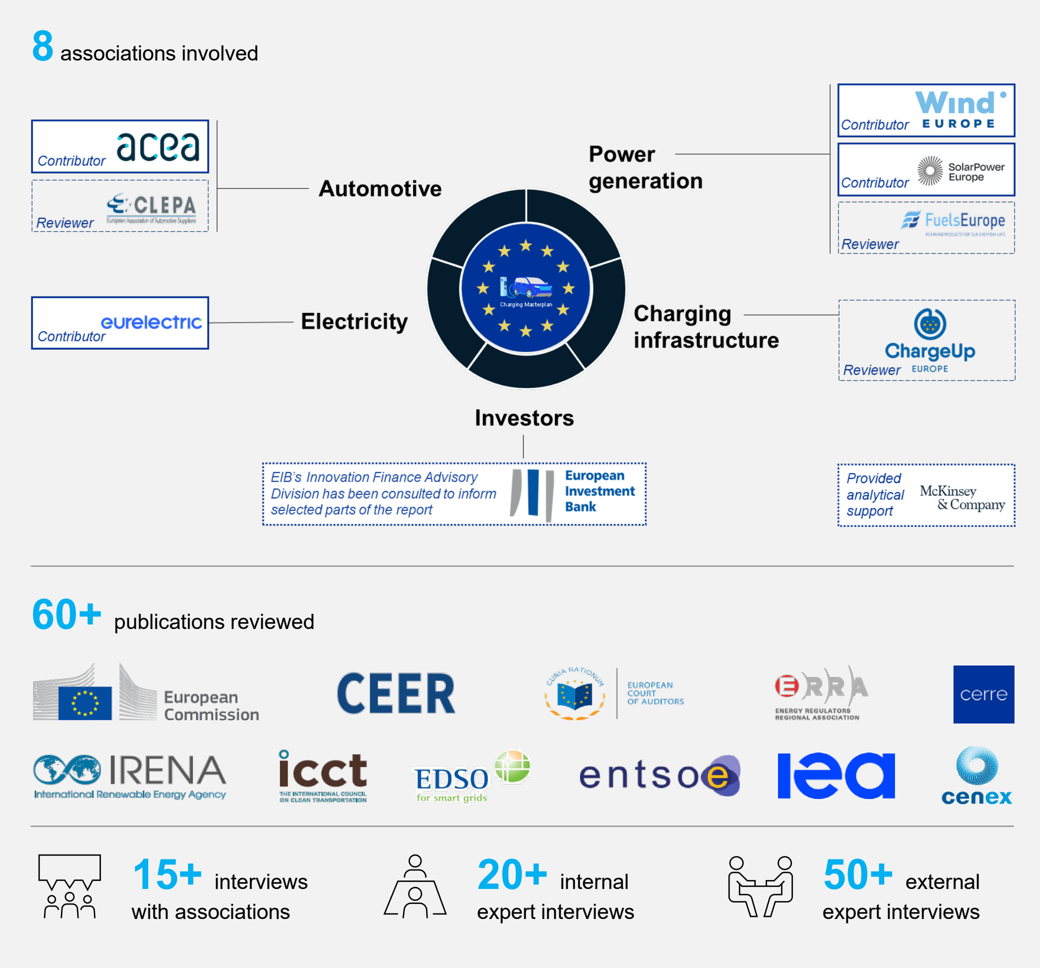
This report focuses on the EV Charging Masterplan for the EU-27, a masterplan that demonstrates how a smooth transition to BEV mobility—from an electric vehicle driver point of view—can be achieved. More specifically, its aim is two-fold. First, it provides transparency on the infrastructure and investment needs to reach EU "Fit for 55" CO_2 reduction targets for road mobility. Second, it creates awareness of the factors that may slow down deployment and suggests interventions to accelerate the build-up of EV charging infrastructure. With few countries on track to deliver such targets, a significant ramp-up in the deployment of EV charging is required. In synching EV charging, grid expansion, and renewable energy needs with CO_2 targets and resulting EV sales and parc, the EV Charging Masterplan provides a holistic perspective across geographies (all EU-27 countries included) and vehicle types (encompassing PCs, LCVs, trucks, and buses).

The Masterplan centers around the PC consumers' and CV customers' key concerns for purchasing EVs: access to charging infrastructure and EV driving range. In order to facilitate a fast and smooth adoption of EVs, the demand-driving-oriented charging infrastructure pathway involves an accelerated built-out of charging infrastructure within this decade. The demand-driving-oriented pathway relies on a dense build-up of slow public charging infrastructure in cities to ensure that each EV owner has close and convenient access to a public charger. As a result, the demand-driving-oriented pathway will not result in an investment and profit optimizing utilization of chargers. Therefore, an alternative pathway, the utilization-oriented pathway, that balances the average network utilization of charging points and consumer- as well as customer needs was also developed. To achieve higher levels of utilization, the utilization-oriented pathway relies more on the build-up of fast charging infrastructure, also in cities.

Charging infrastructure can only be deployed successfully by adopting a cross-industry and cross-country approach. For this reason, eight industry associations from across the e-mobility landscape contributed to the EV Charging Masterplan, and McKinsey provided analytical support. The eight associations include the European Automobile Manufacturers Association (ACEA) and the European Association of Automotive Suppliers (CLEPA), representing automotive original equipment manufacturers (OEMs) and suppliers; WindEurope and SolarPower Europe representing the energy generation sector; Eurelectric representing the wider electricity industry; ChargeUp Europe, representing charge-point operators; and FuelsEurope bringing in the perspective of alternative fuels. ACEA, WindEurope, SolarPower Europe, and Eurelectric contributed to the report in their respective area of expertise, while CLEPA, ChargeUp Europe, and FuelsEurope only reviewed the report. Also, the Bank's Innovation Finance Advisory Division has been consulted to inform selected parts of the report, notably on potential EIB instruments of relevance to finance-relevant investments. In addition to the input from each association, more than 60 publications and over 85 interviews helped inform and refine the following insights (Exhibit 1). The report does not reflect the unique view of one association but rather the range of industry views with two potential pathways.

Exhibit 1: 8 associations involved and 85+ interviews conducted

Sources of insight



Source: EU EV Charging Masterplan

The Masterplan is derived from a granular bottom-up model that calculates number of chargers, required capital investments into charging points, grid reinforcement, and new renewable energy sources (namely solar and wind)[2] to meet the proposed EU CO_2-reduction targets of 55% (PCs and LCVs) and 30% (trucks). An extract of the underlying model methodology is explained in Text box 1 and partly visualized in Exhibit 2. The complete explanation of the model can be found in the appendix.

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[2] It must be noted that although nuclear can also be used to cater for increased energy needs, it was excluded from the analysis.

Text box 1: Example of methodology used to calculate required number of charging points for PCs

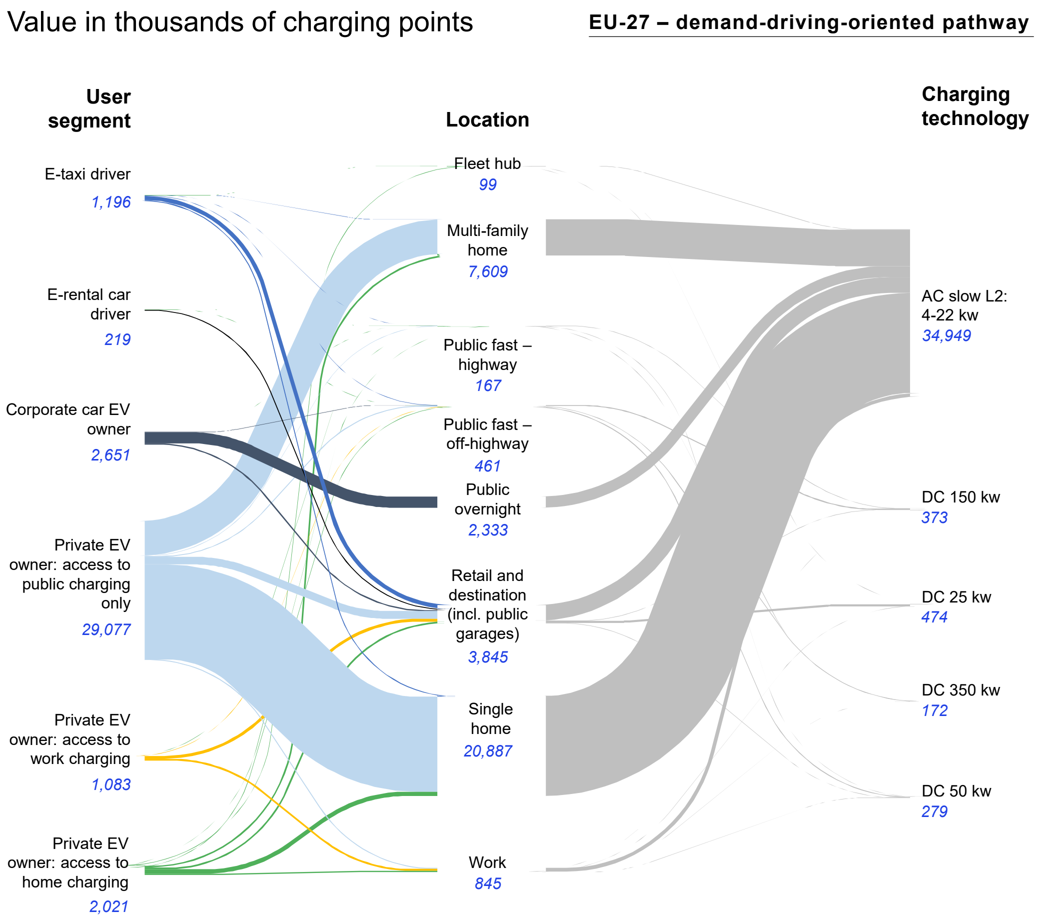
Methodology

How is the total number of **required charging points for PCs by 2030** calculated?	**Exemplary result**
First, the required EV sales and **car population from 2020 to 2030** are derived based on the CO_2 reduction target of –55%. Considering the current EV share, level of subsidies, and charging rollout, different speeds of EV uptake are modelled by country.	**42.8 mn EVs** in all EU-27 countries by 2030
Second, the EV car population is attributed to different categories across **three dimensions:** - Where the car is used, called **regional archetype** (eg, car-reliant cities or rural areas) - The use case of the vehicle, called **vehicle segmentation** (eg, private, corporate and government fleet, rental) - How the car is used/charged, called **user segment** (eg, EV owner with access to home charging, EV owner relying on street and public charging)	**20%** of private EV owners in cities have **access to public charging only** in 2030
Third, the **energy demand** is calculated based on annual distance of EVs, their efficiency and the segmentation in the previous step. The energy demand is then allocated to different **charging locations** (eg, multi-home, public fast off-highway).	**70% public overnight** charging of private EV owners with access to public charging only expected in 2030
Fourth, the 9 charger types used in the model, from AC 4-22 kW to DC 500+ kW, are combined with the different charging locations, called the **charging technology split.** Then, for AC slow and DC fast charging, an **average network charging point utilization** is assumed.	**80% of workplace** charging points with **AC 4-22 kW** technology
In the last step, the energy demand needing to be charged is converted to the **required number of charging points for PCs** using the charging technology split and assumed utilization.	**6.8 mn public charging points** in demand-driving-oriented pathway required in EU-27 by 2030

Exhibit 2 provides an overview of how user segments, charging location, and technology are combined in the model.

A more detailed explanation of this and all other methodologies used can be found in the **appendix.**

Exhibit 2: User segments, charging location, and technology for passenger cars (same view available for buses and trucks as well as LVCs in the appendix)



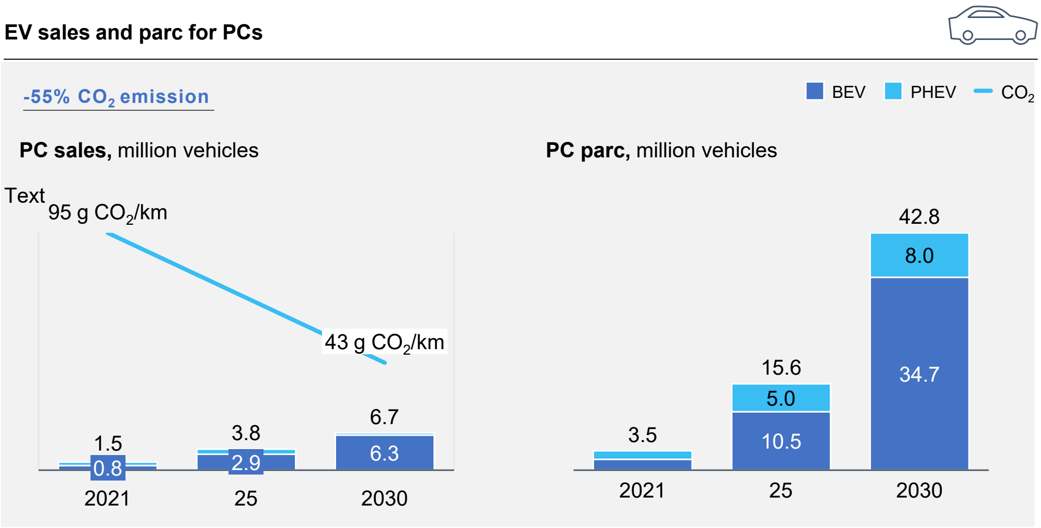
Source: EU EV Charging Masterplan

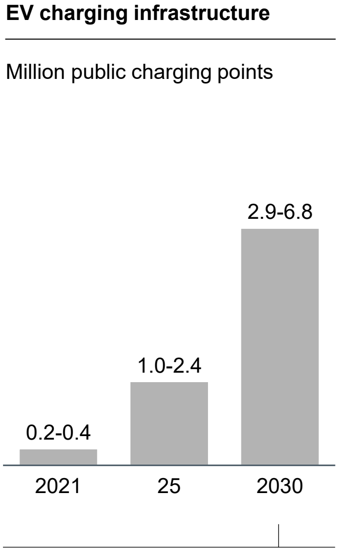
2. Key insights

The EV Charging Masterplan for the EU-27 estimates that by 2030, approximately €280 billion need to be invested in installing charging points (hardware and labor), upgrading the power grid, and building capacity for renewable energy production for EV charging. Of this total, approximately €185 billion can be attributed to PCs, €50 billion to LCVs, and €45 billion to trucks and buses. In this analysis, both public and nonpublic charging points have been taken into consideration. Across the EU, a public charging point is defined as a charging point with nondiscriminatory access. By this definition, charging points at supermarket parking lots or in openly accessible parking garages are included within public charging.

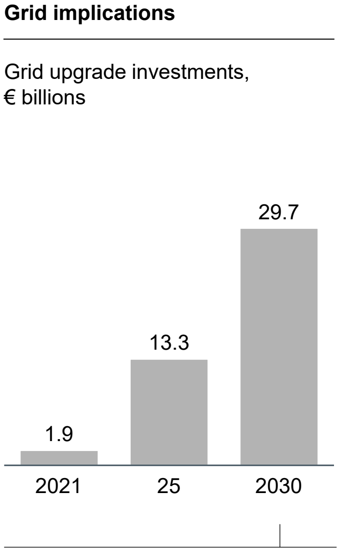
A total investment of approximately €1,000 billion by 2050 in charging infrastructure (public and nonpublic), grid upgrades, and renewable energy sources are necessary to complete the transformation to electric road mobility in EU-27. According to the EV Charging Masterplan, approximately 30% of this total capital expenditure would need to be invested in infrastructure to reduce CO_2 emissions in road transport by 2030, although less than 20% of the car parc will be electric by 2030.

Exhibit 3: The Masterplan translates into a synced build-up of PC charging infrastructure, grid, and energy implications (1/4)

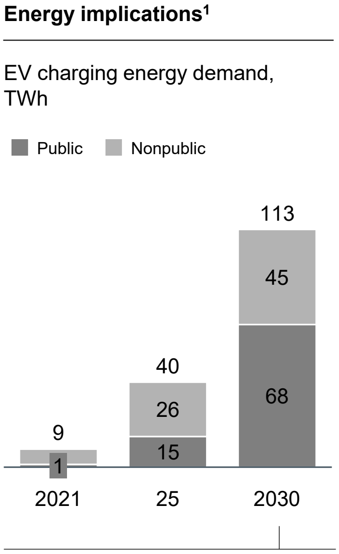




€30-70 bn
Investments until 2030



€30 bn
Investments until 2030



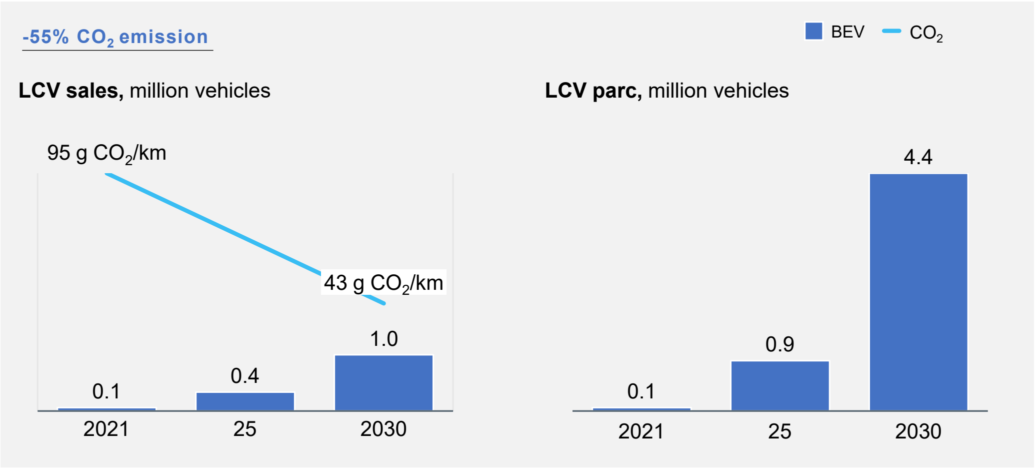
€49 bn
Investments until 2030

1. Split referred to demand-driving-oriented pathway

Source: EU EV Charging Masterplan

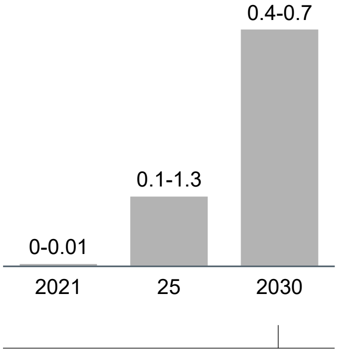
Exhibit 4: The Masterplan translates into a synced build-up of LCV charging infrastructure, grid, and energy implications (2/4)

EV sales and parc for LCVs



EV charging infrastructure

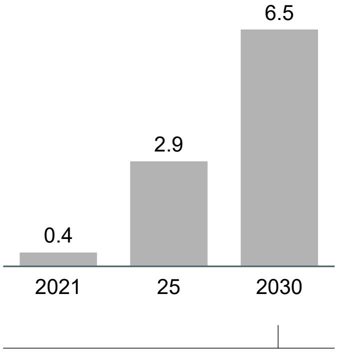
Million public charging points



€4-5 bn
Investments until 2030

Grid implications

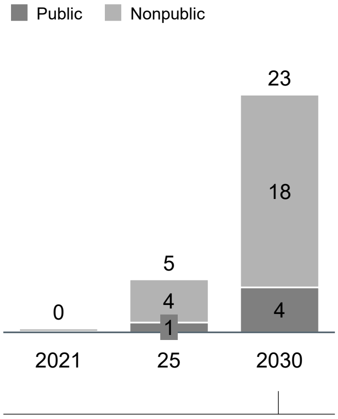
Grid upgrade investments, € billions



€6.5 bn
Investments until 2030

Energy implications[1]

EV charging energy demand, TWh



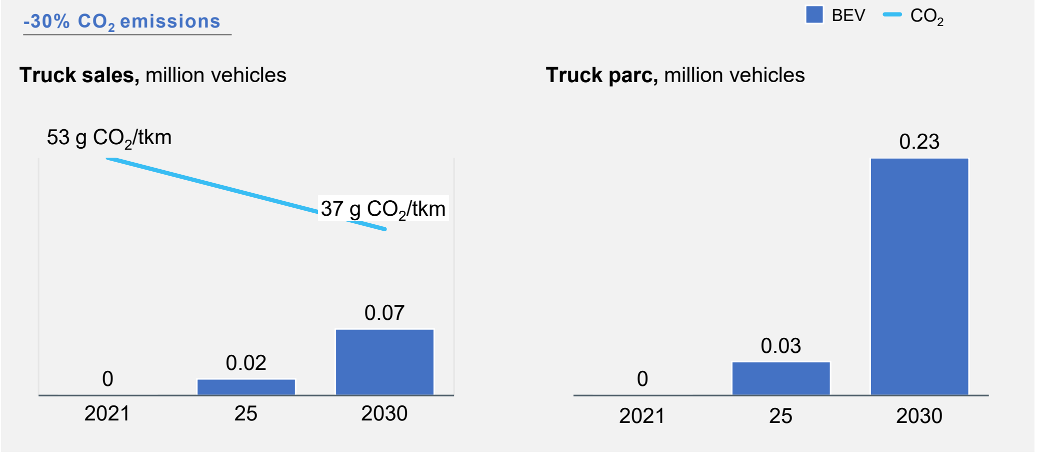
€8.9 bn
Investments until 2030

[1] Split referred to demand-driving-oriented pathway

Source: EU EV Charging Masterplan

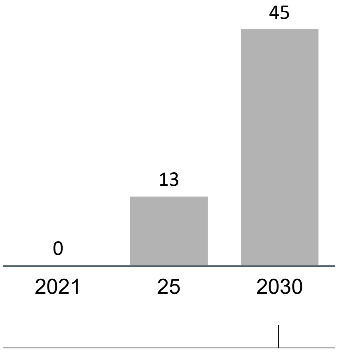
Exhibit 5: The Masterplan translates into a synced build-up of trucks charging infrastructure, grid, and energy implications (3/4)

EV sales and parc for trucks



EV charging infrastructure

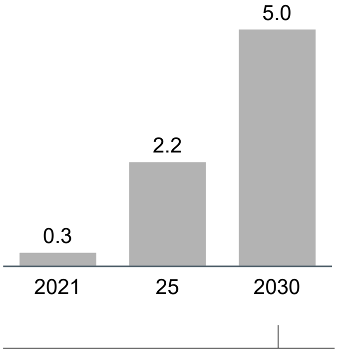
Thousand public charging points



€5 bn
Investments until 2030

Grid implications

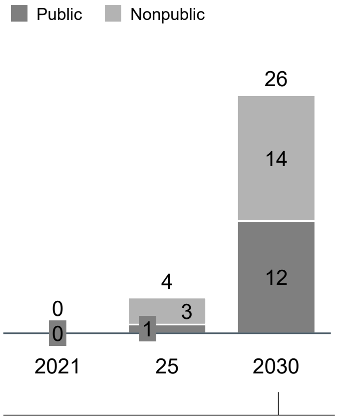
Grid upgrade investments, € billions



€5 bn
Investments until 2030

Energy implications

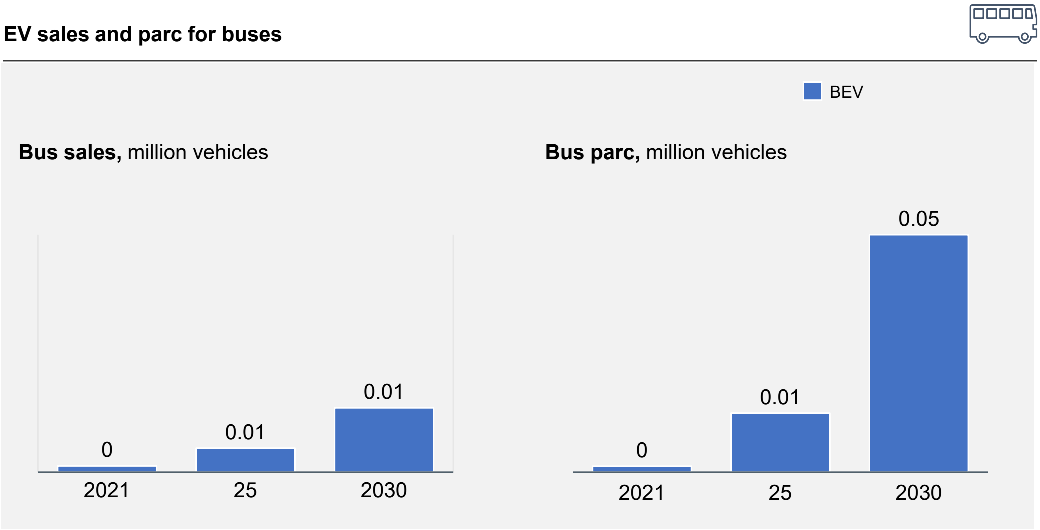
EV charging energy demand, TWh

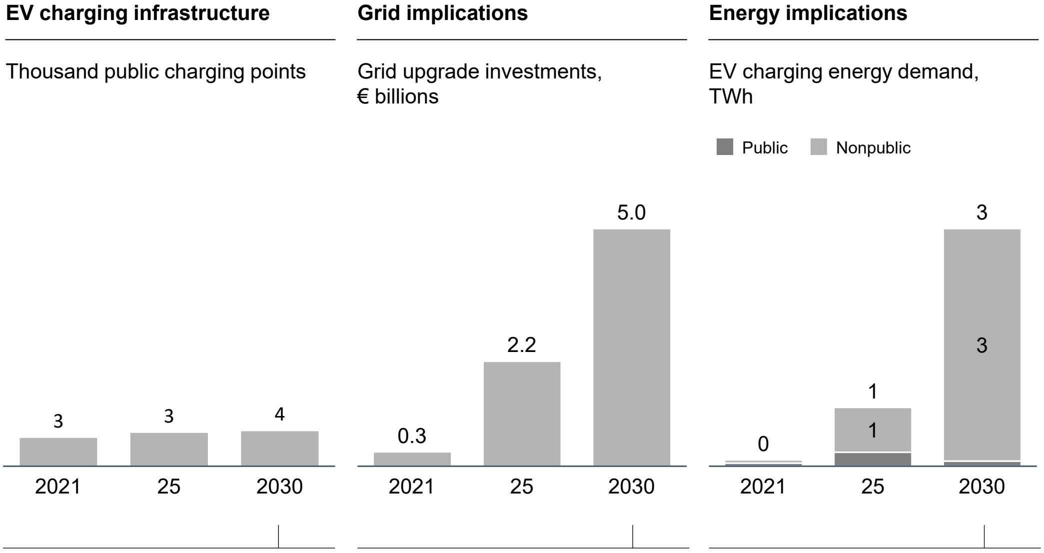


€10 bn
Investments until 2030

Source: EU EV Charging Masterplan

Exhibit 6: The Masterplan translates into a synced build-up of buses charging infrastructure, grid, and energy implications (4/4)





€0.4 bn
Investments until 2030

€5 bn
Investments until 2030

€1 bn
Investments until 2030

Source: EU EV Charging Masterplan

Although these investments are sizeable, they represent only a fraction of the total investments into comparable infrastructure projects (Exhibit 7). For instance, yearly EVCI investment for PCs and CVs is 16% of the estimated required investment for 5G and glass fiber infrastructure in EU-27. Similarly, the required distribution grid upgrades for EVs are 11% of past annual distribution system operator (DSO) investments and deployment of renewable power. This is because EV charging accounts for 18% of the total renewable energy that is expected to be installed until 2030.

The investments require a balance of private and public investments, where public investments focus on regions and public chargers with initially low utilization before positive business cases are achieved. Private investments so far have focused on building out more profitable fast DC charging infrastructure, while slow AC charging infrastructure has relied on public funding.

Exhibit 7: Required investments in charging infrastructure are a fraction of total investment needs

EU-27 – demand-driving-oriented pathway

		Comparison of infrastructure projects
Charging infrastructure, annualized[1]		
€8 bn for public EV charging infrastructure incl. installation and hardware	**€50 bn** for full 5G and high-speed internet ramp-up across EU-27 from 2021 to 2025 annually	**18%** of 5G and high-speed internet investments in EU-27
Grid upgrade, annualized		
€4 bn for upgrades to distribution system incl. network extensions and transformer upgrades	**€36 bn** average annual EU-27 investments in grid upgrades from 2021 to 2030	**11%** of yearly EU-27 grid investments
Renewable investment, annualized		
€7 bn to meet increased e-mobility energy demand with renewables (solar, wind, hydro, and biomass)	**€38 bn** average annual EU-27 investments in renewable energy from 2021 to 2030	**20%** of total investments in RES for energy transition

[1] For annualized numbers, the total investment sum was divided by the number of years the investment program runs (2021-30)

Source: EU EV Charging Masterplan, ACEA, WindEurope, Eurelectric, European Telecommunications Network Operators’ Association

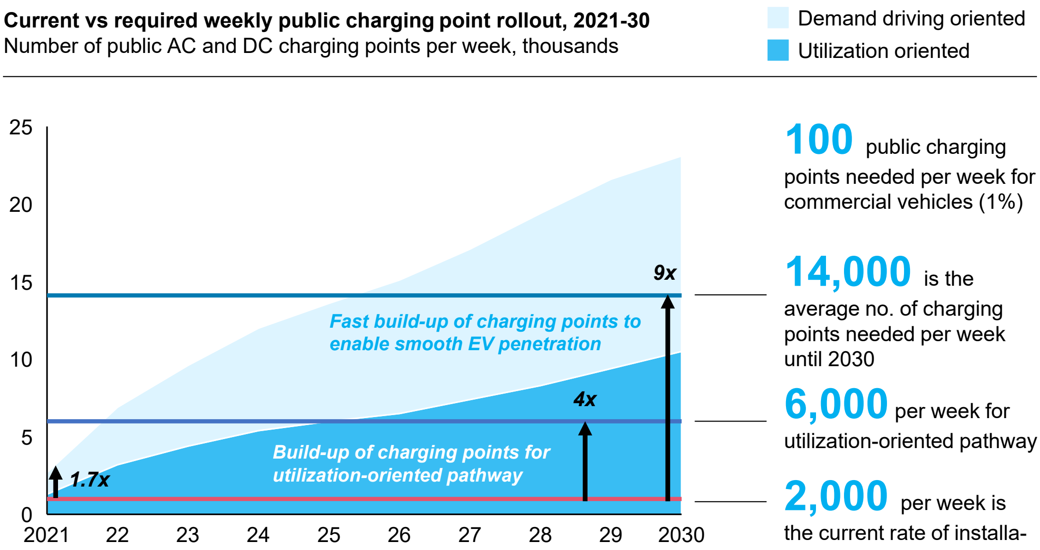
Achieving a 55% CO_2 reduction for PCs and LCVs and a 30% CO_2 reduction for trucks requires an EV parc share of more than 17%, 13%, and 3.5%, respectively, by 2030. This translates to 42.8 million EVs (BEVs and PHEVs), 4.4 million electric LCVs, and 0.3 million electric trucks and buses on the road by the end of the decade. A rapid EV Charging Infrastructure (EVCI) rollout is required for smooth customer adoption. The EV Charging Masterplan estimates that by 2030 a total of 6.8 million public chargers for PCs, 0.7 million for LCVs, and 0.1 million for trucks and buses would need to be installed in the demand-driving-oriented pathway. To achieve this goal, deployment would have to increase from about 2,000 public charging points per week in 2021 to over 23,000 charging points per week in 2030. On average, 14,000 public charging points would have to be deployed weekly between 2021 and 2030 (Exhibit 8). For the utilization-oriented pathway, an average of 6,000 public charging points would need to be deployed weekly (approximately three times the current deployment rate).

Overall, a quick acceleration of the rollout of charging stations is required. The current installation rate of around 2,000 charging points per week is already 1.7 times below the weekly requirement and needs to increase even more each year.

Exhibit 8: A nine-fold acceleration in charging point installation speed is required to reach required charging points by 2030

EU-27 – demand-driving-oriented pathway

Current vs required weekly public charging point rollout, 2021-30
Number of public AC and DC charging points per week, thousands



100 public charging points needed per week for commercial vehicles (1%)

14,000 is the average no. of charging points needed per week until 2030

6,000 per week for utilization-oriented pathway

2,000 per week is the current rate of installation of new charging points

9x Average weekly EVCI rollout acceleration needed by the mid-2020s to reach required number of public AC and DC charging points[2]

1. Required number of charging points is derived from the EV Charging Infrastructure Masterplan
2. 470 weeks left until end of 2030 and 7.6 million public charging points to be installed

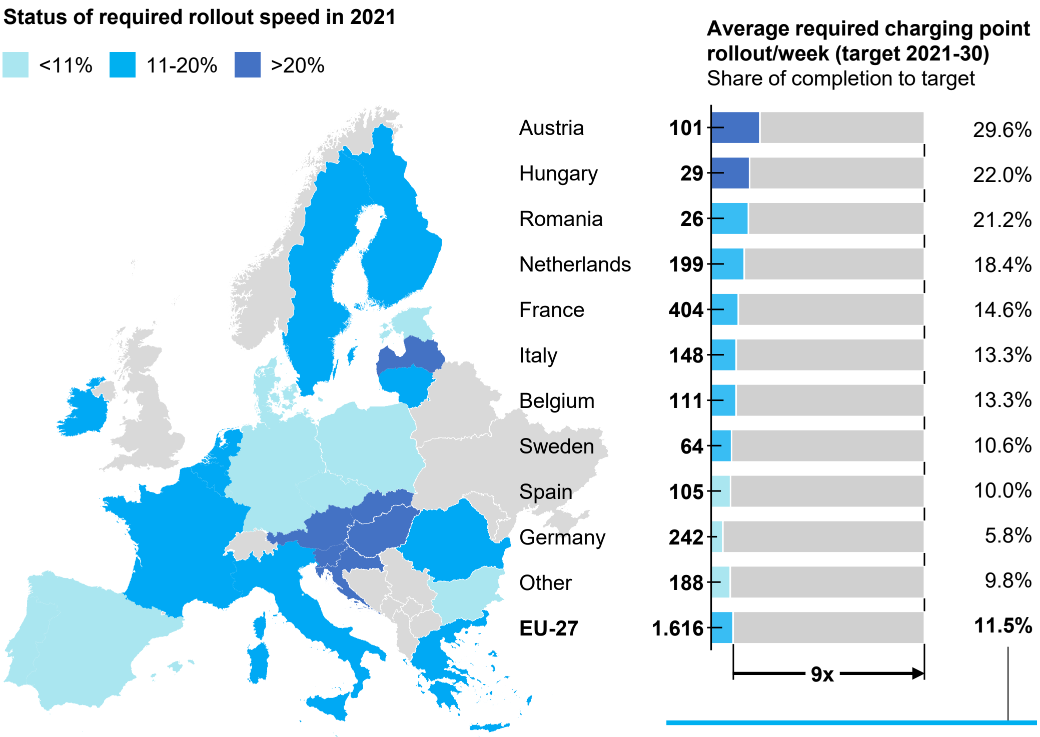
Source: European Alternative Fuels Observatory, national transport and mobility organizations, EU EV Charging Masterplan

It is interesting to note that of the 14,000 required chargers to be installed per week, EU-27 countries are, on average, currently installing at a rate that is 11% of this number (see Exhibit 9). Thus, a nine-fold acceleration is needed. However, countries are expected to require differing degrees of acceleration, primarily due to EV market share and adoption outlook differences. Current and required rollout speeds are compared at a country level to understand these country-specific rollout acceleration needs. The current percentage of the average required installation rate is used for the comparison. Using this methodology, Austria is currently closest to reaching the average required rollout speed, installing at a rate that is 30% of its required 344 chargers per week (Exhibit 9). However, larger countries are installing at a rate that is less than 10% of their required number of charging points. Germany, for example, is installing 6% of its required 4,200 chargers per week.

Exhibit 9: In 2021, largest EU countries lag behind required weekly rollout of charging points

EU-27 – demand-driving-oriented pathway

Current vs required average weekly public charging point rollout, 2021-30
Share of required public AC and DC charging points[1]



9x Rollout acceleration needed to stay on track for necessary public charging infrastructure

1. Required number of charging points is derived from the EV Charging Infrastructure Masterplan

Source: European Alternative Fuels Observatory, national transport agencies, mobility organizations, EU EV Charging Masterplan

B. Charging infrastructure

EVCI needs can be determined in three levels of granularity (Exhibit 10): the first level of granularity is by country, the second is by regional archetype (cities, towns, and rural areas), and the third is by highways. Taking Germany as an example, the model can be used to determine charging infrastructure needs across the country, throughout German cities, towns, and rural areas, or even along Germany's core trans-European transport network (TEN-T) highway corridors. This model forms the basis for the numbers presented in this report.

Exhibit 10: The model used has differing granularities for countries, regional archetypes, and highway corridors

Figures refer to EU-27 totals by 2030

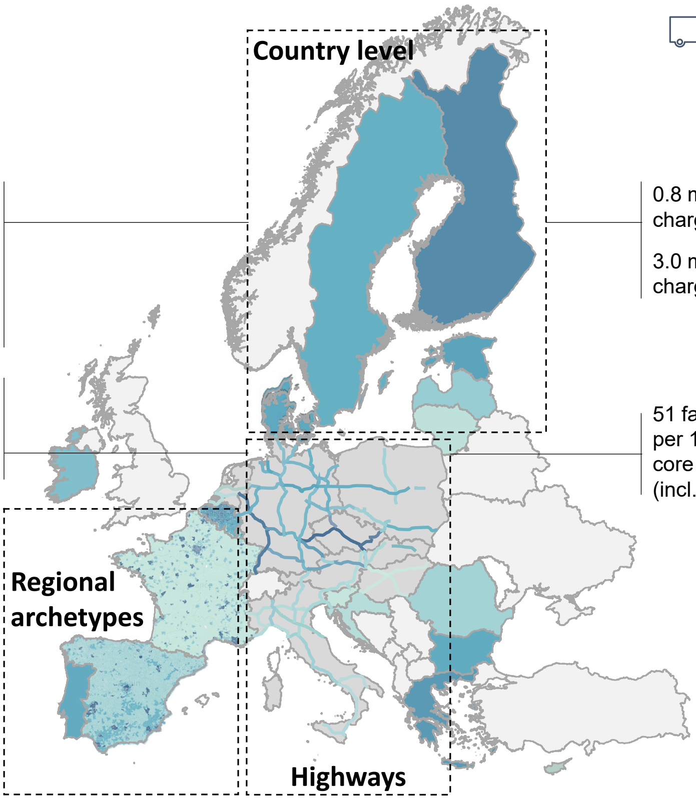
Demand-driving-oriented pathway

Charging point distribution

Low High

PCs

CVs and LCVs[1]



6.8 mn public charging points

29.4 mn non-public charging points

184 fast charging points per 100 km on TEN-T core network (incl. 9 corridors)

5 EVs per public charging point in cities

7 and 8 EVs per public charging point in towns and rural areas, respectively

0.8 mn public charging points

3.0 mn nonpublic charging points

51 fast charging points per 100 km on TEN-T core network for trucks (incl. 9 corridors)

€69 bn investments in public charging infrastructure until 2030

€11 bn investments in public charging infrastructure until 2030

1. Incl. trucks, buses, and LCVs

Source: EU EV Charging Masterplan

This chapter is divided into four subsections: EV sales and parc penetration, PC infrastructure requirements, CV infrastructure requirements, and total investment needs.

1. EV outlook

To achieve the “Fit for 55” target of CO_2 reductions in road transport, both PCs and CVs will require a transition from ICE vehicles to zero-emission vehicles (BEVs, PHEVs during the transition, and FCEVs). For passenger cars and LCVs, the announced –55% reduction target for new cars by 2030 is incorporated and for HDT trucks the current –30% reduction target, that will be revised this summer.

Considering the current targets, the share of EVs among total PC and LCV sales is expected to rise above 50% by 2030 amounting to a BEV and PHEV parc of 47.5 million EVs on the road (Exhibit 11). This shift will grow the total EV (BEV and PHEV) PC and LCV parcs in 2030 to 42.8 million and 4.4 million, respectively. As for trucks and buses, BEVs will still account for less than half of the total sales in 2030, but their vehicle population (parc) will amount to 235,000 and 53,000 in 2030, respectively.[3]

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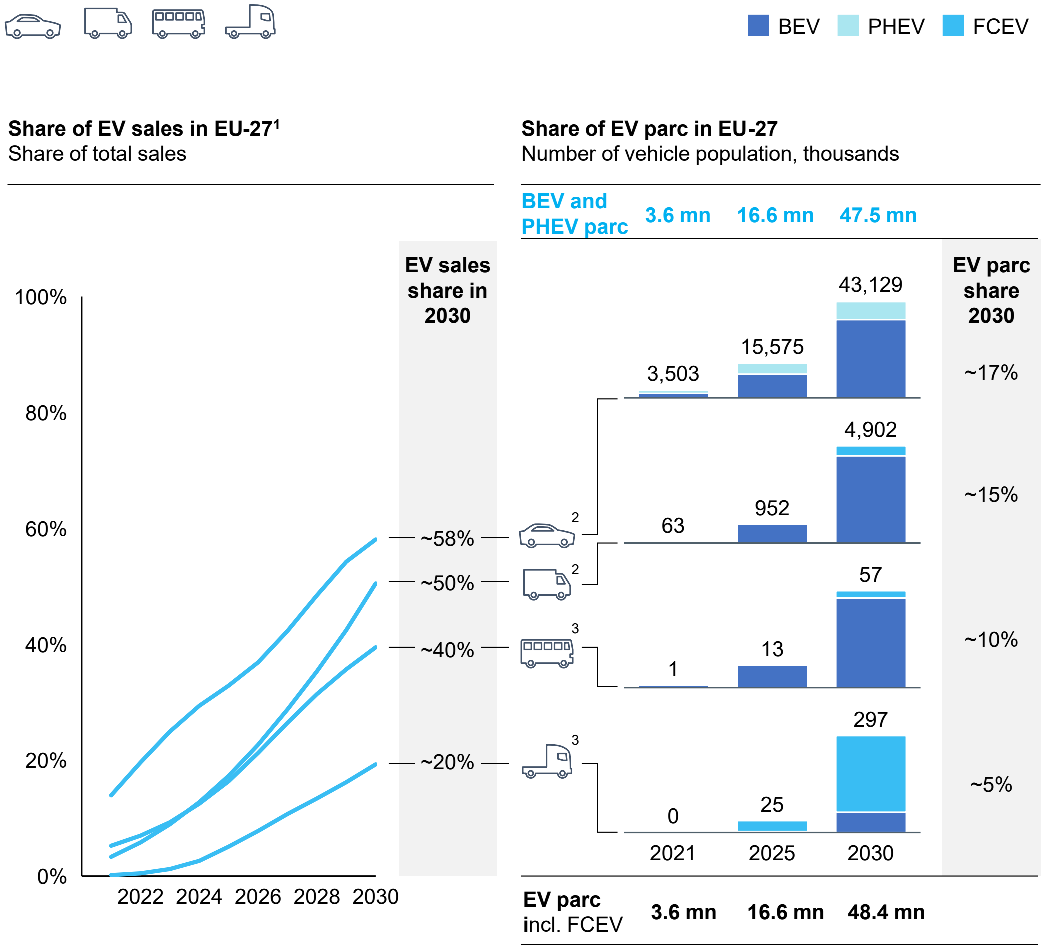
[3] In addition to the BEV and PHEV segments, the FCEV share in 2030 accounts for 360,000 PCs, 500,000 LCVs, 62,000 trucks, and 4,000 buses—the FCEV segment will not be discussed in this report.

Exhibit 11: The EU's 2030 CO_2 reduction target translates into ~58% PC EV sales and 42.8 mn electric PC vehicles in the parc by 2030



1. BEVs and PHEVs only
2. CO_2 reduction target: 55% by 2030
3. CO_2 reduction target: 30% by 2030

Source: EU EV Charging Masterplan

2. Charging infrastructure for PCs

Charging infrastructure requirements

Different approaches to developing charging infrastructure can be taken to achieve the required EV parc targets. More specifically, two distinct pathways for the rollout of EVCI were developed, namely the demand-driving-oriented pathway and the utilization-oriented pathway (Exhibit 12). The two approaches differ on two key factors: the split between slow and fast public charging and the average network utilization of charging points. Charging point utilization refers to the energy provided by the charging point, as a percentage of its total charging capacity, within a specific timeframe.

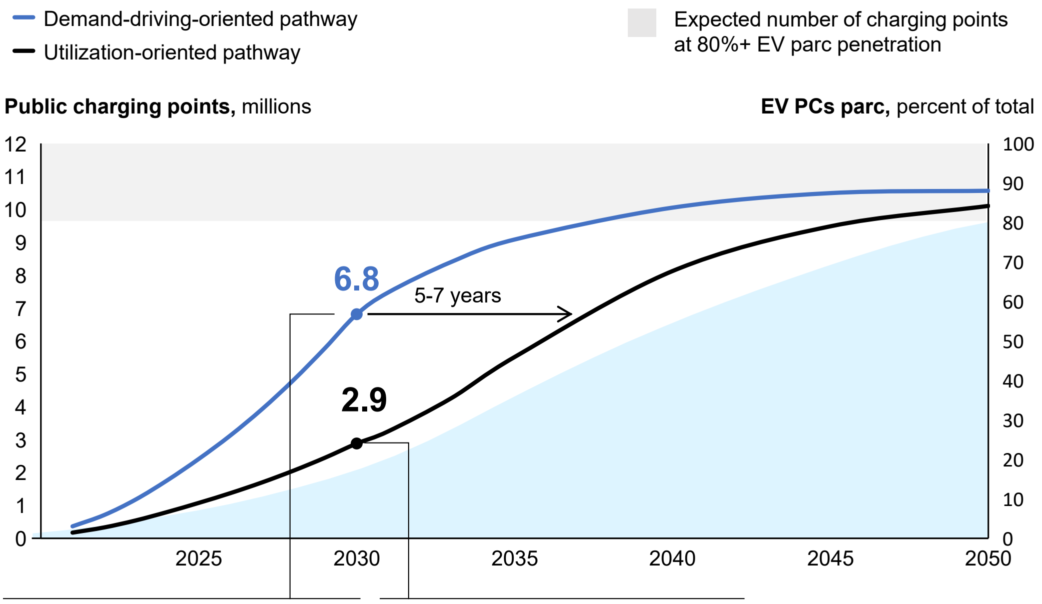
The demand-driving-oriented pathway is anchored in the minimal accepted average network utilization of charging points of 5%. It focuses on quickly establishing a dense, slow AC charging infrastructure network to enable proximate and convenient consumer adoption and accelerate the transition to EVs. However, the low average network utilization in the demand-driving-oriented pathway is not economically sustainable in the long term, limiting investments from private charging point operators (CPOs). Therefore, a second pathway, the utilization-oriented pathway, was developed, using an average network utilization of 15% for DC fast charging, the rate currently observed by top-tier CPOs in Europe.

In the utilization-oriented pathway, 2.9 million public charging points would be required by 2030, approximately 40% of the 6.8 million public charging points necessary in the demand-driving-oriented pathway. While the latter accelerates the installation of charging points by four to six years compared to the utilization-oriented pathway, it requires more financial support to install and operate the 6.8 million public charging points. The rollout investment gap is expected to amount to €40 billion by 2030 between the demand-driving and utilization-oriented pathway. Significant private investments have already been made into establishing today's fast charging infrastructure along main highways. Public investments are also essential to overcoming low utilization in regions that electrify slower and slow on-street charging to ensure the development of charging infrastructure across Europe and rural areas. Average network utilization of 15% is required for economic viability in the medium to long term. In the EU, the industry is expected to converge toward even higher utilization in the next five to 15 years.

Although the number of charging points in both pathways eventually converges, the earlier the charging infrastructure is in place, the more seamless the transition will be for consumers. A 2020 McKinsey EV Consumer survey shows that charging infrastructure remains a crucial bottleneck for consumer adoption; faster and earlier uptake of public charging infrastructure is fundamental. For this reason, the rollout of the EVCI proposed in the EV Charging Masterplan will follow the demand-driving-oriented pathway.

Exhibit 12: The demand-driving infrastructure rollout requires a rollout of ~6.8 mn public charging points by 2030

EV parc and public charging points for demand-driving and utilization pathways



Demand-driving-oriented pathway: smooth EV consumer adoption

(+29 mn nonpublic charging points)

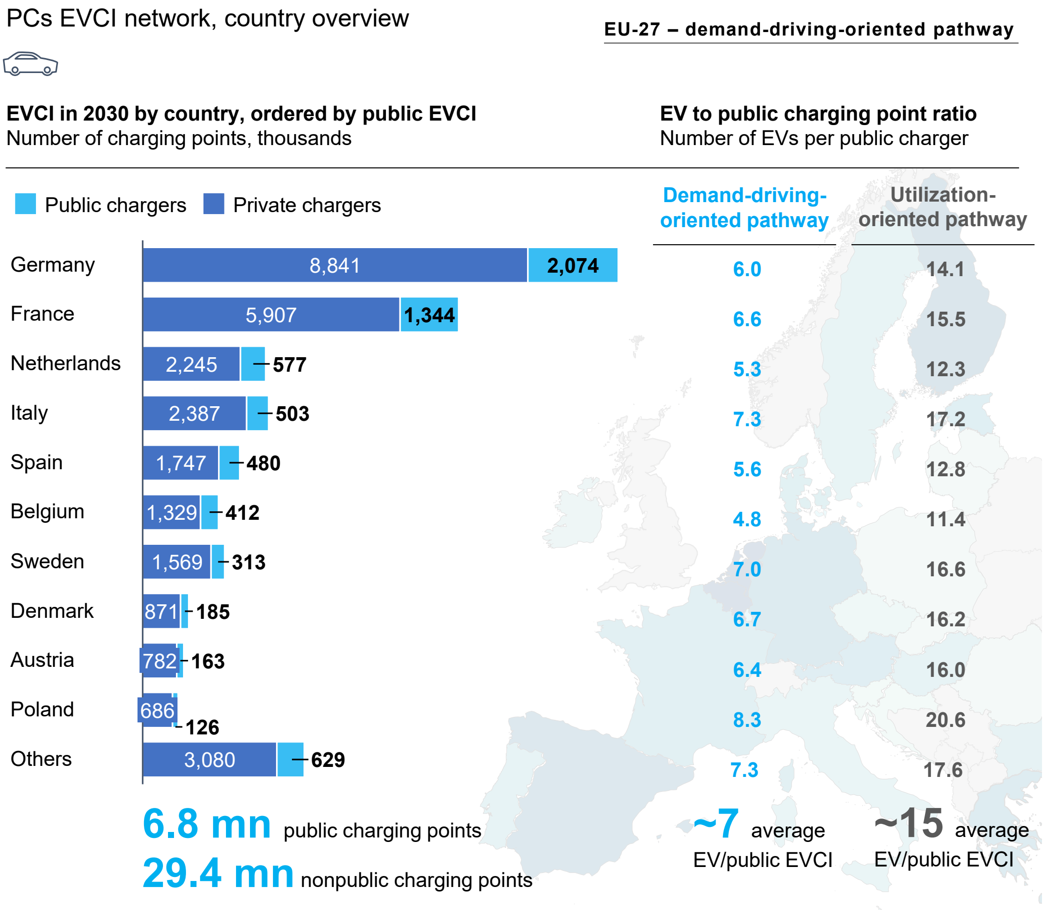
Utilization-oriented pathway: balance of utilization and EV consumer adoption

(+29 mn nonpublic charging points)

Source: EU EV Charging Masterplan

Despite the single CO_2-reduction target across EU-27 countries, cross-country differences are expected to impact charging point needs per country. The ratio of EVs per public charging point can be used to illustrate such differences: while the ratio is expected to average seven in EU-27 (Exhibit 13), the value ranges from six in Germany to eight in Poland in 2030 according to the Masterplan. The primary driver of such cross-country differences is the difference in EV drivers' opportunities to install and use a personal charger at home.

Exhibit 13: EV to public charging point ratio driven by EV penetration and user behavior



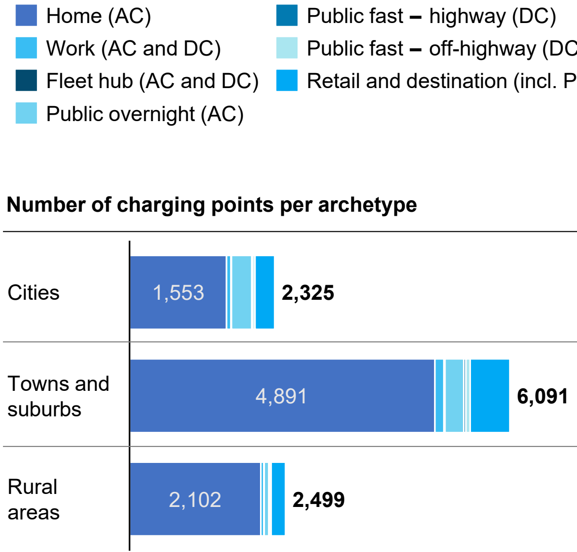
Source: EU EV Charging Masterplan

The detail of this analysis can be increased further by comparing the 2030 EV to public charging point ratio for the three geographical archetypes: expected to average five, seven, and eight, for cities, towns, and rural areas, respectively. As for the former, this lowest ratio of five is driven by the lower opportunities in cities to install private charging points, thus obliging EV owners to rely more on public-charging infrastructure. While the previously mentioned ratios refer to EU-27 averages, cross-country differences are expected. Taking Germany as an example (Exhibit 14), the ratio is expected to be four for large cities (such as Berlin, Munich, and Hamburg), seven for towns (for example, Kiel), and seven for rural areas. A contrary example is Poland, where cities such as Warsaw are expected to have six EVs per charging point, towns (for example, Bialystok) nine EVs per charging point, and ten EVs per charging point in rural areas. In the utilization-oriented pathway, the EV to public charger ratio is around two times higher than in the demand-driving-oriented pathway, at an average of 15 EVs per public charger.

Exhibit 14: Cities, towns, and rural areas have different concentration of charging points

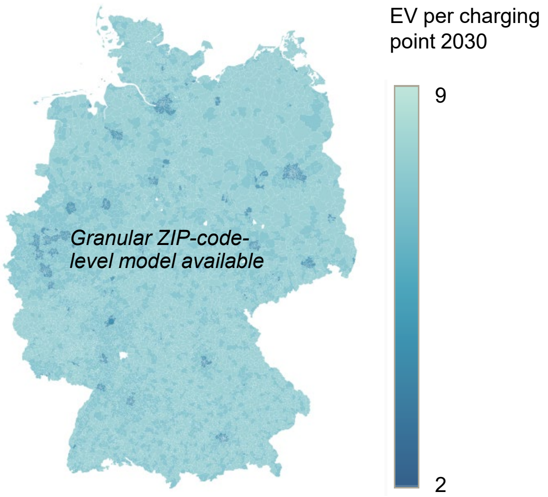
Germany example

Demand-driving-oriented pathway



Number of charging points per archetype		**Share of population** Percent	**Share of EV parc** Percent	**EVs/ charging point**[1]
Cities	2,325	31	24	4
Towns and suburbs	6,091	48	56	7
Rural areas	2,499	21	20	7

Public fast – non-Highways (DC)



Comments

Germany has the highest number of public charging infrastructures in towns and suburbs, followed by cities and rural areas

In cities, there will be 1 public charger for every 4 electric PCs, and 1 charger for every 7 electric PCs in towns, suburbs, and rural areas

1. Ratio refers to public EVCI network only
2. Cities in Germany: Berlin, Munich, Bonn, Bremen, Dresden, Düsseldorf, Frankfurt am Main, Hamburg, Hannover, Karlsruhe, Cologne, Leipzig, Mannheim, Münster, Nuremberg, Stuttgart, Bielefeld, Bochum, Dortmund, Duisburg, Essen, Wuppertal

Source: EU EV Charging Masterplan

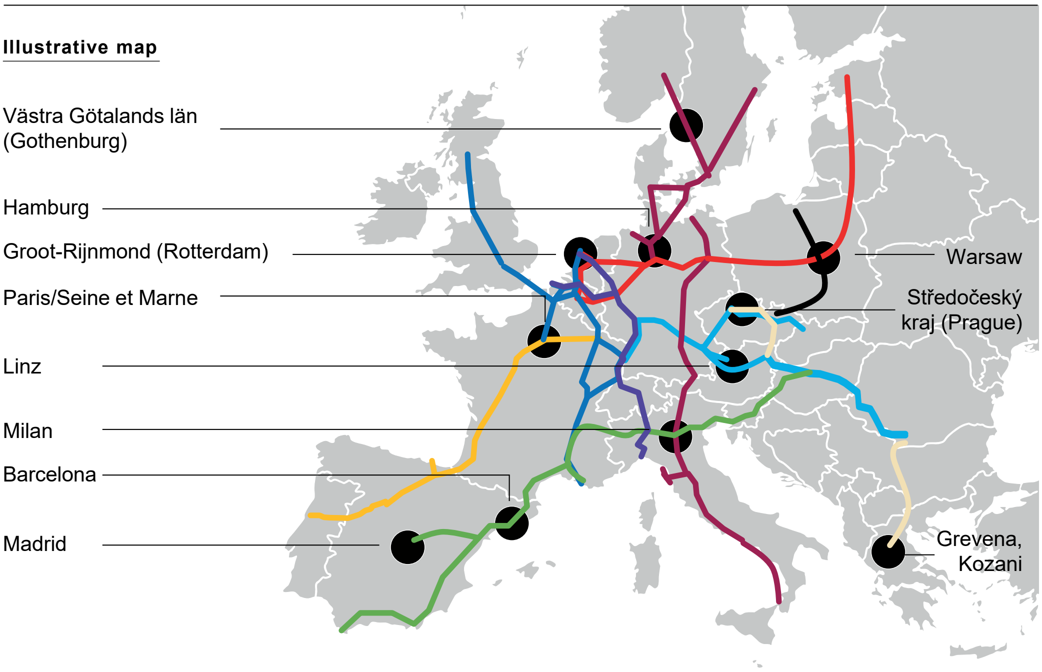
Highway infrastructure requirements

Another measure relevant for the deployment of public charging infrastructure is the required number of fast chargers for every 100 kilometers of highway, with particular emphasis on the core TEN-T corridors. The core TEN-T network (nine core corridors) represents some of Europe's most heavily used and significant roads, with an average of about 50,000 vehicles per day per corridor traveling approximately 62% of the total yearly vehicle kilometers traveled in the entire TEN-T network (core and noncore). By 2030, 85,000 fast chargers for passenger cars will span the 47 thousand kilometers of the core TEN-T network (Exhibit 15), equivalent to 184 fast-charging points every 100 kilometers (92 fast-charging points every 100 kilometers in each direction of travel). These chargers will serve the approximately 6,000 vehicles that travel on these routes each hour during peak times, of which 1,500 are estimated to be EVs and ~75 to 85% of those to be passenger cars.

The density of fast chargers differs widely across corridors and countries due to differences in traffic volume (Exhibit 16). The Netherlands, for example, considering its high density of EVs and port cities, requires 360 fast chargers for every 100 kilometers of TEN-T highway in 2030.

Exhibit 15: Passenger cars will need 184 fast chargers for every 100 km of road to charge on core TEN-T corridors by 2030

Main corridors of the EU TEN-T road network



EU-27 – demand-driving-oriented pathway

TEN-T corridor	Length Thousand km	Publicly accessible fast chargers[2] Thousands	Public fast chargers per 100 km of road
▬ Scandinavian – Mediterranean	4.9	10.3	215
▬ Mediterranean	6.4	8.4	132
▬ North Sea – Baltic	3.1	6.8	223
▬ North Sea – Mediterranean	1.7	4.6	264
▬ Rhine – Danube	1.4	3.1	215
▬ Atlantic	4.6	6.4	139
▬ Rhine – Alpine	1.1	2.5	311
▬ Baltic – Adriatic	2.7	3.4	125
▬ Orient – East Mediterranian	2.9	2.9	100
••• Other core network highways	18.1	37.0	207
	47.0[1]	85	184

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1. Referred to current completed kilometers of road along TEN-T 9 corridors and other core-network highways
2. Incl. public fast – highway

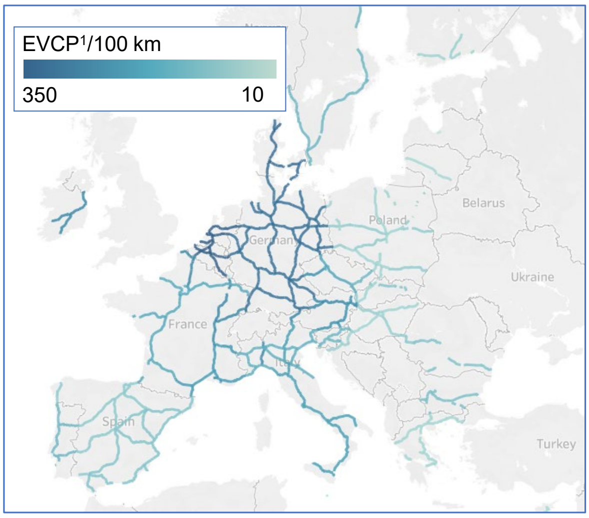
Source: EU EV Charging Masterplan, Trans-European Transport Network (TEN-T), EU Commission

Exhibit 16: The average of 184 charging points per 100 km for passenger cars on the TEN-T corridors in 2030 varies significantly across countries

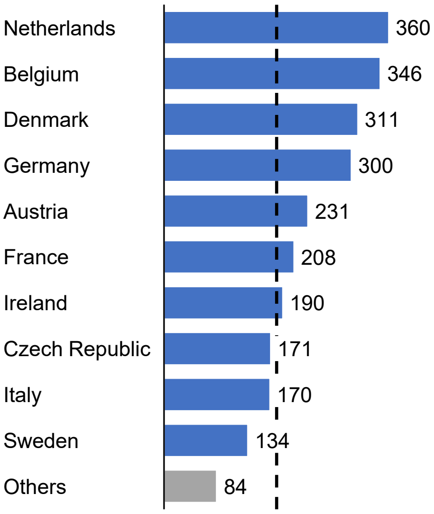
Overview of core TEN-T corridors by country, PCs

EU-27 – demand-driving-oriented pathway

EVCI TEN-T density on EU-27 core corridors, passenger cars



Top 10 countries for total EVCI density along core TEN-T corridors



Average[2] 184

1. EV charging points
2. Weighted average of the other 17 EU-27 countries

Source: EU EV Charging Masterplan, Trans-European Transport Network (TEN-T), EU Commission

User segments and corresponding charging behavior

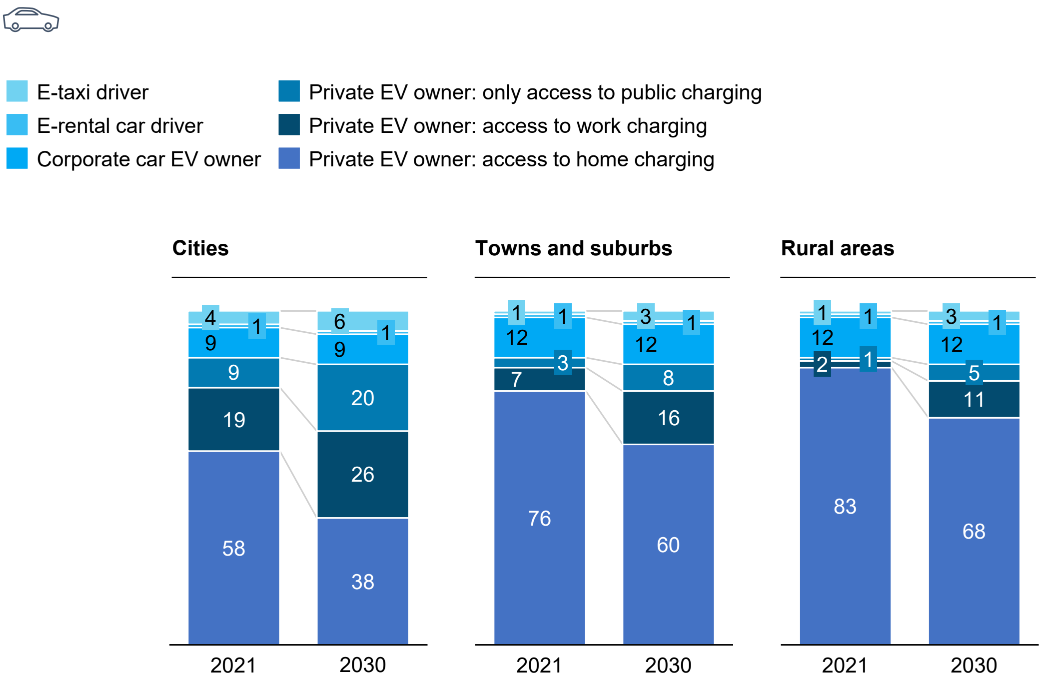
To understand the charging location of EVs, six user segments with different charging behaviors are modelled (Exhibit 17). Three of these segments are private EV owners (one segment with access to home charging, one segment with access to workplace charging but no access to home charging, and one segment with access to public charging only). The remaining three are corporate EV owners, e-Rental drivers, and e-Taxi drivers. The behavior of each user segment is taken into account to derive the share of energy demand per charging location. Each charging location is in turn associated with charging technologies of differing powers, and our modelling assumes an optimal distribution of such technologies: from DC 1MW fast chargers expected to appear on the market over the next few years, to curbside AC slow chargers. The latter can be as slow as 3 to 5 kW, which is sufficient to charge for a daily commute range overnight, and which is not expected to put large strains on the grid.

Each user segment is defined by a particular charging behavior (Exhibit 18). Private EV owners with home charging use their home charging equipment for 31% of charging. Private EV owners with access to workplace charging charge 42% of required energy in the workplace. Private EV owners with no access to either home or workplace charging charge 70% overnight at public charging stations. Corporate EV owners are expected to use workplace charging as their dominant location (22% of charging). In contrast, e-Rental and e-Taxi EVs are expected to have retail and destination charging as their dominant location (56% of charging) followed by public fast charging on and off highways (combined 39% of charging). It must be noted that throughout this report, public overnight charging includes curbside charging and chargers that range from 4 to 11 kW.

Of the six user segments, it is primarily the EV owners with access to home charging who influence the lower EV to public charging point ratio across archetypes: a lower proportion of EV owners with access to home charging is associated with a lower ratio. In cities, 58% of EV owners have access to home charging in 2021, a value which is 76% in towns and 83% in rural areas. Between 2021 and 2030, the share of EV drivers with access to home chargers is expected to decrease for all three archetypes, reaching 38%, 60%, and 68% for cities, towns, and rural areas, respectively. This decrease is primarily driven by the fact that although drivers with access to home charging are most likely to buy an EV, a robust public charging network rollout will facilitate access for EVs when home charging is not possible. In the EU, it is estimated that approximately 50% of the EV owners do not live in homes that can easily be equipped with charging points (see Exhibit 17). These drivers are expected to adopt EVs later when public charging infrastructure is more widespread.

Exhibit 17: Six populations of user segments are used to define charging behaviors across archetypes

User segmentation for PCs in 2021 and 2030, percent



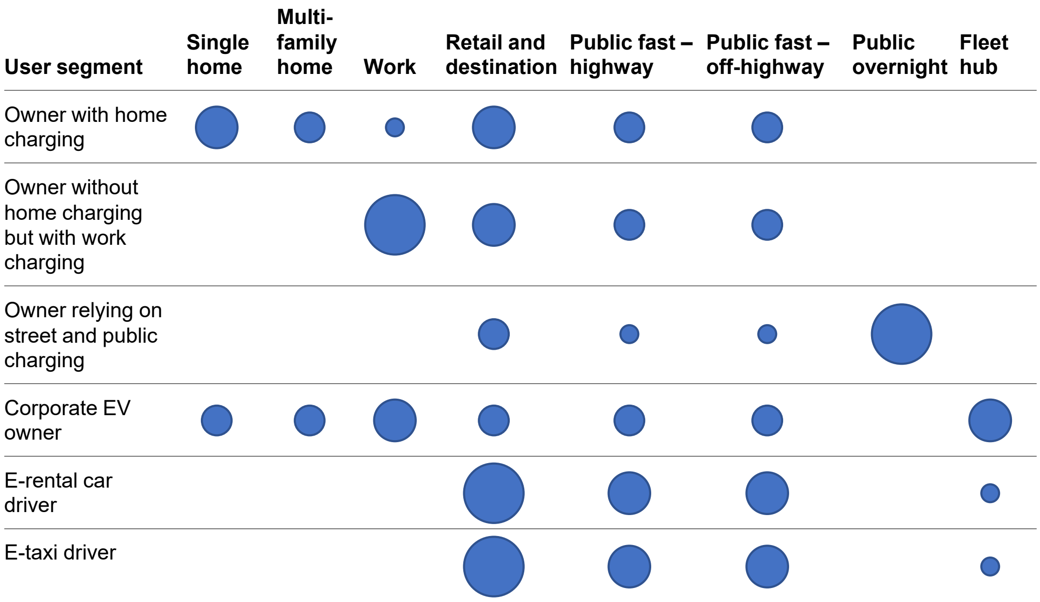
Population in regional archetype Percent	36	40	24

Source: Institute of Transport Economics, London Vehicle Infrastructure Delivery Plan, Mobilität in Deutschland, web search, EU EV Charging Masterplan

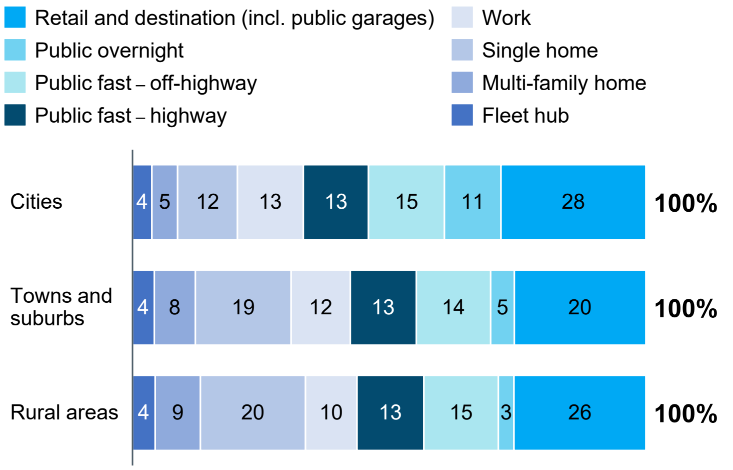
Exhibit 18: Each user segment is defined by its share of charging (in percent of energy charged) across charging locations

EU-27 – demand-driving-oriented pathway

Average charging location by user segment in 2030
Percent of energy by user segment



Average charging location by regional archetype in 2030
Percent of energy



Source: EU EV Charging Masterplan, expert interviews and insights

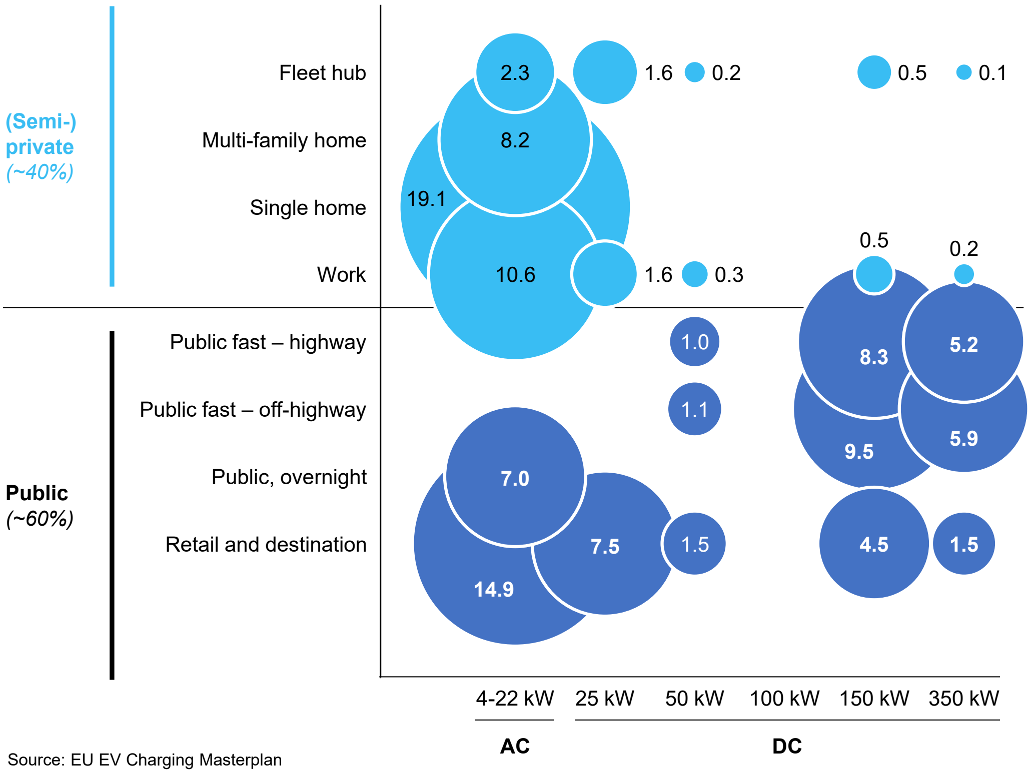
By 2030, it is expected that the majority (about 60%) of PC energy demand will come from public locations (Exhibit 19). Public charging stations will be equally divided into slow AC charging on streets, retail, and destination locations, and DC charging along highways, rural areas, cities, and retail and destination locations. In the demand-driving-oriented pathway, public charging energy demand is split equally into AC slow charging (including DC 25 and DC 50) and DC fast charging (over 150 kW). In the utilization-oriented pathway, public fast charging supplies more than 65% of the public energy demand.

Exhibit 19: Charging energy demand is split into charging locations and by charging speed

Demand-driving-oriented pathway

PC energy demand in 2030, by location and charging speed, TWh

Total: 113.1 TWh



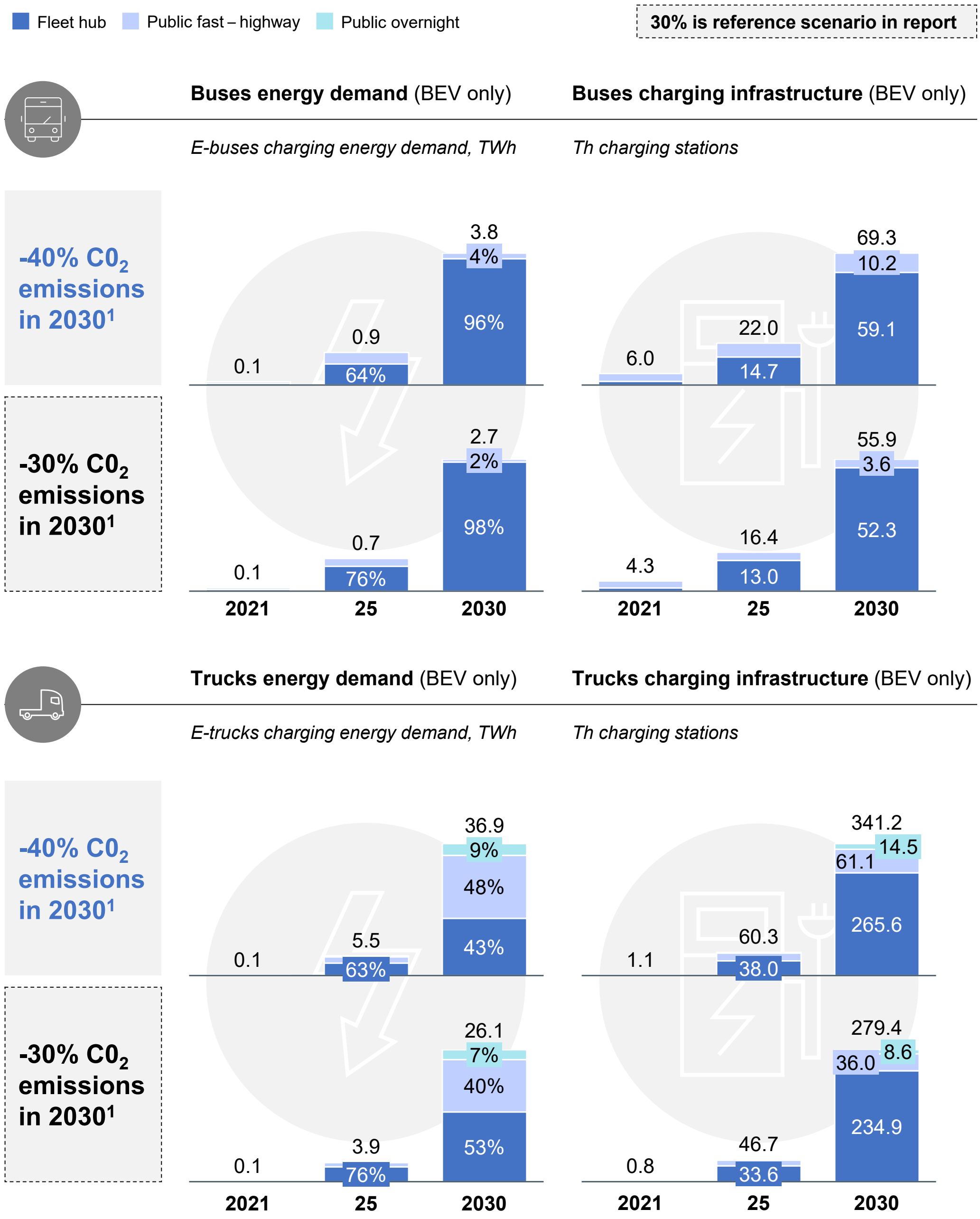
Source: EU EV Charging Masterplan

3. Charging infrastructure for CVs

Charging infrastructure requirements for LCVs, trucks, and buses

While the EU Commission set official regulatory targets for CO_2 emissions reduction in new sales for the PC and LCV segment (–55% by 2030), policymakers are still debating a revised target level for commercial vehicles. Based on the discussions with the associations involved and the information availability about the upcoming regulatory changes, two scenarios have been developed, driving two underlying EV (BEV) parcs for trucks: –30% CO_2 emissions in 2030 and –40% CO_2 emissions in 2030; this report takes into consideration the first scenario.

Exhibit 20: Trucks and buses energy demand will surge to ~26.1 TWh and ~2.7 TWh in 2030 respectively, requiring ~50,000 public charging stations



1. All scenarios are referred to EU-27 only, emissions savings vs 2020

Source: EU EV Charging Masterplan

In contrast to PCs, CVs are often charged in private-fleet hubs (where vehicles are safely parked and usually maintained). This is so as CVs are an investment that needs to be operational by the start of the vehicle service life. Long-haul and regional trucks and buses also rely on public charging for fast (daytime stops) and overnight charging (on long multiday trips).

Taking a closer look at the specific charging infrastructure needs for these vehicle types by 2030 (Exhibit 20), trucks will require 279,000 charging points, of which 84% will be in fleet hubs. The remaining charging points will predominantly be made up of public, fast-charging points along highways (36,000) and public overnight charging points (9,000). For buses, a total of 56,000 charging points will be required, of which 92% will be in fleet hubs, while the other 4,000 charging points allow fast charging off highways, especially for regional buses and coaches.

The average charging speed highly correlates with the number of public chargers. The emergence of the Megawatt Charging System (MCS)—allowing average charging speeds of 700 to 800 kW for trucks and buses—is expected to become the industry standard for fast public charging for CVs by 2025. Considering that most installed public chargers could become MCS chargers, the number of public charging stations could be reduced by around 70%, as they would provide charging that is twice as fast and has one-and-a-half times higher utilization rates, assuming the energy demand from electric trucks remains constant (Exhibit 21).

Text box 2: Introduction to Megawatt Charging Systems

Megawatt Charging System (MCS)

Description

New **CV high-power charging** solution to maximize customer flexibility when using fully electric commercial vehicles, specifically class 12+ ton (N2+, M2+) trucks and buses. The technology can also be leveraged in marine (ie, ferries), aviation (short haul, VTOLs), and rail.

Motivation

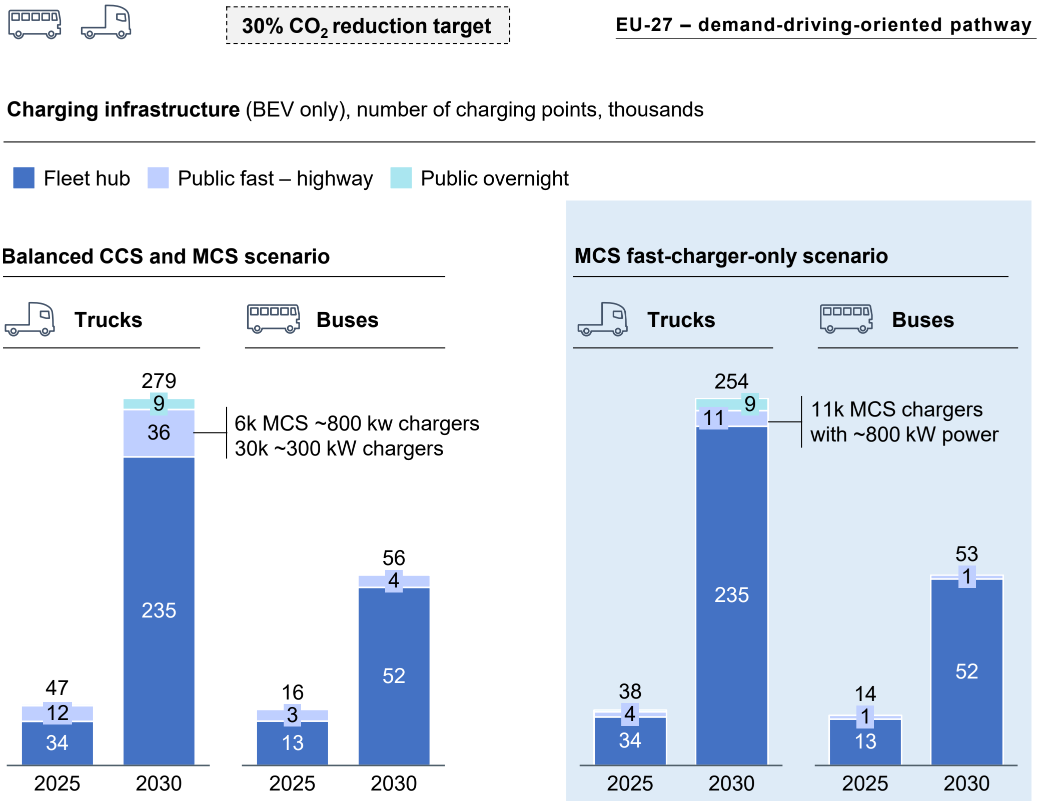
Cross-industry effort involving truck manufacturers, suppliers, and charging operators to ensure fast charging of commercial vehicles at **charging speeds of up to 1+ MW**, since current technology (CCS) is limited to 500 kW, which is **not sufficient to drive electrification** of HDT transport and charge trucks within the 45 minutes breaks that truck drivers are legally required to take in the EU.

Requirements

MCS up to **1,250 V and 3,000 A**
Vehicles equipped with MCS should be able to charge from the **existing CCS infrastructure.**

LCVs show different usage patterns; nevertheless, most charging points (56% or 1.9 million) are also in fleet hubs. LCVs, depending on the use case, are also often charged in public overnight (18% or 647,000 charging points) and at home (for example, passenger LCVs, SME, and utilities LCVs and rental LCVs) with a cumulative 24% of all charging points (810,000).

Exhibit 21: An estimated 40k fast charging points are required in public (incl. highways) for trucks and buses



Total fast public charging points, thousands

2025	2030	2025	2030
15	40	5	12

~12,000-40,000

fast public charging points for trucks and buses in 2030

~10,000

public overnight chargers for trucks

80%+

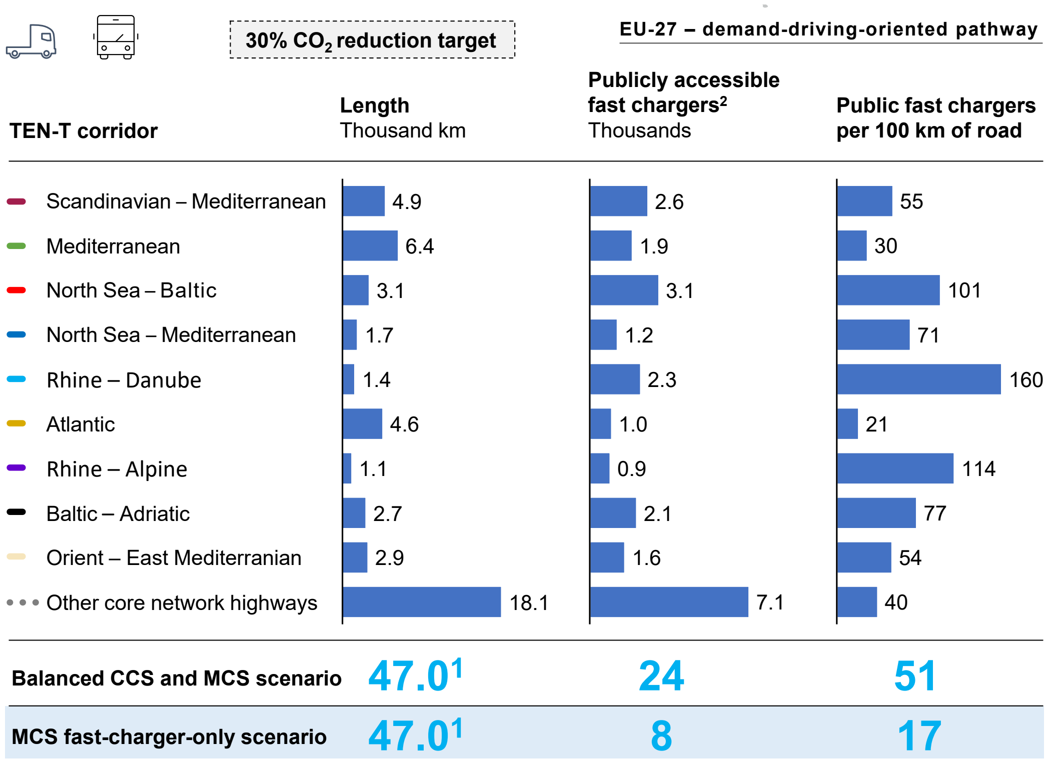
of chargers to be in fleet depots for trucks and buses

Source: EU EV Charging Masterplan

Deep dive: highway charging infrastructure requirements for trucks and buses[4]

A reliable network of fast chargers on the TEN-T core network is of great importance for electric CVs, specifically trucks. On average, 24,000 public fast chargers will be required across the 47 thousand kilometers, resulting in an average of 51 fast charging points every 100 kilometers (Exhibit 22).[5]

Exhibit 22: Trucks and buses will require 51 fast chargers every 100 km of road to charge on core TEN-T corridors by 2030



TEN-T corridor	Length Thousand km	Publicly accessible fast chargers[2] Thousands	Public fast chargers per 100 km of road
Scandinavian – Mediterranean	4.9	2.6	55
Mediterranean	6.4	1.9	30
North Sea – Baltic	3.1	3.1	101
North Sea – Mediterranean	1.7	1.2	71
Rhine – Danube	1.4	2.3	160
Atlantic	4.6	1.0	21
Rhine – Alpine	1.1	0.9	114
Baltic – Adriatic	2.7	2.1	77
Orient – East Mediterranian	2.9	1.6	54
Other core network highways	18.1	7.1	40
Balanced CCS and MCS scenario	47.0[1]	24	51
MCS fast-charger-only scenario	47.0[1]	8	17

1. Referred to current completed kilometers of road along TEN-T 9 corridors and other core network highways
2. Incl. public fast – highway

Source: EU EV Charging Masterplan, Trans-European Transport Network (TEN-T), EU Commission

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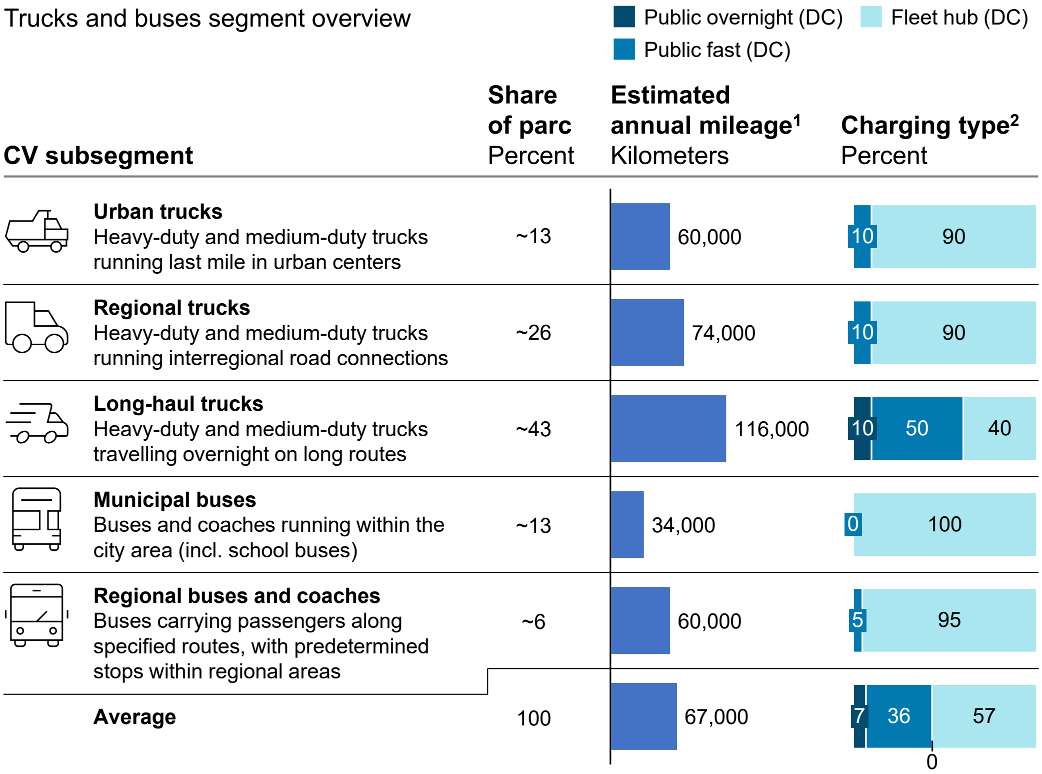
[4] The following deep dive on highway charging infrastructure will focus on trucks and buses because LCVs are predominantly used for shorter trips. Only a negligible fraction of rental LCVs is used for long-distance trips, for example, for moving or recreational activities.

[5] The 8,000 to 24,000 charging points are in addition to the 160 charging points already estimated for PCs. The reason that charging points are calculated separately and not assumed to be used by all vehicle types, is that CVs will need DC 500+ kW charging points, whereas charging points of up to DC 350 kW will be sufficient for PCs.

User segments and corresponding charging behavior for trucks and buses

As was done for PCs, the assessment of charging infrastructure for trucks and buses is based on representative subsegments (Exhibit 23), each having a differing share of energy charged in three locations: public fast, public overnight, and fleet hubs. On average, across the five subsegments, 57% of charging in 2030 will happen in fleet hubs, 36% will be public fast, and the remaining 7% will be public overnight. As for the former, with the exception of long-haul trucks, all truck and bus subsegments are expected to charge 90% of the energy at fleet hubs. On the other hand, long-haul trucks—43% of the electric trucks and buses parc—are expected to charge 50% of the energy at public fast charging stations. Long-haul trucks are expected to charge at a public fast charger once daily, and they will not make it to a fleet charger once every five nights, in which case they will charge at an overnight charger.[6]

Exhibit 23: For trucks and buses, five use cases (with distinct annual mileages and charging patterns) have been used for modelling charging infrastructure



CV subsegment	Share of parc Percent	Estimated annual mileage[1] Kilometers	Charging type[2] Percent
Urban trucks Heavy-duty and medium-duty trucks running last mile in urban centers	~13	60,000	10 | 90
Regional trucks Heavy-duty and medium-duty trucks running interregional road connections	~26	74,000	10 | 90
Long-haul trucks Heavy-duty and medium-duty trucks travelling overnight on long routes	~43	116,000	10 | 50 | 40
Municipal buses Buses and coaches running within the city area (incl. school buses)	~13	34,000	0 | 100
Regional buses and coaches Buses carrying passengers along specified routes, with predetermined stops within regional areas	~6	60,000	5 | 95
Average	100	67,000	7 | 36 | 57

1. Germany taken as reference data point
2. Figures referred to 2030

Source: EU EV Charging Masterplan based on IHS Markit and KBA sales data

User segments and corresponding charging behavior for LCVs

On average, LCVs are expected to obtain 47% of their energy from fleet charging, 34% from home charging, and the remaining share split relatively evenly between public overnight and public fast charging. Five subsegments were defined for LCVs (Exhibit 24), each representing

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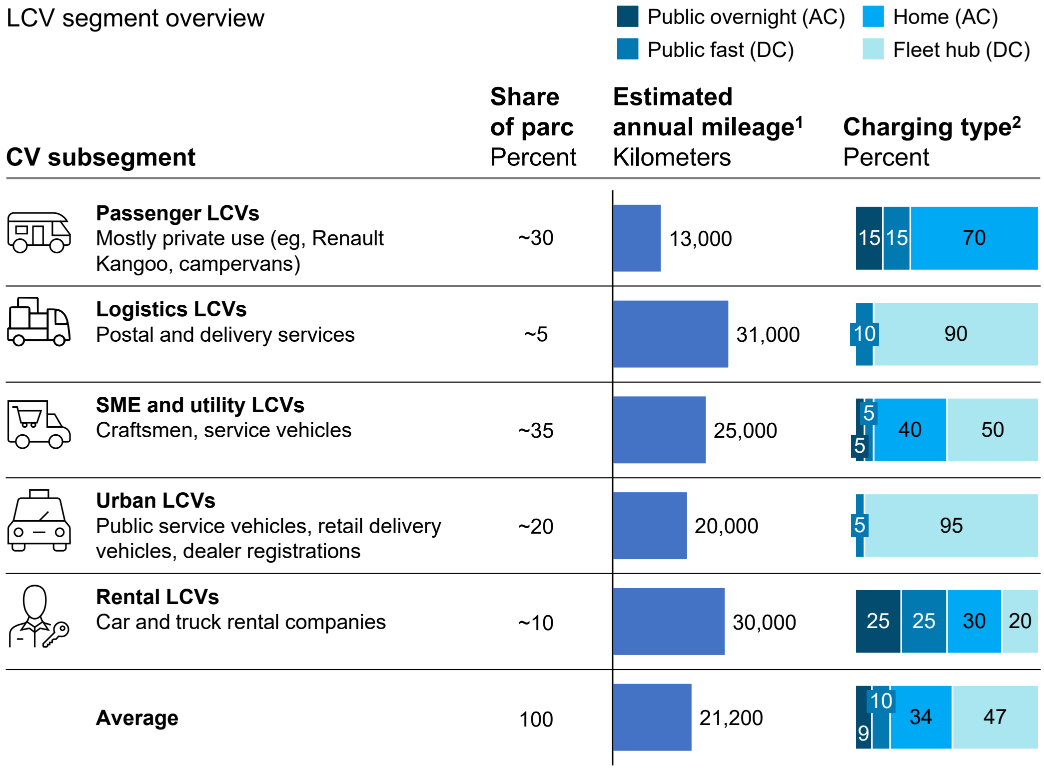
[6] All three subsegments of trucks include medium-duty trucks as well as heavy-duty trucks.

a distinct charging and usage pattern with its own mix of charging locations. The high share of fleet charging is primarily driven by urban LCVs, which are expected to obtain 95% of their energy from fleet hub charging and make up 20% of the parc. The home charging share is primarily driven by passenger LCVs, which are owned and driven in a similar way to PCs and thus have a similar charging pattern to PCs, with 70% home charging expected. Public overnight and public fast charging are reserved for circumstances in which home charging is not possible. Other use cases, such as logistics LCVs, are charged similarly to trucks and buses, where fleet overnight charging is the predominant method.

Exhibit 24: For LCVs, five use cases (with distinct annual mileages and charging patterns) have been used for modelling charging infrastructure



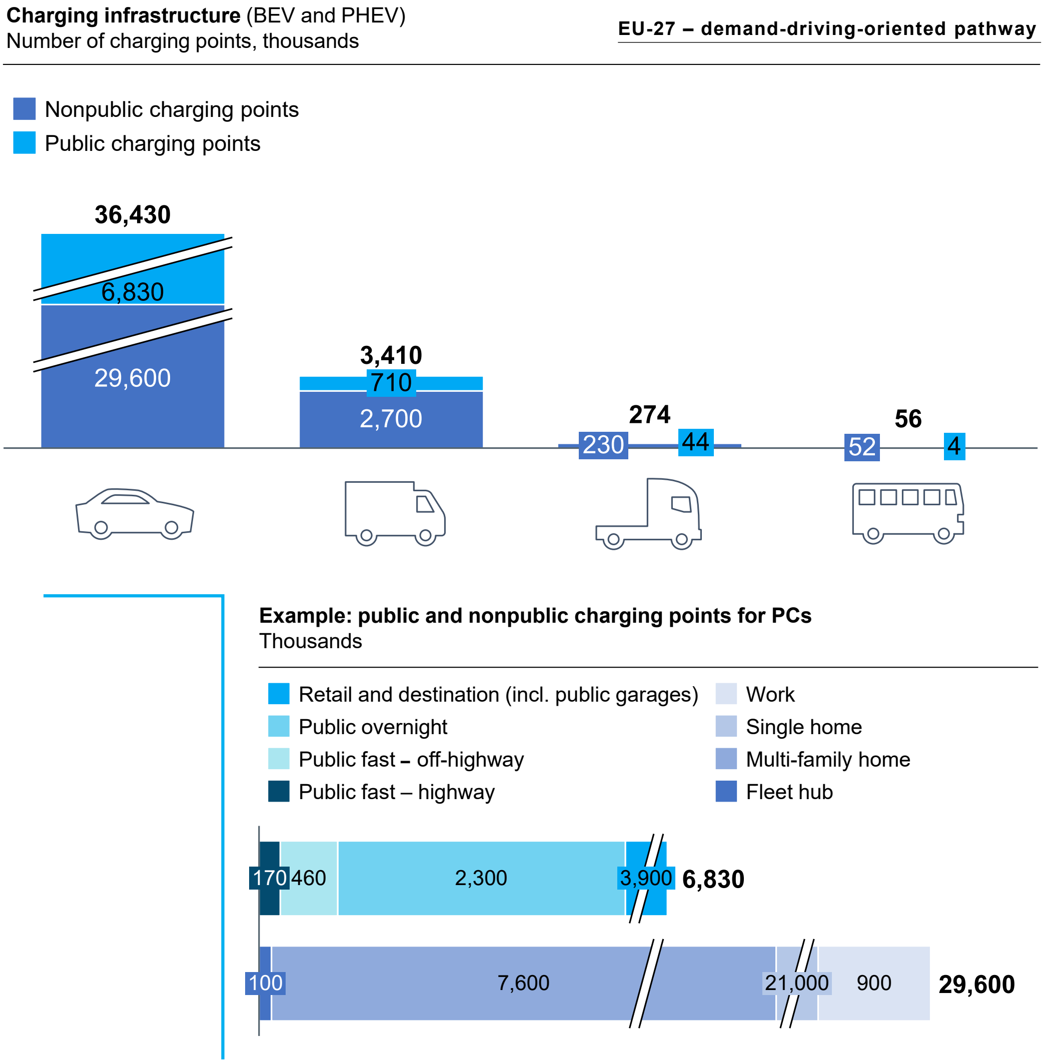
1. Germany taken as reference data point
2. Figures referred to 2030

Source: EU EV Charging Masterplan based on IHS Markit and KBA sales data

4. Required investment in charging infrastructure

For the demand-driving-oriented pathway, the cumulative investment to develop the required infrastructure for PCs and CVs amounts to €172 billion by 2030 (Exhibit 26). From a charging location perspective, €85 billion, out of the total €172 billion, would have to be invested for public charging infrastructure, of which €59 billion are needed for public fast charging. The €172 billion refer to both public and nonpublic charging points, necessary to meet the EV uptake needs by 2030 (Exhibit 25).

Exhibit 25: Both public and nonpublic charging points will be necessary by 2030 to meet the EV uptake needs

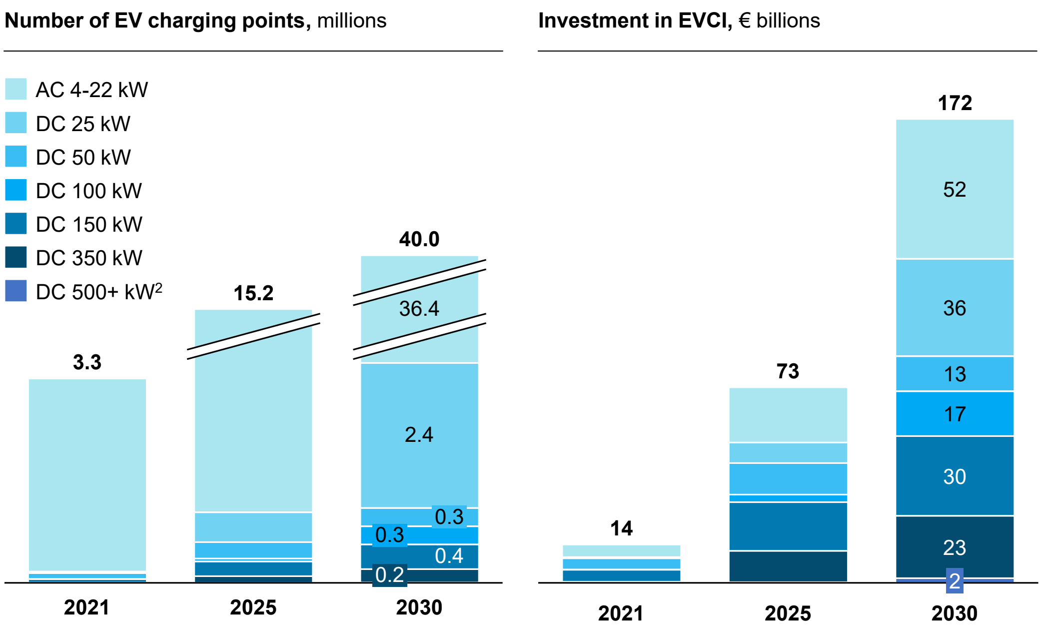


Source: EU EV Charging Masterplan

Exhibit 26: Total investments into private and public charging infrastructure for PCs and CVs will equate to EUR 172 bn in the demand-driving-oriented pathway

Private and public chargers **EU-27 – demand-driving-oriented pathway**

Cumulative charging points and investment in EVCI[1]



Comments

The **vast majority of EV public charging infrastructure** will consist of **AC 4-22 kW** charging points, mainly due to the nonpublic chargers segment

The most common technologies for PCs, **AC 4-22 kW, will induce ~30% of the total cost**

DC 100 kW technology will be key for **public overnight chargers** and **fleet depots** for trucks and buses

1. Split between fast and slow charging is based on energy demand
2. DC 500+ kW technology scales up to ~1 MW of power per charger at 2030

Source: EU EV Charging Masterplan

Of the €172 billion investment, approximately 60% (€120 billion) will be allocated to DC fast charging points (Exhibit 26). While fewer in number compared to the AC charging points, the hardware and installation of DC charging points is more expensive (Exhibit 27): the 2030 investment per kW ranges from €125 for AC 11 kW to €400 for DC 150 kW. In terms of total investment, while an AC 11 kW charger is expected to cost €1,000 per unit, this is expected to be €104,000 for DC 500+ kW and reach €260,000 for DC 1 MW chargers.

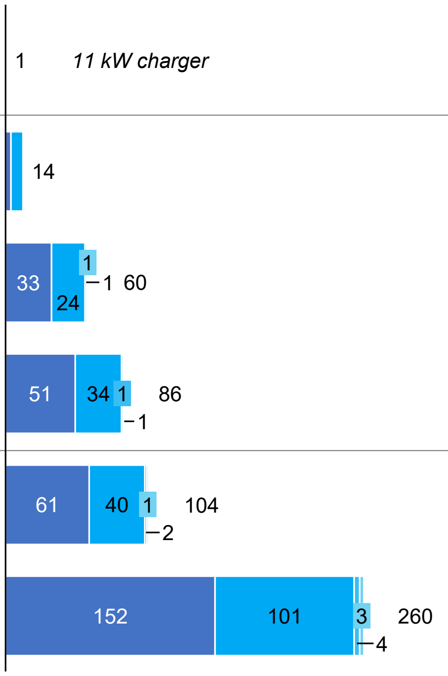
Exhibit 27: The per kW cost of installing chargers varies from €125 for AC 4-22 kW chargers to €260 for DC 1 MW chargers

Capex for different charger types in 2030

Excludes grid investments

🟦 Hardware 🟦 Installation 🟦 Planning and engineering 🟦 Administration

Technology	**Description**	**Charger capex,** € thousands	**Cost per kW of capacity, €**
AC 4-22 kW	Separate wallbox wired to home's electricity supply or public station wired to lamp post for curbside overnight charging	1 *11 kW charger*	**125**
DC 25 kW	Standalone fast charging stations – these can range from 25 kW to 350 kW, and charge for a range of ~100-200 km in ~10-20 minutes depending on the charger and the vehicle	14	**558**
DC 150 kW		60	**400**
DC 350 kW		86	**247**
DC 500+ kW	Standalone fast charging stations currently ~500 kW are ready for commercial use (trucks)	104	**208**
	In the next 2-3 years, the ~1MW will become commercially available	260	**260**



1. These numbers are averages and great variability may arise due to local differences

Source: Selected RFPs, expert interviews

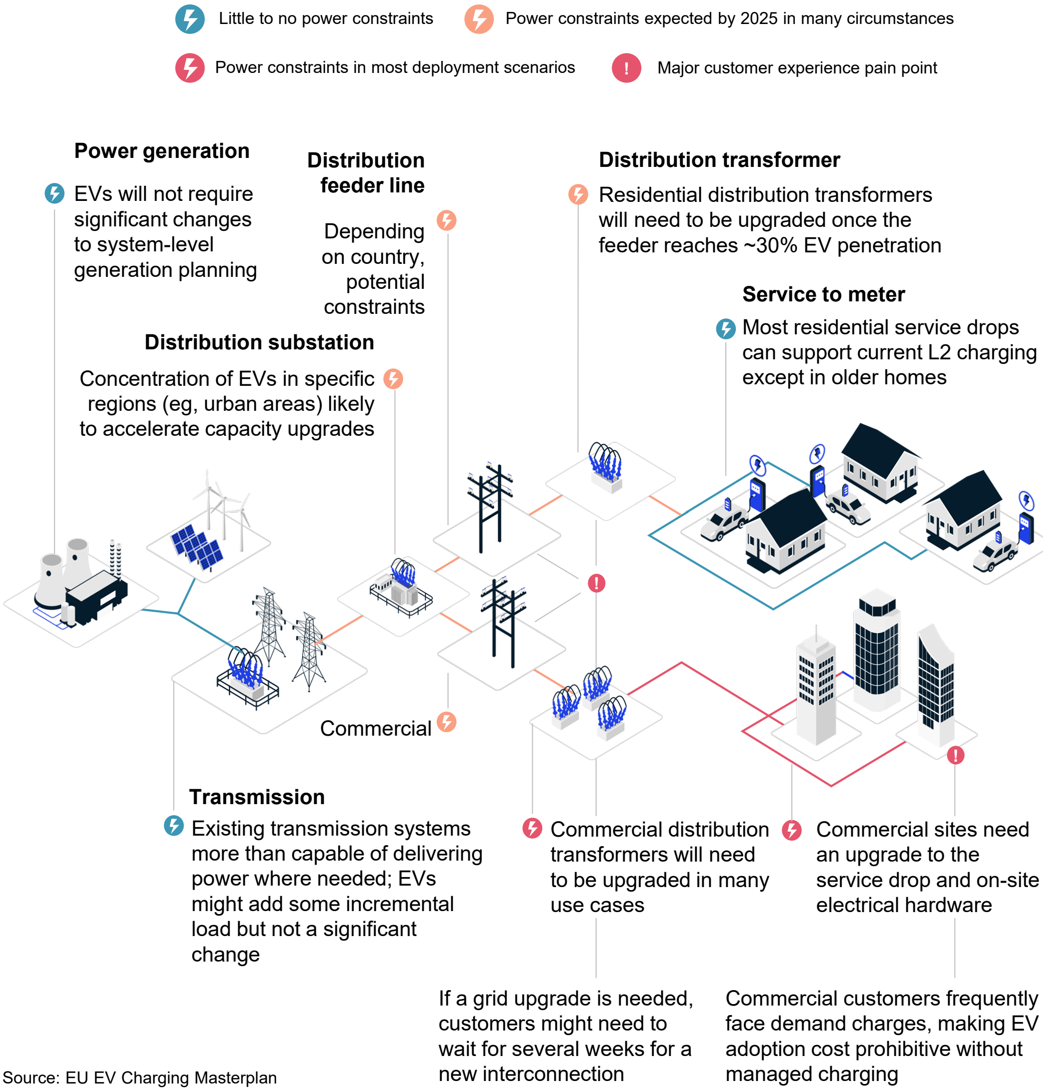
C. Electricity grid upgrades and energy supply

1. Electricity grid upgrades and investments

To support the development of e-mobility and the rollout of EVCI, grid reinforcement will be necessary before connecting chargers to the electricity network. This reinforcement will ensure EVs are effectively integrated into the power system, guaranteeing that the required power quality and security levels can be maintained (Exhibit 28). While the whole electricity network consists of both transmission (carrying high-voltage electricity from a power plant to a substation) and distribution systems (carrying medium- and low-voltage electricity from substations to end consumers), only distribution systems are likely to be upgraded due to e-mobility. As such, all investments referred to in this chapter only consider this latter part of the network, and all estimates refer to upgrades strictly related to e-mobility, namely grid capacity extensions, smart charging, and vehicle-to-grid charging functionality. Investments in smart meters, digitization, automation, modernization, or resilience upgrades are not included. However, these latter investments are critical and will act as enablers, as e-mobility investments will take place in tandem with generic grid upgrades.

With the distribution network consisting of medium- and low-voltage grids, the most common upgrades will be transformer upgrades, modifications, and network extensions at low-voltage grids, which is where slow chargers will be connected. Since slow charging is typically associated with a high level of simultaneous usage (in residential and commercial transformers), the low-voltage grid is where peak power issues will be most critical, and the largest congestion is expected. However, fast chargers are connected to the medium-voltage grid, which typically has sufficient capacity. Congestion issues are only likely to cause concern when several fast chargers are close to each other, and all have the same connection to the medium-voltage grid. On average, the addition of EV loads will accelerate the reinforcement of the medium-voltage grid. However, e-mobility will not be the primary driver for such reinforcements, which will mainly be driven by electrification unrelated to e-mobility (for example, heating).

Exhibit 28: An extensive number of grid upgrades on the distribution network will be required



Power generation

EVs will not require significant changes to system-level generation planning

Distribution feeder line

Depending on country, potential constraints

Distribution transformer

Residential distribution transformers will need to be upgraded once the feeder reaches ~30% EV penetration

Service to meter

Most residential service drops can support current L2 charging except in older homes

Distribution substation

Concentration of EVs in specific regions (eg, urban areas) likely to accelerate capacity upgrades

Commercial

Transmission

Existing transmission systems more than capable of delivering power where needed; EVs might add some incremental load but not a significant change

Commercial distribution transformers will need to be upgraded in many use cases

Commercial sites need an upgrade to the service drop and on-site electrical hardware

If a grid upgrade is needed, customers might need to wait for several weeks for a new interconnection

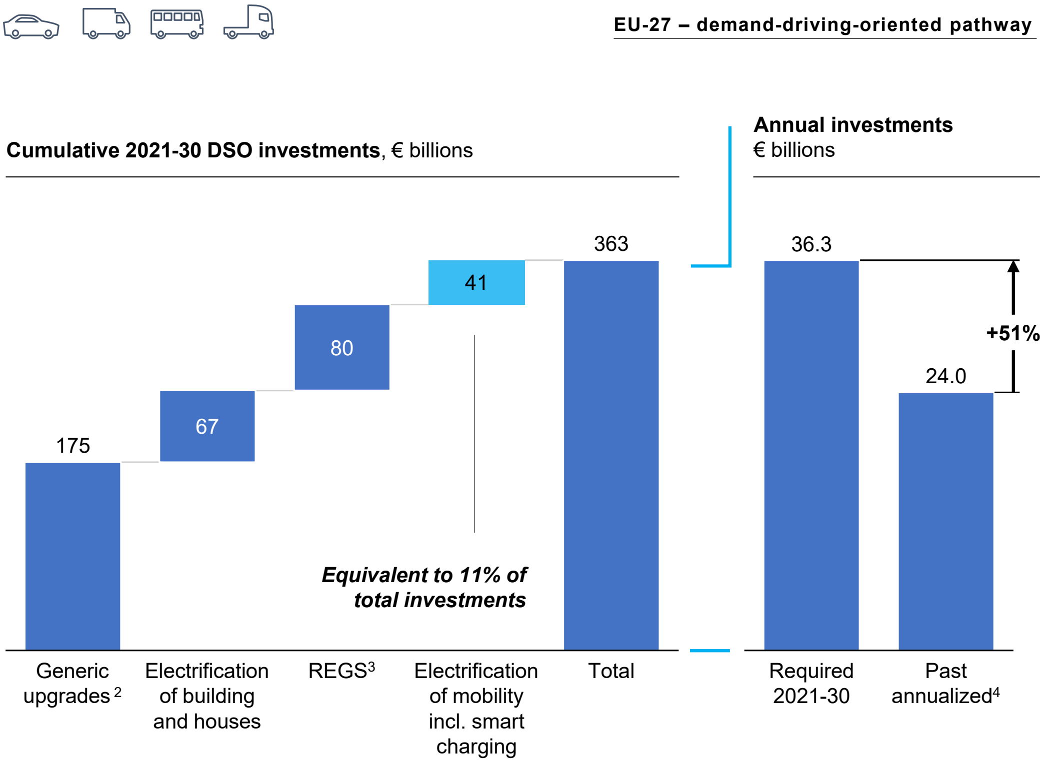
Commercial customers frequently face demand charges, making EV adoption cost prohibitive without managed charging

Source: EU EV Charging Masterplan

Expected cumulative investments into grid upgrades between 2021 and 2030 have been calculated as €41 billion (€900 per EV on the road), 11% of total annual investments of €363 billion (Exhibit 29). Thus, over the ten years between 2021 and 2030, yearly grid upgrades related to e-mobility amount to €4.1 billion. With 2015 DSO investments of €24 billion, total annual investments are expected to increase by 51% to reach the required €36 billion. It must be noted that between 2021 and 2030, a linear increase is unlikely, but rather an increase in part dependent on EV market share. Step functions are, for example, expected to take place in 2025, 2028, and 2030 where the EV share of the total vehicle parc is expected to exceed 5%, 10%, and 15%, respectively. However, minimizing the peak load via smart-charging solutions can reduce the number of grid reinforcements. Smart charging facilitates a reduction in grid investments, especially for slow home, workplace, and fleet-depot charging, where vehicles are parked and connected to the charger for a prolonged period. By 2030, smart charging, centrally controlling the times at which the vehicle charges, will be widely rolled out. Bidirectional charging, which allows discharging where vehicles also provide electricity to the grid, will similarly play a role.

Smart charging can actively balance the grid and avoid peaks, reducing the required grid investments.

Exhibit 29: €41 bn DSO investments into upgrades for EV charging by 2030, ~10% of total investments



€41 bn

cumulative e-mobility grid investments until 2030

11%

of total DSO[1] investments needed for electrification of mobility

1. Distribution system operator
2. Such upgrades include smart metering, grid modernization, digitization and automation, resilience, and storage
3. Renewable energy generation systems
4. Historicals refer to 2015

Source: Eurelectric 2020 study, a top-down estimate that uses EVCI model energy demand, and a bottom-up estimate based on EVCI model charging locations, European Commission, expert interviews, EU EV Charging Masterplan

Due to the number of slow chargers connected to the low-voltage grid at home and the workplace, it is in these two charging locations where approximately 75% of the investments originate (€30 billion). The investments are related to upgrades of lines and transformers. Line upgrades refer to the replacement of existing cables and overhead lines and the extension of the meshing of the grid. For transformer upgrades, the nominal power of transformers can be increased by replacement or by adding switchgears or switchboards. The €30 billion for home and workplace charging upgrades are thus mainly driven by excavation costs and civil works associated with cable upgrades and the material and installation costs of the transformers themselves. The remaining 25% of investments are related to public fast chargers connected to the medium-voltage grid, which typically refer to transformer upgrades at high- or medium-voltage substations. Negligible investments are expected to be needed for public overnight charging since analyses suggest that by 2030 these charging needs can be met with regular modernization of the grid (Exhibit 30). Commercial vehicle charging normally occurs around noon at public fast chargers or at night in depots or in private fleet depots.

Exhibit 30: Grid upgrade investments until 2030 equate to an average cost of €1,000 per charging point

Location	**Grid upgrade required**[1]	**Cumulative 2030 cost,** € billions	Share of total cost[2]	**Cumulative 2030 cost/charging point**, € thousands
Home	Upgrade of residential transformers (between 50 kVA and 100 kVA), and addition of lines	22	54%	1
Work	Upgrade of commercial transformers (typically 100 kVA), and addition of lines	8	20%	6
Public fast	Upgrade of 5+ MVA transformers, and network extension	10	24%	14
Public overnight	No grid upgrades applicable	<1	0%	<1
Fleet depot	Upgrade of 5+ MVA transformers upgrade per fleet depot	1	<1%	<1
Retail and destination	Upgrade of commercial transformers (typically 100 kVA), and addition of lines	1	<1%	<1
Total		41	100%	1

---

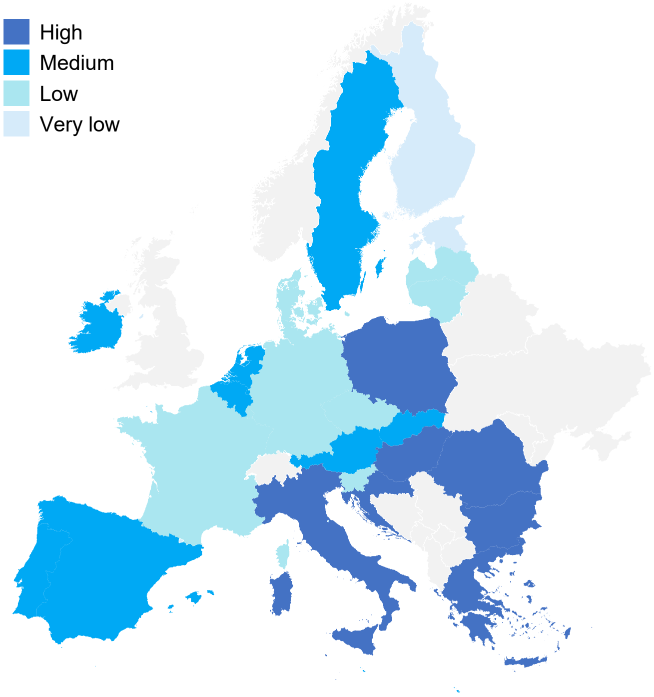
1. Detailed logic relies on number of chargers, penetration of EVs, concentration of EVs, size of charging hub, and average load of transformers
2. Total % does not sum to 100% due to rounding errors

Source: Web search, expert interviews, EU EV Charging Masterplan

An index to measure the grid's reliability and the continuity of the power supply is the System Average Interruption Frequency Index (SAIFI). This indicator measures the average number of service interruptions experienced by a customer annually. Countries with the highest power supply continuity had a SAIFI of less than 0.25 in 2020, those with the lowest power supply continuity had a SAIFI greater than 1.0 (Exhibit 31). On average, SAIFI has decreased over the past years, indicating that DSOs have dealt with increasing volumes of distributed generation despite an aging grid and increased climate hazards. Country differences also exist, with some countries lagging in grid reliability. In addition, DSOs are expected to be challenged further with the EVCI rollout to keep the network running smoothly. As a result, increased system flexibility will be critical to guarantee the grid's stability.

Exhibit 31: Country differences regarding grid stability have been considered

2020 SAIFI[1] country overview



SAIFI is used as proxy for continuity of power supply and thus for readiness of the grid for EVCI rollout

SAIFI measures the average number of service interruptions experienced by a customer in one year

There has been an average improvement in continuity of supply seen since 2015, indicating positive impact of investments on distribution networks

0.92 **Average 2020 EU-27 SAIFI index**

Key insights

So far, DSOs have been able to deal with rising volumes of distributed generation even in the presence of an ageing grid and more frequent climate hazards (eg, due to grid strengthening)

With EVCI rollout, DSOs will be challenged further in order to:

- Keep the network running smoothly
- Maintain and upgrade the infrastructure

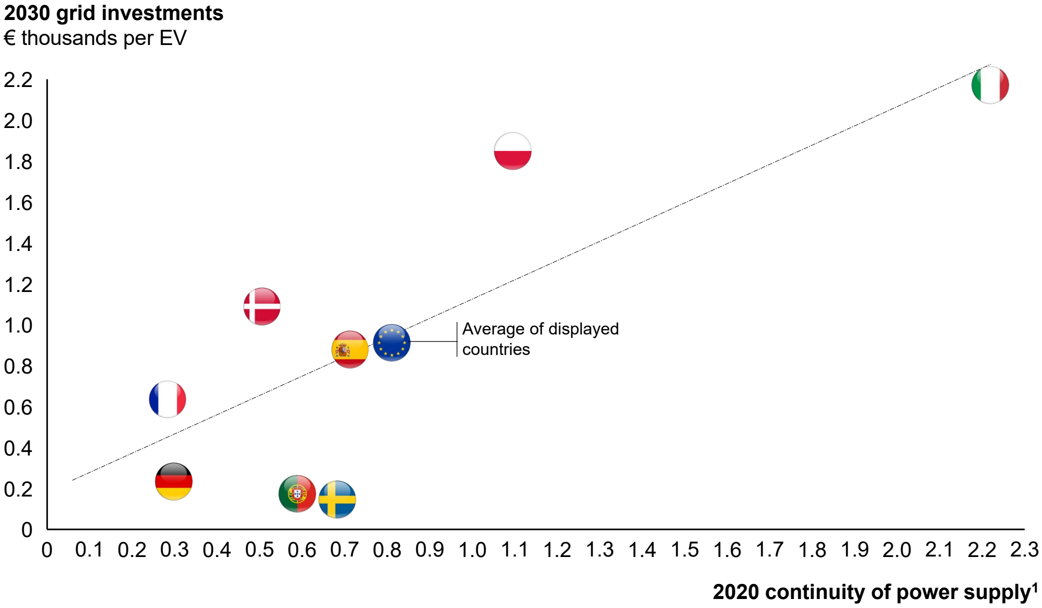
Increased system flexibility will be key to guarantee stability of the grid

1. System Average Interruption Frequency Indices, high: 1; medium: 0.5-1; low: 0.25-0.5; very low: <0.25; for Belgium, 2019 data was used as 2020 data was not available

Source: World Bank, Eurelectric, CEER

The medium- and low-voltage grids are not uniform across countries; cross-country differences exist as grid size and capacity are influenced by country-specific factors, including the infrastructure's age, population density, and electrification levels (for example, heating). For instance, fewer concerns are expected around distribution grid capacity for countries with widespread electric heating. To understand how the €41 billion differ between countries, country power supply continuity was used as a proxy since the data suggests a correlation between SAIFI (and thus power supply continuity) and grid investment per country (Exhibit 32). This correlation informed the calculations underlying countries' investment needs. For example, of all countries displayed in Exhibit 32, Italy is estimated to have the highest investment needs, in line with being the country with the highest 2020 SAIFI of 2.2.

Exhibit 32: There is some evidence of correlation between the investments in grid upgrades and continuity of power supply



Key insights

0.65 R^2 correlation between expected grid upgrade investments per EV by 2030 and continuity of power supply[1]

Of the selected countries, Italy shows the highest power supply continuity, and the highest investment needs of €2.2 k per EV. The average investment need of all selected countries is €0.9 k per EV

[1] SAIFI used to quantify power supply continuity

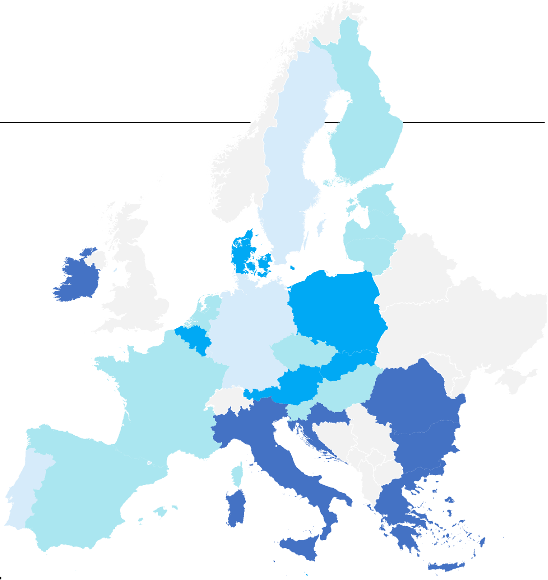
Source: The World Bank, Eurelectric 2020 study, a top-down estimate that uses EVCI model energy demand, and a bottom-up estimate based on EVCI model charging locations, EU EV Charging Masterplan

As a result of such calculations, differences across countries have been quantified in terms of € billion investments and € per EV investments (Exhibit 33). For example, Ireland requires the largest investment per EV at €5,100, almost six times greater than the EU average of €900 per EV. Similarly, Italy requires a total investment of €9 billion from 2021 to 2030, which is around 20% of the total investment. As previously mentioned, such country differences are expected due to differing grid conditions. For example, Ireland's high investment needs are associated with the low-voltage reinforcement needs due to the rural spread of the population. On the other hand, Sweden has the lowest investment needs per EV at €100 since the grid can integrate most charging needs until 2030, and 50% of EVs adjust charging time according to charging cost and thus reduce their impact on the grid.

Exhibit 33: Grid upgrade investments until 2030 vary highly by country

2021-30 country investments in distribution grids[1], € thousands/EV parc[2]

- 🟦 High
- 🟦 Medium
- 🟦 Low
- ⬜ Very low



2021-30 investments in distribution grids due to e-mobility, € k/EV parc[2]		**2021-30 investments,** € billions	**Description**
Ireland	5.1	3	Large proportion of residential charging points due to rural spread of customers resulting in high investments to reinforce the LV grid in particular
Italy	2.2	9	~30% of households with an EV will require additional connection capacity to charge their vehicles
Poland	1.9	3	Low impact of charging infrastructure on the grids as most residential charging is assumed to happen at off-peak hours (especially at night)
Denmark	1.1	1	Electricity demand (not exclusively related to e-mobility) is expected to grow at 6.1% CAGR
Spain	0.9	3	With 2021 EV penetration below 1%, moderate EV uptake expected up to 2030, where EV penetration will reach 10%; major penetration after 2030
Hungary	0.6	<0.5	With 2021 EV penetration below 1%, moderate EV uptake expected up to 2030, where EV penetration will reach 10%; major penetration after 2030
France	0.6	6	With 2021 EV penetration at less than 2%, significant EV uptake expected up to 2030, where EV penetration will reach 24%
Germany	0.2	3	Most of the charging points expected in urban areas; urban grids have spare capacity to integrate most of the charging points
Portugal	0.2	<0.5	With 2021 EV penetration at less than 1%, moderate EV uptake expected up to 2030, where EV penetration will reach 14%
Sweden	0.1	<0.5	The grid has capacity to integrate majority of charging needs by 2030; 50% of EVs smart charge during off-peak hours
Other[3]	1.2	12	
Average	0.9	41	

1. High: >€2,000/EV; medium: €1,000-2,000/EV; low: €500-1,000/EV; very low: <€500/EV
2. PCs, LCVs, and CVs parc (number of vehicles)
3. Investments of countries in the "other" category are scaled according to SAIFI and the System Average Interruption Duration Index

Source: EU EV Charging Masterplan, Eurelectric 2020 study and SAIFI

2. Renewable energy power generation and investments

According to McKinsey estimates, 57% of the total electricity supply (1,721 TWh) will be generated by renewable energy sources by 2030. The dominant renewable energy sources will be solar (470 TWh) and wind (806 TWh), while the remaining 445 TWh will be supplied by biomass and hydropower. Overall electricity consumption in the EU-27 will rise in line with electricity generation, resulting in around 2,813 TWh of consumption (demand) in 2030, 93% of the total electricity generated.

Electricity demand created by EV charging is likely to increase from 9 TWh in 2021 to 165 TWh in 2030 (Exhibit 34). This increase of 165 TWh represents 6% of the expected EU-27 electricity consumption in 2030.

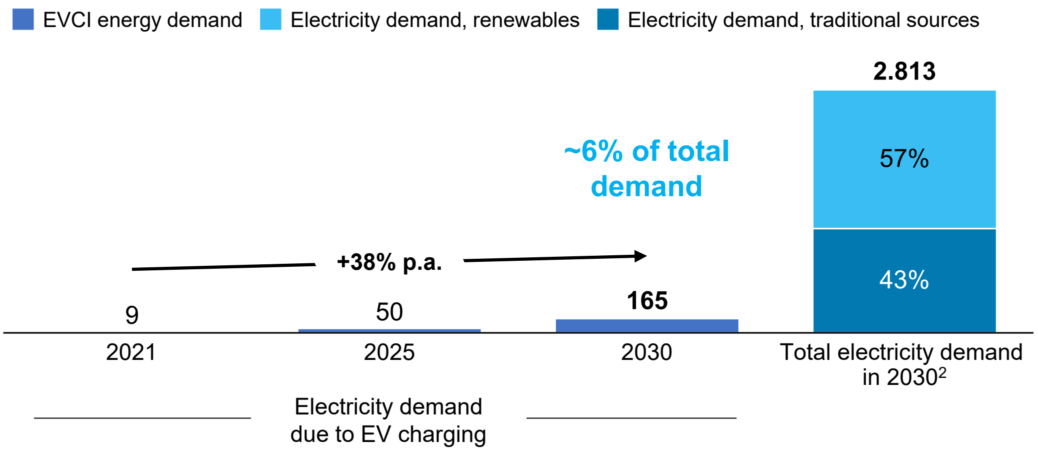
In the full contribution case, it is assumed that by 2030, the additional 75 GW demand from EV charging will be met entirely by renewable energy sources, namely solar and wind. All renewable energy is supplied by newly installed solar and wind capacity. This 75 GW will be made up of 44 GW from solar, 22 GW from wind onshore, and 9 GW from wind offshore. The cumulative investment needed by 2030 would be €69 billion in the full contribution case. This €69 billion investment represents around 18% of the EU-27's total investments in renewable energy sources by 2030 (€375 billion).

In the fair contribution case, the €69 billion investment could be reduced by around 57% to €30 billion, considering the current and expected contribution of other traditional energy sources to the electricity generation mix (around 43%) and leveraging the existing capacity of other nonscalable renewables, such as hydropower and biomass (approximately 14%).

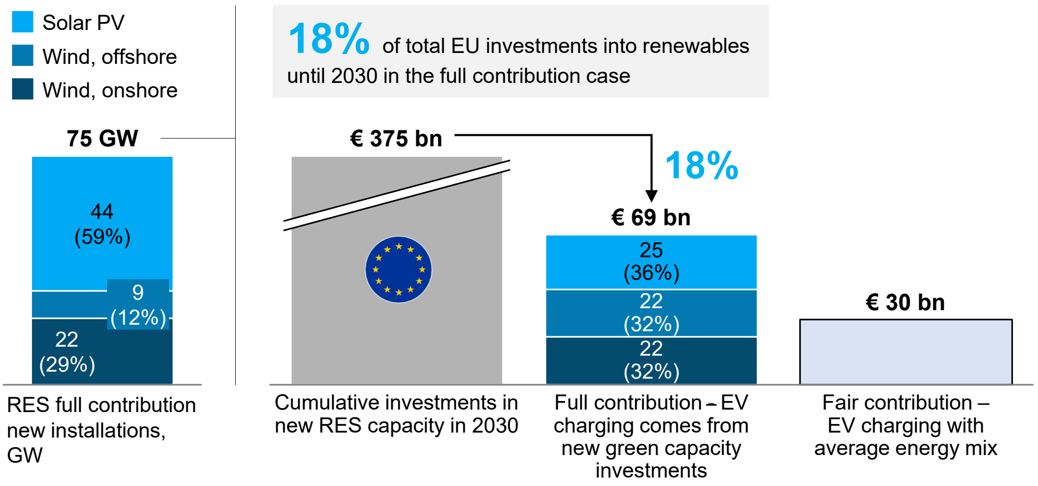
Exhibit 34: Deployment of renewable power will require €69 billion investments by 2030

EU-27 – demand-driving-oriented pathway

Electricity demand due to EV charging infrastructure in 2030[1], TWh



Cumulative investments in renewables by 2030, € billions



1. The analysis assumes that additional installed capacity is renewable energy sources, but nuclear could also be used for decarbonizing electricity
2. Based on electricity production split between renewables and traditional sources

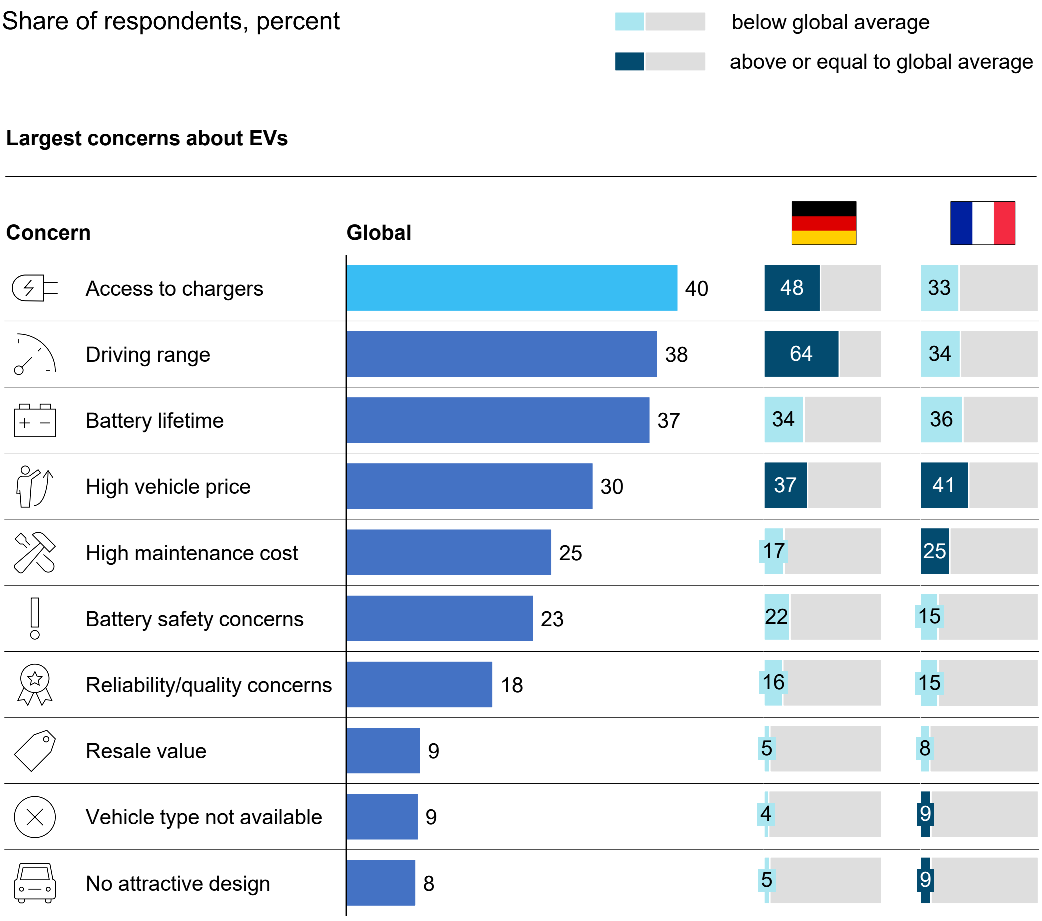
Source: EU EV Charging Masterplan, McKinsey Global Energy Perspectives, WindEurope, SolarPower Europe

D. Key interventions

1. Consumer concerns around charging

Being aware of and addressing consumer concerns will be critical in reassuring consumers and ensuring a smooth rollout of EVCI. A McKinsey 2021 consumer survey shows that besides high vehicle prices of EVs, access to chargers and driving range are key concerns. By building an accessible and fast charging infrastructure the concerns around access to chargers and driving range can be alleviated.

Exhibit 35: Multiple consumer concerns around EVs exist, with the primary concerns being access to EV charging infrastructure, driving range and high vehicle prices

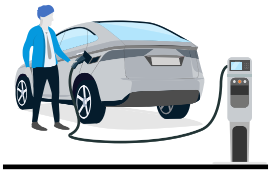


Source: McKinsey Center for Future Mobility 2021 Consumer Survey

Public charging concerns can be divided into three distinct categories: charger localization, charger access, and charging experience (Exhibit 35). As for the former, drivers encounter difficulties localizing chargers, with 47% of Italian, French, and Spanish EV drivers frustrated by this process. Creating accurate real-time dashboards with centralized information from multiple operators has been identified as the most effective mitigating measure. As for charger access, consumer concerns include fears that the plug type may be incompatible or that the charger may be inaccessible (for example, due to plugged-in and charged EVs). 44% of Italian, French, and Spanish EV drivers are frustrated by waiting for an available charger. Such concerns could be mitigated by enforcing adequate restrictions to avoid blockage and by using time-based tariffs to avoid chargers occupied by fully charged vehicles. Lastly, during the charging experience itself, 65% of Norwegian EV owners consider charging costs as the first key buying factor. In addition to the cost itself, consumers are concerned about incompatible payment methods and accounts or location safety and comfort. The standardization and ease of use of payment systems (for example, through “one-click payment ”) and the increased transparency of charging point location (with regard to safety and comfort) could help mitigate such causes of anxiety and facilitate a seamless interoperability of charging stations.

Exhibit 36: Public charging is associated with pain points attributed to charger localization, access, and charging experience

Public charging **Not exhaustive**

Step	**Localization**	**Access**	**Charging**
Pain points	Real-time information on charger location, availability, and working status	Charger blocked by vehicle or by plugged-in EV not charging, or plug may not be compatible	Incompatible payment methods, limited cost transparency, feeling uncomfortable during charging (eg, due to unlit area)
	47% of EV owners are frustrated by locating and driving to chargers 🇮🇹 🇫🇷 🇪🇸	44% of EV owners are frustrated by waiting for a free charger 🇮🇹 🇫🇷 🇪🇸	65% of EV owners consider charging cost as the first key buying factor 🇳🇴
Inter-vention	Ensure real-time maps are available that centralize information[1] from multiple operators onto one single platform	Enforce adequate restrictions to avoid charger blockage; use time-based tariffs to avoid EVs plugged in without charging	Standardize payments and accounts, and ensure chargers are in well-lit and comfortable areas
			

1. Including location, availability, working status

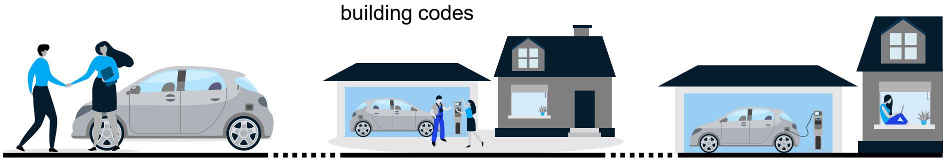
Source: F2M eSolutions customer survey (n = 303 respondents), EVCI Norwegian customer survey (n = 200 respondents)

Home charging concerns have also been split into three categories: charger installation feasibility, charger installation, and charging experience. As for the former, approximately 50% of EV car owners in cities are not expected to install a home charger. Local laws may act as barriers to installation (such as monument protection), as could resistance from co-owners in multi-family homes. Two equally effective interventions are strengthening EV-ready building codes and introducing a “right to socket.” As for the installation, 65% of EV owners in Germany and the United Kingdom consider efficient installation as one of the essential criteria for home charging; enforcing clear guidelines around the installation is recommended to guarantee this. Lastly, room for improvement exists around the home charging experience itself, with 85% of EV owners in Germany and the United Kingdom considering cost as one of the most important criteria for home charging. A call for action is required to increase the transparency of costs of installing and charging point usage, which could also serve as a way to increase consumer awareness of the financial benefits associated with charging off-peak, reducing the expected impact on the grid.

Exhibit 37: Home charging is associated with pain points attributed to feasibility, installation, and charging experience

Home charging **Not exhaustive**

Step	**Feasibility**	**Installation**	**Charging**
Pain points	Assessing feasibility of charger installation and costs in single/multi-family homes	Finding a certified installer and understanding end-to-end installation process	Having transparency on charging costs and servicing needs, and limited charging access due to plugged-in EV not charging
	50% of car owners in cities are not expected to be able to install a charger at home 🇪🇺	**65%** of EV owners consider efficient installation as one of the most important criteria for home charging 🇩🇪 🇬🇧	**85%** of EV owners consider cost as one of the most important criteria for home charging 🇩🇪 🇬🇧
Inter-vention	Strengthen EV-ready building codes; introduce a “right to a charging spot”	Ensure clear guidelines are in place to inform consumers as necessary; strengthen EV-ready building codes	Make cost, and status/ availability of chargers transparent as a standard feature of chargers[1]



1. This would also serve to incentivize smart charging

Source: Fleet manager survey in Germany and UK (n = 40)

Numerous stakeholders, including governments, CPOs, and OEMs, that are already taking action have been identified to minimize user concerns around charging (Exhibit 38). As for public charging, Zap-Map facilitates localization in the United Kingdom by displaying information on more than 95% of charging points, of which around 70% show live availability. ChargePoint has also implemented a strategy to reduce EV-driver waiting times: a driver signs up to a “waitlist” and gets notified as soon as the driver before has finished charging. In parallel, the driver who has completed their charging is notified to move their EV. Actions are also being taken to mitigate concerns attributed to home charging: a 2020 EU Directive requires the EU Member States to implement their own EV-ready building policies by 2025. This will inevitably serve as one way to increase the feasibility and speed of home charger installation. France and Spain are two countries that have also introduced a “right to socket.” Regarding the installation process itself, the Mobility House and Zeplug are two companies that support customers throughout the end-to-end installation process.

Exhibit 38: Several stakeholders are taking action to address consumer pain points

Charging location	Step	Best practice example	
Public	Localization	ZAP MAP	UK app with 95%+ of public charge points and ~70% showing live availability
	Access	chargepoint	Drivers get a message when their EV is charged, asking them to move it; the next driver on the waitlist is notified and the charger held for the driver
	Charging	TESLA	Tesla enables “plug and charge,” enabling automatic charging after vehicle is connected
Home	Feasibility		Requires EU Member States to implement their own EV-ready building policies by 2025
	Installation	THE MOBILITY HOUSE	Supports customers through charger planning, building, and operation
		ZEPLUG	Supports customers through end-to-end home and work installation process
	Charging	ev.energy	The app keeps track of costs, energy, and carbon usage

Source: EU EV Charging Masterplan, expert interviews, Eurelectric, CLEPA

2. Key interventions for accelerating charging infrastructure rollout

Eight critical bottlenecks have been identified for the rollout of the charging infrastructure, five of which are related to long lead times (Exhibit 39). CPOs require around three to 18 months to obtain construction work permits for DC 150 kW or higher chargers, and DSOs need about five to eight months to obtain approvals for network extensions and substation creation. Such approvals are made by permit-granting authorities, including highway bodies, energy or geology local authorities, authorities dealing with archeological studies, and transport ministries. Additional lead times are related to grid connections (for example, in Portugal, up to 20 months may be needed for new transformer delivery and installation) and EVCI hardware delivery (with six to eight months typically necessary across the EU). Also lead times to find qualified electricians for installation are significant. The demand for charging infrastructure installation has more than doubled in 2021, while the number of qualified electricians has not significantly changed.

The three remaining bottlenecks are related to the grid. Limited visibility of user load profiles reduces the opportunities to integrate alternative energy resources into the grid, which could increase blackouts and energy waste in the future. Similarly, capped investments of DSOs (typically as a fixed percentage of revenues) lag investment needs for modernization. This is a particular concern for aging grids, such as the Polish grid built in the 1970s and 1980s. Lastly, the complex DSO landscape that certain countries have (for example, Germany with more than 850 DSOs) leads to significant effort for CPOs to coordinate with diverse stakeholders.

The rollout of renewable electricity, especially photovoltaic panels, faces the same challenges. Permit and approval processes are long, and the lack of qualified electricians also slows down adoption of renewable electricity installations.

Exhibit 39: Eight grid and charging infrastructure bottlenecks have been identified

● High ○ Medium

Bottleneck	Severity	Example	
~3- to 18-month lead times for construction work permits for DC 150+ kW chargers, due to approvals from city planning and highway bodies and local energy/geology authorities, and performance of archaeological studies	●	EVCI setup for DC 150+ kW highway chargers takes ~14 months, of which ~8 months are for acquiring the required planning permissions from the Ministry of Infrastructure and Water Management	🇳🇱
~5- to 8-month lead times for DSO approvals for network extension and substation creation for approvals from city planning, transport/environmental ministries, and authorities dealing with archeological discoveries	●	It takes ~3 months for the project to be assessed and queued by an engineer, then ~3 months for the DSO to secure planning permissions	🇳🇱
Up to 20 months time to get access to grid, also due to shortage and long delivery times of transformers	●	Lead time for delivery and installation of new transformers is 20 months when new substation is required	🇵🇹
+1 month waiting time for installation, due to lack of experienced electricians	●	Electricians are overbooked due to PV and EVCI installations, often waiting +3 weeks	🇩🇪
6+ months to deliver EVCI hardware	○	DC 150 kW chargers have lead time of 6-8 months for hardware delivery	🇪🇺
Limited visibility of user load profiles hinders deployment of smart charging solutions	○	With 5% smart meter penetration rate, DSOs have limited opportunities to predict and evaluate alternative solutions to grid reinforcements (eg, ToU, decentral power solutions)	🇸🇰
Capped investments of DSOs (fixed percentage of revenues) lag behind investment needs for modernization	○	In Poland, DSOs have an obligation to invest each year 10-30% of annual profits, this is insufficient to upgrade grid built in the 1970s and 1980s	🇵🇱
Significant effort by CPOs to coordinate with multiple DSOs across Europe and within countries	○	850+ DSOs throughout Germany require CPOs to follow different processes for deploying EVCI	🇩🇪

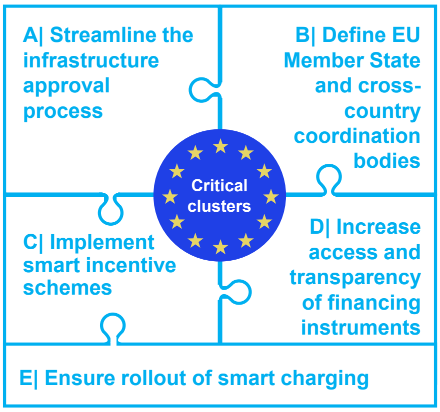
Source: EU EV Charging Masterplan, expert interviews, Eurelectric, CLEPA

The identified consumer challenges and EVCI bottlenecks were used to define five clusters of critical interventions (Exhibit 40). First, the infrastructure planning process requires streamlining in order to reduce long lead times. This could be achieved by standardizing the approval process to minimize the back-and-forth between stakeholders and publishing clear guidelines, illustrating the steps to be taken. Second, EU Member State and cross-country coordination bodies must be established. Such central bodies are vital in overlooking and tracking rollout and could also effectively manage capital allocation as required. An example could be a digital central EU-wide data office that tracks and shares charging infrastructure rollout status, identifies potential bottlenecks for grid and renewable energy production, and develops mitigation measures in collaboration with relevant players. This would improve transparency to all players involved and help to address charging infrastructure rollout issues at an early stage. Two critical clusters are centered around financing: public investments are to be allocated efficiently via smart-incentive programs, and access and transparency of financing instruments is to be increased.

The final cluster is centered on the importance of smart charging. The first stage of smart charging controls the charging of vehicles. It reduces the grid load in times of high electricity demand (load balancing), increases the share of solar power when charging around noon, and reduces charging costs for consumers by introducing time-of-use tariffs. The second stage of smart charging involves vehicle-to-grid charging. In this case, EVs can be discharged to balance the grid and reduce electricity generation in peak times. EV owners that support vehicle-to-grid charging will be financially rewarded for their services. The entire EV ecosystem needs to work together to ensure successful smart-charging capabilities. Charging operators and hardware manufacturers should install and produce smart-charging stations, OEMs and suppliers need to bring the vehicle-to-grid charging technology to the market, and grid players and energy producers need to build the capabilities and promote business models to increase and incentivize the use of smart charging.

Exhibit 40: Five critical clusters of interventions to boost the rollout of the infrastructure have been identified

Example interventions shown



Standardize approval process to minimize back-and-forth between stakeholders, and publish clear guidelines with steps to be taken (eg, Sustainable Transport Forum guidelines)

Devise complementary incentives to EV purchase subsidies for EVCI and grid upgrades

Devise central bodies to track availability and progress of rollout, coordinating efforts and readdressing funds as needed

Facilitate access to financing instruments and increase transparency on financing instruments available for EVCI rollout

Drive rollout of smart charging to reduce load on grid, reduce costs for consumers, and increase share of renewables

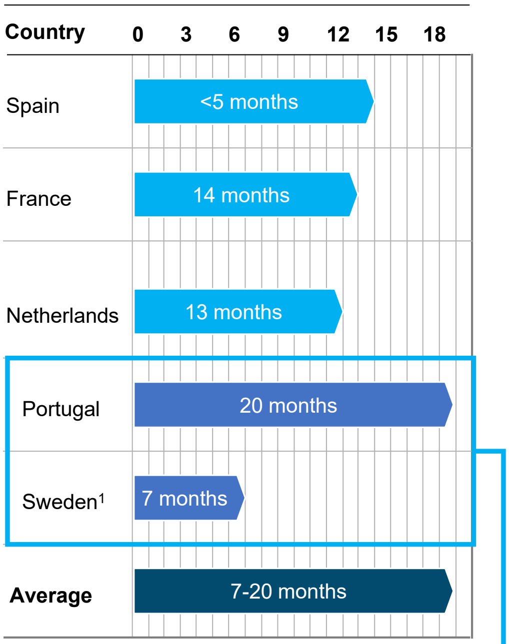
Source: Expert interviews (incl. associations as EIB, Eurelectric, CLEPA, others)

Streamline the infrastructure approval process

Streamlining the infrastructure planning process would play a key role in reducing lead times (Exhibit 41). Regarding the EVCI setup of DC 150 kW or higher chargers, the time necessary can range between seven and 20 months depending on country specificities. Stockholm is a leader in this area, with an average end-to-end installation time of seven months. While the city's planning-oriented approach requires an upfront time investment to identify and publish potential charging locations in collaboration with DSOs, this accelerates CPO planning and feasibility assessments. It also speeds up approval processes since both the DSOs and the city perform high-level feasibility screenings before publishing potential charging point locations. Stockholm's approval time is around three months; in contrast, Portugal requires 12 months. Besides Stockholm's planning-oriented approach, other best practices to streamline installation have been identified. Oslo has a checklist to accelerate project approvals. The Netherlands has a knowledge platform to address concerns quickly. France's "right to a socket" eliminates the back-and-forth required for home installation approvals. Including speed of grid access as an annual efficiency improvement metric for the DSOs could potentially improve lead times attributed to grid upgrades needed for EV charging infrastructure rollout.

Exhibit 41: Streamlining the infrastructure approval process can be achieved by following best practice examples

Time needed to install DC 150+kW chargers on highways, months



Additional best practices for streamlining the infrastructure planning process

Oslo's Agency for Urban Environment has developed a checklist to accelerate project approvals

The Knowledge Platform for Charging Infrastructure allows any questions about installation processes to be addressed, reducing delays

All tenants have a "right to install," meaning that tenants have the right to install charging without seeking permission

Approaches to charger rollout

	Time		
Step	**Sweden[1]**	**Portugal**	**Description**
Location identification and feasibility	2 months	4 months	In Stockholm, the city identifies all potential charging station locations and, in collaboration with the DSO, publishes a map displaying these locations and the estimated cost of connecting them to the grid; in Portugal, CPOs individually perform feasibility assessments
DSO/CPO approvals and DSO lead times	3 months	12 months	Planning approvals and permits are required from city planning and highway bodies and local energy/geology authorities, and archaeological studies must be carried out. In Stockholm, lead times are shorter, as high-level screening/feasibility assessments are performed in the planning phase
Site preparation, installation, and commissioning	2 months	4 months	The charging station operator contacts the grid operator and together, they prepare the area (wiring, foundation, and any other civil work)
Total	7 months	20 months	

1. The 7-month process refers to Stockholm

Source: 2021 International Council on Clean Transport, expert interviews

Define EU Member State and cross-country coordination bodies

The majority of stakeholders in the complex e-mobility landscape require strong collaboration within and across the EU Member States (Exhibit 42). Coalitions are encouraged to have well-defined roles, set clear and tangible deliverables, and engage with customers. Taking the DSO ecosystem as an example, multiple coalitions exist (for example, Eurelectric and E.DSO), and the EU DSO entity is the first to have been mandated by regulation. The entity aims to strengthen the cooperation between Europe's 2,500 DSOs. Centralizing the DSOs will have the additional advantage of creating a forum of expertise to encourage exchanging ideas. Other examples of best-practice collaboration include the CoordiNet project to improve TSO-DSO-consumer collaboration projects, and the EVI-PCP, intending to create a global platform to facilitate cross-city communication.

A central EU-wide data office could be a concrete instrument to measure and steer the e-mobility transition. First, the office should gather, process, and share relevant data to create transparency on EV distribution and the status of charging infrastructure rollout (vs target) on a granular level (ideally on country, region, and zip code level). Second, the data office should identify potential future grid bottlenecks and future renewable energy production capacity needed. Third, it should share this information with relevant players and collaborate with them to accelerate charging infrastructure rollout and develop tailored mitigation measures. Such a data office would improve transparency to all players involved in charging infrastructure rollout and help to address issues early on.

Exhibit 42: The EU DSO Entity is one example of cross-member collaboration to accelerate EVCI rollout

Recommended actions for successful collaboration bodies

Convene a coalition with relevant stakeholders in the e-mobility landscape

Engage with consumers and customers to understand concerns and address questions

Define specific roles for each of the stakeholders

Case study: **EU DSO entity**

With multiple DSO entities coordinating efforts (eg, Eurelectric, E.DSO), the EU DSO entity is the first of these mandated by regulation

With 2,500 DSOs in Europe, the EU DSO entity is aimed at strengthening cooperation between DSOs at EU level

The entity was fully set up in Q1 2021 and aims to:

- Reflect the new central role of DSOs in the energy transition
- Strengthen the cooperation between DSOs
- Create a forum for expertise and exchange of views between DSOs on a range of topics
- Facilitate the DSO/TSO cooperation as well as the technical expertise dialogue with other stakeholders

Additional examples of ongoing collaboration programs

The CoordiNet project aims to establish different coordination programs between TSOs, DSOs, and consumers

The EVI-PCP[2] aims to create a global platform to facilitate communications among global cities interested in stimulating and increasing the uptake of e-mobility[3]

London has set up an EV infrastructure task force as a coalition of stakeholders to jointly work towards EVCI rollout

1. Mobility service providers
2. EVI Global EV Pilot City Programme
3. 15 countries are currently participating in the Electric Vehicles Initiative: Canada, Chile, China, Finland, France, Germany, India, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Sweden, and the United Kingdom

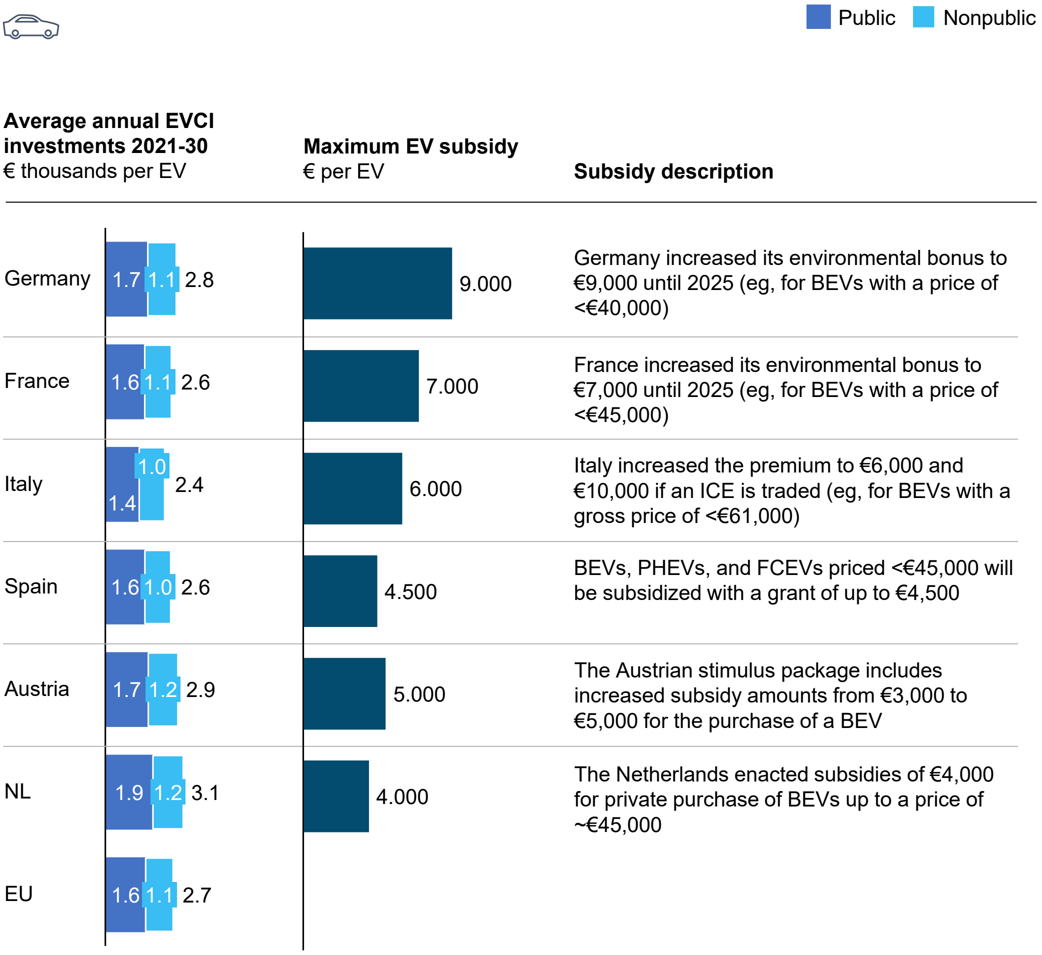
Source: 2021 International Council on Clean Transport, expert interviews

Implement smart incentive programs

Governments are encouraged to ensure efficient capital allocation through smart incentive programs, which can complement purchase subsidies (Exhibit 43). Comparing current EV purchase subsidies to average annual EVCI investments needs of €2,700 per EV by 2030 shows that current subsidies generally exceed such infrastructure investment needs.

Germany, for example, has subsidies of €9,000 per EV purchase and requires €2,800 per EV to be invested in EVCI between 2021 and 2030. While each country has different subsidy and investment needs, they are encouraged to consider grants for EVCI and grid upgrades equally to purchase subsidies. With significant benefits attributed to smart charging capabilities, both in terms of grid congestion and in terms of investments, the possibility of linking subsidies to smart charging capabilities is one to be considered.

Exhibit 43: The investments of charging points will average €2.7 k per EV, lower than subsidies in most countries



	Subsidy description
Germany	Germany increased its environmental bonus to €9,000 until 2025 (eg, for BEVs with a price of <€40,000)
France	France increased its environmental bonus to €7,000 until 2025 (eg, for BEVs with a price of <€45,000)
Italy	Italy increased the premium to €6,000 and €10,000 if an ICE is traded (eg, for BEVs with a gross price of <€61,000)
Spain	BEVs, PHEVs, and FCEVs priced <€45,000 will be subsidized with a grant of up to €4,500
Austria	The Austrian stimulus package includes increased subsidy amounts from €3,000 to €5,000 for the purchase of a BEV
NL	The Netherlands enacted subsidies of €4,000 for private purchase of BEVs up to a price of ~€45,000
EU	

🇩🇪

€9,000

purchase subsidy per new EV within certain criteria

€2,800

in annual infrastructure investments per EV on the road by 2030

3x

larger subsidies than EVCI investment needs

Source: EU EV Charging Masterplan

Increase access and transparency of new financing instruments

This intervention cluster is centered around facilitating access to financing instruments and transparency of what instruments exist for EVCI rollout. More specifically, the EIB is the world's largest multilateral provider of climate finance and plays a significant role in decarbonizing transport in Europe. It has an extensive range of financial instruments (Exhibit 44) to mobilize public and private sector investments for projects of differing risk levels. More transparency should be placed on what these instruments are. Six instruments can be leveraged from the EIB, ranging from public sector financing (where debt loans are issued by government institutions), equity type (investment in a company via purchase of shares), and risk sharing (where public and private funds are both used to manage risks). Instrument selection should be calibrated to specific project criteria.

Exhibit 44: The EIB has an extensive range of instruments to mobilize public and private sector investors, and fund projects of differing risk levels

Financial instruments	Description
Public sector financing	Debt loans through various government and quasi-government institutions
Private sector/ corporate/project finance direct loans	Loans and guarantees made directly to private businesses without government guarantees
Intermediated loans	A local bank or financial intermediary takes out a loan and then lends this money to small firms in its area
Project finance with direct project risk	A loan that relies on the project's cash flow for repayment (project's assets, rights, and interests held as secondary collateral)
Equity type (direct and indirect)	Investment in company via direct or indirect purchase of shares
Risk sharing/blending	Refers to blending of public and private funds that can help reduce the risk

Source: EIB

With the “InnovFin – EU Finance for innovators” initiative launched for the 2014 to 2020 budget period, the EIB has supported more than 140 innovative projects and invested a total of €31 billion since 2014. Recent e-mobility-related investments include lending €17 million to GreenWay to support the expansion of charging stations for EVs in central and eastern Europe, and lending €41.5 million to Galp, a Portuguese energy company, to install 5,500 EV charging points by 2025 (Exhibit 45).

Exhibit 45: The EIB has contributed to financing e-mobility projects in Europe

greenway

The EIB has signed a loan agreement with Greenway, the largest charging provider in CEE, to support the expansion of charging stations

€17 mn loan

50% of total project cost

863 EV charging stations by 2020

> *We are honored to have the support and confidence of the EIB as we pursue our vision for the widespread adoption of electric mobility”*

wenea

The EIB has invested in Wenea, a Spanish charge point operator, to strengthen long-distance and interurban e-mobility in Spain

€50 mn investment

50% of total investment

470 EV charging stations by 2022

31,000 tons per year CO_2 reduction

> *The EIB's support enables us to make a qualitative step forward with Wenea, providing coverage to charge EVs*

galp

The EIB has signed a loan agreement with Galp, a Portuguese energy company, to support the deployment of an EV charging network across Spain and Portugal

€41.5 mn loan

50% of total project cost

5,500 EV charging points by 202

> *The support from EIB is key to help us increase the pace of [our] projects’ development*

Source: EU EV Charging Masterplan

As well as the six financial instruments that have been identified by the EIB, three enablers may be critical in accelerating EV charging infrastructure rollout: “new” asset classes, public private partnerships, and anchor investors (Exhibit 46). Regarding “new” asset classes (for example, a charging infrastructure fund for a confined rollout of charging infrastructure), it is important for them to be well-diversified to enable financing for differing risk levels, and to bundle projects across themes and/or geography. Such project “bundling” may serve as one way to boost initiatives and facilitate access to capital. Public private partnerships may also act as an enabler, by including private-public funds dedicated to EV investments or concession agreements between the public and private sectors. The last enabler refers to anchor investors: investors that would ensure prominent shareholders for projects exist, in turn facilitating access to capital.

Exhibit 46: Various enablers can be used to accelerate charging infrastructure rollout

Enablers	Description
Asset classes	**Define diversified assets** that enable access to financing for differing risk levels (eg, grants, guarantees, quasi-equity loans, venture debt)
	Set up thematic and/or geographic investment platforms to bundle projects and boost initiatives; include first loss coverage from specific sources as necessary
Public-private partnership	**Create schemes with public sector financing** (eg, private-public fund dedicated to EV investments where both private and public sector become shareholders)
	Leverage concession agreements between public and private sectors (where final user of service pays private partner with limited remuneration from public sector)
Anchor investors	**Ensure prominent shareholders for projects exist** (eg, by creating a clear value proposition centered around portfolio diversification)
	Attract stakeholders that can in turn facilitate access to capital (eg, use financial intermediaries to channel institutional investors’ money towards EVCI projects)

Source: 2021 International Council on Clean Transport, European Court of Auditors, European Commission

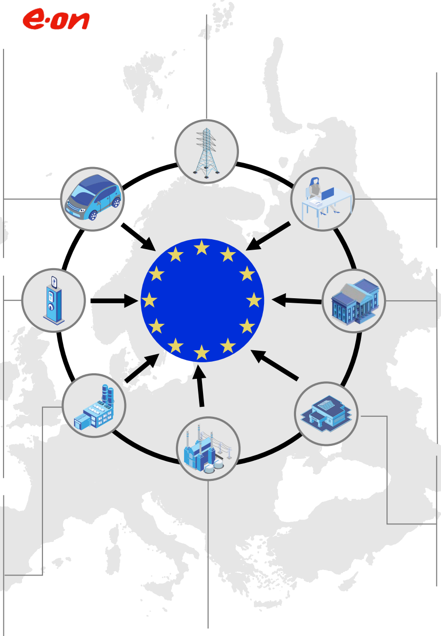
It must be noted that the need for third- and fourth-intervention clusters could be minimized with solutions such as ultra-slow charging and smart charging, which reduce investment needs. For this intervention cluster, much can be learned from telecommunications: many countries issue licenses or rights to firms to run mobile networks, and, in return, the networks built must abide by specific schedules. According to the Economist, the past two decades have seen cumulative investments of €3.5 trillion globally on telecommunications infrastructure, investments that have inevitably played a part in rendering the mobile phone the widespread object it is today.

E. Conclusion and outlook

The EU is on the right track to making zero-emission transport a reality and meeting its targets. While the EU's e-mobility players cannot predict what the future holds, they can strategically act to shape the transformation towards 2050 climate neutrality. With this transformation proceeding at an unprecedented speed and cutting across stakeholders and industries, a sophisticated degree of planning is required. The key to success will thus be to embrace collaboration. New competitive interactions, cross-sector partnerships, alliances, and coalitions across the e-mobility landscape will ensure that one single and coherent EU-wide pathway is adopted toward net-zero.

It is only by working together that the necessary support framework and financing schemes to drive consumers and transport operators towards a green mobility future can be devised. As per the financing schemes, all stakeholders may provide their contribution to the €280 billion required investments (Exhibit 47). The private sector, including automotive OEMs, CPOs, oil and gas players, and energy producers, may provide financial support. Likewise, the public sector may also play its role via EU institutions such as the EIB and the 27 Member States themselves. Investment funds which may span the public-private landscape may also contribute towards these investment needs.

Exhibit 47: A diverse set of stakeholders can contribute to the investments required for the Masterplan



Grid players: As well as installing intelligent home EV chargers, E.ON has a network of over 36,000 charging stations across the UK and Europe

OEMs: BMW, Ford, Hyundai, Mercedes-Benz, and Volkswagen Group founded Ionity in 2017

EU institutions: The EIB has invested €50 mn in Wenea, a Spanish CPO, to deploy 470 charging stations in Spain by 2022

CPOs: Allego is continuously investing in and expanding the size of its network, it has deployed over 26,000 charging ports across 12 European countries

Member States: The Italian government is expected to invest €750 mn in EVCI roll-out between 2021 and 2030

Oil and gas players: BP in 2021 has made a $7 mn investment in EV charging firm IoTecha

Investment funds: In 2021, Ionity has received a €700 mn investment from Blackrock

Energy producers: In 2020, EDF has acquired a majority stake in Pod Point, one of the largest CPOs in the UK

Source: EU EV Charging Masterplan

Over the past 12 months, the EU has accelerated its transition to e-mobility. The nearly 20% EV sales in 2021 have placed Europe at the forefront of electrification (ahead of China and the United States). Over the coming decade, Europe has the chance to create a world leading ecosystem for zero emission mobility. If all industry stakeholders work together successfully along the lines of this masterplan, Europe can be a role-model for an integrated zero mobility transition: coupling the energy sector, infrastructure, and transport sector, enabling healthy business models along the value chain, creating new jobs, and growing the transport sector GDP contribution. The diversity of the European mobility footprint is a challenge and an opportunity at the same time. Successfully mastering the transition to zero mobility ensures the prosperity of the European society.

Appendix

1. Methodology for modelling charging infrastructure

The EV charging infrastructure model encompasses the implications of the development of the charging network end-to-end, generating an exhaustive set of outcomes to navigate the EU EV Charging Masterplan's road to 2030 (and beyond). Across all vehicle segments, the level of detail for the EVCI figures is the following: pathway, country, vehicle type, archetype, powertrain, vehicle segment, user segment, location, and charging technology (Exhibit 48). The model logics for the EV parc, energy demand, and charging infrastructure network are tailored for PCs (Exhibit 2 in chapter A.), trucks and buses (Exhibits 49 and 50), and LCVs (Exhibit 51).

All the segments share the same logic for assessing the EVCI and renewable energy investments and the TEN-T corridors' EV charging point density mapping.

Exhibit 48: EV Charging Master Plan model: granular overview

Pathway	• Utilization-oriented pathway • Demand-driving-oriented pathway		• Demand-driving-oriented pathway (unique pathway)	
Country	• EU-27 countries			
Archetype	• Cities • Urban followers • Rural areas			
Powertrain	• BEV • PHEV	• BEV		
Vehicle segment	• Corporate and government fleet • Private • Rental • Taxi and ride-share		• Heavy-duty vehicles (HDT) • Medium-duty vehicles (MDT)	
User segment	• E-taxi driver • E-rental car driver • Corporate car EV owner • Private EV owner: only access to public charging • Private EV owner: access to work charging • Private EV owner: access to home charging	• Passenger LCVs • Urban LCVs • Logistics LCVs • SME and utility LCVs • Rental LCVs	• Urban trucks • Regional trucks • Long-haul trucks	• Municipal buses (incl. school buses) • Regional buses and coaches
Location	• Fleet hub • Multi-family home • Single home • Work • Public fast – highway • Public fast – off-highway • Public overnight • Retail and destination (incl. public garages)		• Fleet hub • Multi-family home • Single home • Work • Public fast – highway • Public overnight • Retail and destination (incl. public garages)	
Charger technology	• AC 4-22 kW • DC 25 kW • DC 50 kW • DC 100 kW • DC 150 kW • DC 350 kW • DC 500+ kW			

Source: EU EV Charging Masterplan

2. Tailored methodology for PCs

The driving input of the PC EVCI model is the BEV and PHEV parc (number of vehicles) from 2020 to 2030, available on a country level. The parc is synced with the EU decarbonization targets of –55% CO_2 emissions, including a scenario sensitivity. Six regional archetypes have been identified, with the related parc split (%) customized per country based on industrial and economic KPIs: metropolis, transit-oriented cities, car-reliant cities, multimodal cities, urban followers, and rural areas. The next layer is the vehicles segmentation split (%) per archetype—private, corporate, and government fleets, rental, and taxi and ride-share PCs. This is the primary identifier for the six user segments: private EV owners with access to home charging, private EV owners with access to workplace charging but no home charging, private EV owners with access to public charging only, people who drive above average mileage (for example, salespeople and consultants), and drivers of short-term rental cars. The user segments are the core drivers for mapping the charging behaviors, which ultimately drive the following model bucket, the energy demand.

To quantify the energy demand, PCs' annual distance traveled (kilometers), car efficiency (kWh per kilometer) per country, vehicle segment, and powertrain have been calculated to generate the overall expected energy demand volume (kWh). The model differentiates between two core pathways to understand how energy demand will be supplied: the utilization-oriented pathway (EV charging points are potentially economically viable, and lower public share of energy demand supplied) and the demand-driving-oriented pathway (smooth EV adoption and higher public share of energy demand supplied). The total energy demand has then been split (%) among six charging locations per pathway, vehicle type, powertrain, and user segment: fleet hubs, multi-family and single home, public fast/highway, public fast/off-highway, public overnight, retail, and destination (including public garages), and workplaces. The model includes an adjustment factor for each country's public fast/highway charging location location energy-demand split to mirror the regional infrastructural readiness. Furthermore, for each location and user segment, the energy demand has been divided (%) among five charging technologies: AC 11 kW, DC 25 kW, DC 50 kW, DC 150 kW, and DC 350 kW.

The next model bucket is the charger count (number of chargers). Taking into consideration the power capacity (kW) for each charger technology and the utilization (%) per vehicle type (PC), pathway (the demand-driving-oriented pathway assumes half the average network utilization of the utilization-oriented pathway), charging location, and charging technology, the EVCI Model determines the number of chargers needed to meet the energy demand. Home chargers (both single and multi-family homes) are assumed to depend on yearly EV sales in user segments with access to home charging (for example, private EV owners with access to home charging).

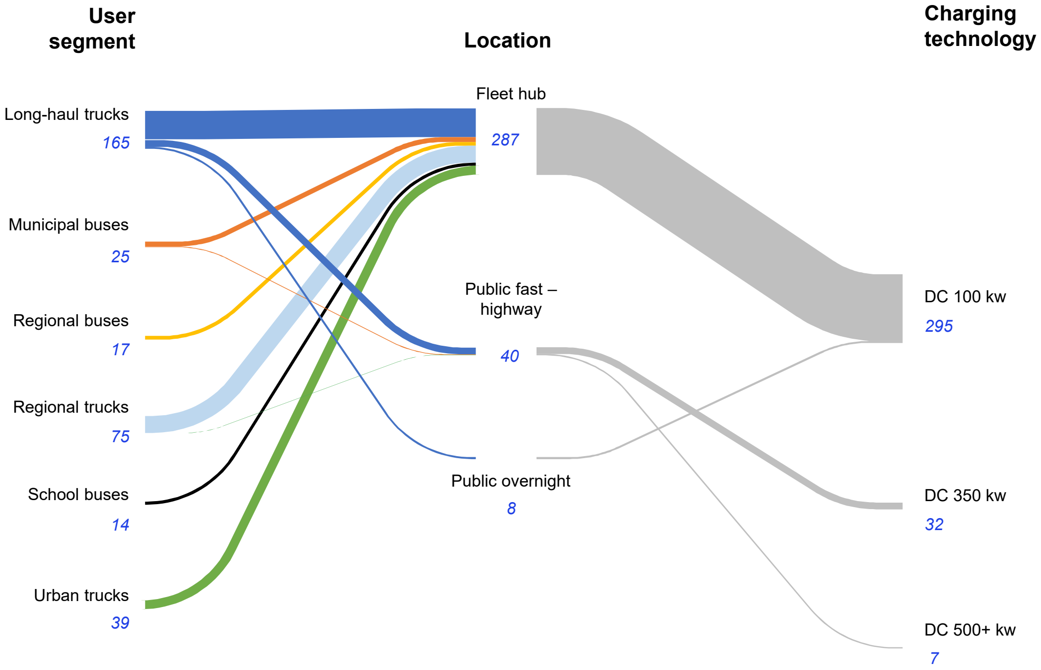
3. Tailored methodology for CVs

The driving input of the PC EVCI model is the BEV parc (number of vehicles) from 2020 to 2030, available on a country level. The parc is synced with the EU decarbonization targets of –30% CO_2 emissions (trucks and buses) and –55% CO_2 emissions (LCVs). Six vehicle segments have been identified, with the related parc split (%) for each vehicle type (trucks, buses, and LCVs): heavy-duty vehicles, medium-duty vehicles, LCVs, municipal buses, and regional buses and coaches. Each vehicle segment has been split (%) between two user segments: vehicles relying on fleet hubs and vehicles relying on public chargers. Based on the vehicle segment, eleven usage archetypes have been identified, with the related parc split (%): urban trucks, regional trucks, long-haul trucks, passenger LCVs, logistics LCVs, SME and utilities LCVs, urban LCVs, rental LCVs, municipal buses, and regional buses and coaches. The archetypes are the core drivers for mapping the charging behaviors, which ultimately drive the following model bucket, the energy demand.

To quantify the energy demand, CVs' annual distance traveled (kilometers), car efficiency (kWh per kilometer) per country, vehicle segment, and archetype have been calculated to generate the overall expected energy demand volume (kWh). The total energy demand has then been split (%) among six charging locations per vehicle type, archetype, powertrain, and user segment: fleet hubs, multi-family and single home, public fast/highway, public fast/off-highway, public overnight, retail, and destination (including public garages), and workplaces. The model includes an adjustment factor for each country's public fast/highway location energy-demand split to mirror the regional infrastructural readiness. Furthermore, for each location and user segment, the energy demand has been divided (%) among different charging technologies (AC, CCS, MCS) and seven charging speeds: AC 11 kW, DC 25 kW, DC 50 kW, DC 100 kW, DC 150 kW, DC 350 kW, and DC 500+ kW.

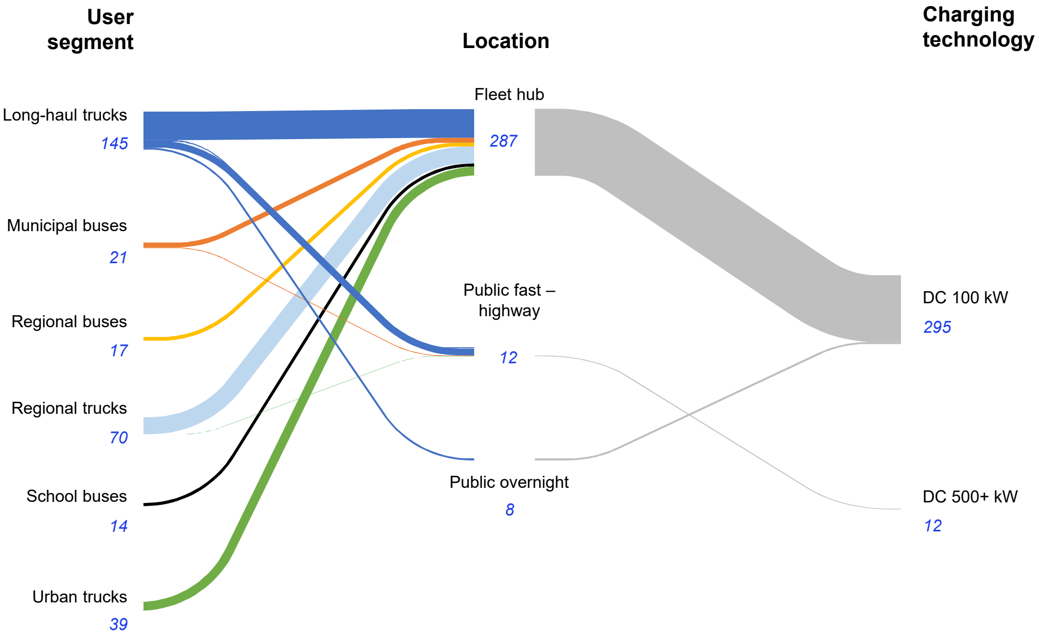
The next model bucket is the charger count (number of chargers). Taking into consideration the power capacity (kW) for each charger technology and the utilization (%) per vehicle type (PC), charging location, and charging technology, the EVCI Model determines the number of chargers needed to meet the energy demand. Fleet hub chargers are assumed to depend on the number of vehicles in the deposits.

Exhibit 49: User segments, charging location and charging power for CVs, trucks and buses, assuming balanced CCS and MCS public chargers



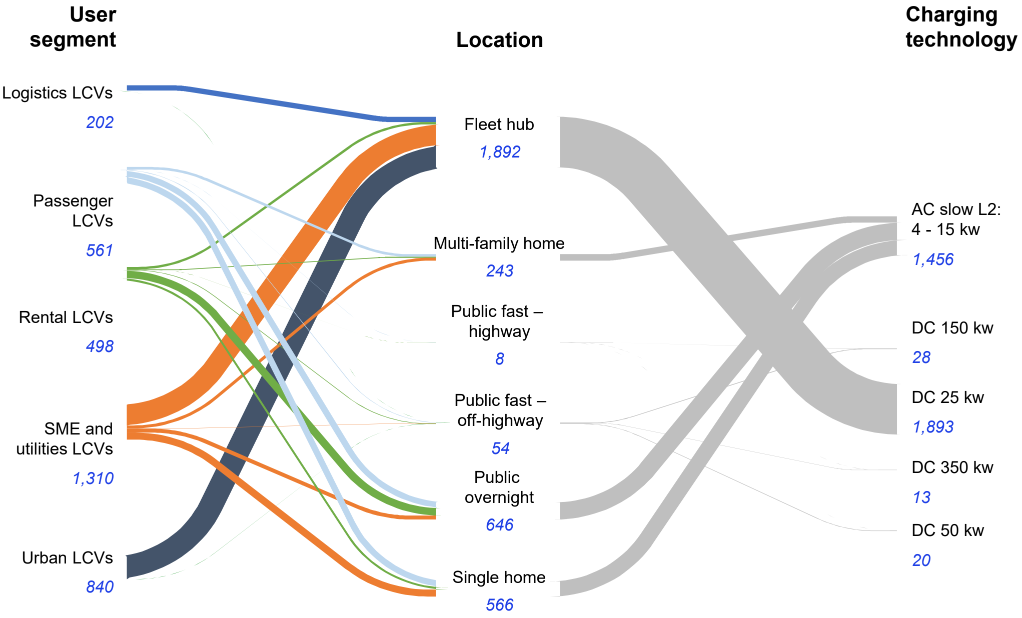
Source: EU EV Charging Masterplan

Exhibit 50: User segments, charging location, and charging power for CVs: trucks and buses assuming MCS fast chargers only



Source: EU EV Charging Masterplan

Exhibit 51: User segments, charging location, and technology for LCVs



Source: EU EV Charging Masterplan

4. EVCI and renewable energy investment assessment

There are two primary underlying investments needed to develop the charging infrastructure and the additional renewable energy capacity investments—the latter refers to the investments associated with supplying the EVCI energy demand with renewable energy sources.

For the assessment, the total annual deployment investment for each charging technology (€) from 2020 to 2030 has been sized bottom-up, considering four main investment items: hardware, installation (such as materials and labor), planning and engineering, and administration.

Regarding renewable energy investments, the model considers two key inputs: the EVCI energy demand and the overall EU electricity production from 2020 to 2030. First, the model extrapolates from the EU electricity production—derived from McKinsey's Global Energy Perspectives models—the share of renewable energy sources contributing to the total energy generated, broken down per country and source: biomass, hydropower, solar PV, wind onshore, and wind offshore. Nuclear is not included as the EV Charging Masterplan's objective is to focus on more sustainable and deployable sources within the ten-year timeframe. Assuming that renewable energy sources will supply the entire EVCI energy demand, the energy demand (kWh) is split (%) among the five renewable energy sources according to their relative electricity generation weight in the EU. Each power source's yearly utilization (running hours) has been identified, leading to the installation capacity needed (MW). Finally, the annual capital expenditure estimates (€ per MW) are included to calibrate the investments required to deploy enough renewable energy source installations to back up the EVCI energy demand ramp-up of the next decade.

5. TEN-T corridors charging infrastructure density mapping

Drawing on the public fast/highway locations' charger count, the TEN-T corridor density map aims to quantify the number of chargers in the nine core TEN-T corridors: the Atlantic, Baltic-Adriatic, Mediterranean, North Sea-Baltic, North Sea-Mediterranean, Orient-East Mediterranean, Rhine-Alpine, Rhine-Danube, and Scandinavian-Mediterranean.

Each corridor's length has been split (kilometers) for the reference countries (each corridor involves different and multiple countries) and determines the related EV charging point density per 100 kilometers. The analysis only considers the completed road kilometers in the TEN-T corridors (around 29,000 kilometers) and other highways (about 50,000 kilometers). The segments defined as incomplete or in progress are excluded. The same outcome has been generated for the PC and CV (trucks and buses) segments.

The model uses official EU Commission TEN-T maps spatial datasets to run the analysis mentioned above. The public fast highway chargers are then allocated to the nine corridors. This allocation factors in the TEN-T corridors' length in kilometers compared to the county's overall highway length, a traffic adjustment for the TEN-T corridors (where traffic is assumed to be more intense), and an additional reallocation across the corridors based on each corridor's annual average daily traffic volume. Finally, each country has been capped in EV charging points per 100 kilometers (kilometers referred to core TEN-T corridors only) with a maximum level tailored to the country's EV parc density on highways.

Glossary

AC: alternating current

BEV: battery electric vehicle

CPO: charge point operator

CV: commercial vehicle (trucks and buses)

DC: direct current

DSO: distribution system operator

EU: European Union (including the 27 current EU Member States)

EV: electric vehicle

EVCI: electric vehicle charging infrastructure

FCEV: fuel cell vehicle

GHG: greenhouse gas emissions

ICE: internal combustion engine

kW: kilowatt

kWh: kilowatt-hour

LCV: light commercial vehicle

OEM: original equipment manufacturer

PC: passenger car

PHEV: plug-in hybrid electric vehicle

TCO: total cost of ownership

TEN-T: trans-European transport network

TWh: terawatt-hour