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A REVIEW OF THE AFIR PROPOSAL: HOW MUCH POWER OUTPUT IS NEEDED FOR PUBLIC CHARGING INFRASTRUCTURE IN THE EUROPEAN UNION?

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EXECUTIVE SUMMARY

This white paper assesses the total publicly accessible charging power output required per electric passenger car and light commercial vehicle (vans) in the European Union (EU) through 2030. We focus on battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHVs) and compare our results to the Alternative Fuel Infrastructure Regulation (AFIR) proposal put forward by the European Commission in mid-2021.

This analysis builds on detailed bottom-up modeling of charging infrastructure needs for the three largest car markets in the EU: Germany, France, and Italy. These countries represent a diversity of transportation and housing situations that are broadly reflective of the EU. And like the EU as a whole, the three are also at different stages of electric vehicle adoption. The charging infrastructure assessments are developed to align with the European Commission Fit for 55 proposal, which sets a goal of zero carbon dioxide (CO_2) emissions from new vehicle sales by 2035. The results are then compared to the AFIR proposal using the proposal's metric of public charging power capacity per electric car or van. Flowing from this analysis, we draw the following conclusions and policy recommendations:

While AFIR targets are sufficient in the long term, higher targets that vary according to the electric car and van stock share are necessary in the short term. Our analysis shows that the total power output needed per electric vehicle (including BEV and PHV) is highly dependent on the share of electric cars and vans on the road. Our findings suggest that the targets of 1 kW per BEV and 0.66 kW per PHV as suggested in the AFIR proposal are insufficient in the short term; in fact, all EU Member States exceeded these targets as of 2021, most by a factor of two or more. Due to lower expected charge point utilization, higher charging targets are necessary for markets with less than 15% electric vehicle stock share. This adjustment can be done using a stepwise approach, as illustrated in Figure ES1 below. This Figure details our recommended total public power output per BEV (blue) and per PHV (red) based on Member States' electric car and van stock share.

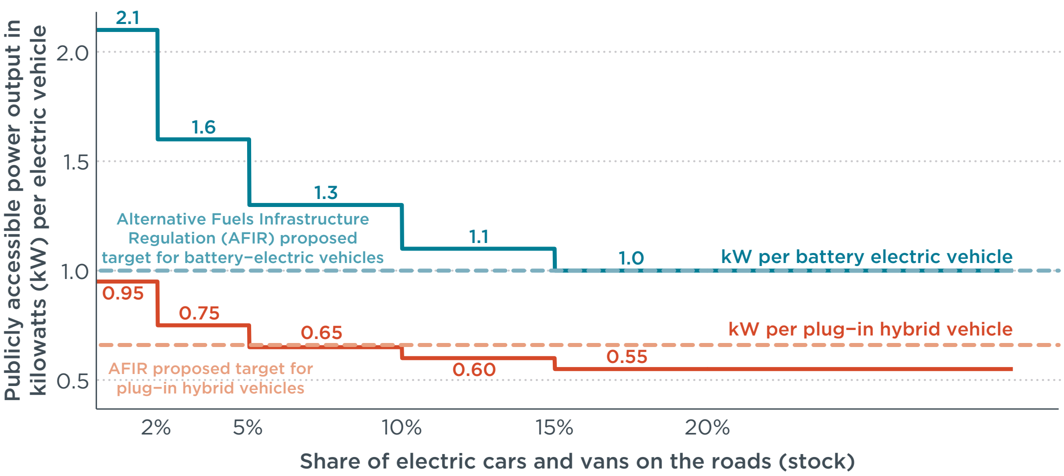

Figure ES 1. Recommended total public power output per BEV (blue) and per PHV (red), as a function of Member States' electric car and van stock share.

As shown in the Figure, electric vehicle markets with electric car and van stock share below 5%—currently the case for all EU Member States but Sweden—will require a public charging power output of at least 1.6 kW per BEV and 0.75 kW per PHV. In the longer run—once 15% of a Member States' car and van stock is electric, expected around the year 2028 in the EU as a whole—the required public charging capacity will be 1 kW per BEV and 0.55 kW per PHV, similar to the AFIR proposal.

Beyond the AFIR, additional policies will be needed to ensure that home and workplace charging also keep pace with electric vehicle adoption. Public charging needs are highly sensitive to the level of access to private home and workplace charging, and the suggested targets for public charging capacity rely on broad access to private charging. If private charging access were decreased by 50%, the required total public power output would increase by 70% to 100%. Because private home and workplace charging are typically less expensive than public charge points to install and are also the most affordable and convenient charging option for drivers, this alternative scenario would likely result in greater system-wide costs. The EU and national governments could thus support home and workplace charging, including by strengthening the Energy Performance Building Directive (EPBD) with binding requirements that align with projected electric vehicle uptake resulting from CO_2 standards and the AFIR's targets for public power output.

Numerous funding schemes from the EU are available to support charging rollout as the private business case develops. Public funding has been key to deploying the early public charging infrastructure network across Europe and will be important to promote the development of public charging infrastructure accessible to all. With this in mind, the EU has established several initiatives to help finance public charging infrastructure for electric cars and vans. Most notably, the Connecting Europe Facility Transport program is aimed at transport infrastructure specifically. Most Member States are also leveraging funding from more flexible EU programs like the Recovery and Resilience Fund and InvestEU to build charging infrastructure for meeting the targets outlined in the AFIR. At the same time, private sector investments are increasing, including from energy providers and car manufacturers, and private sector charging installations are expected to grow further as the electric vehicle market matures.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Creating a comprehensive, accessible charging infrastructure ecosystem is a key step to achieving the transition to electric vehicles and the accompanying air quality and climate benefits. Although European governments have instituted several policies and programs to encourage charging buildout (Hall et al., 2021), the Regulation on the Deployment of Alternative Fuels Infrastructure (AFIR), proposed by the European Commission on 14 July 2021, would be the first binding regulation to institute public charging infrastructure targets aligned with electric vehicle uptake at the European Union (EU) level (European Commission, 2021b).

The proposal suggests at least 1 kilowatt (kW) of publicly accessible charging capacity for each battery electric vehicle (BEV) and 0.66 kW for each plug-in hybrid vehicle (PHV) used as passenger cars or light commercial vehicles and registered in individual EU Member States.[1] The power output targets suggested in the AFIR proposal are to be met at the end of each year. The aim of the proposed regulation setting these targets is to guarantee sufficient power output to meet the needs of a growing fleet of electric cars and vans including BEVs and PHVs in each of the 27 EU Member States. Success in meeting this objective will help to decarbonize Europe's transport sector and to achieve climate neutrality in the EU by 2050, a key target of the European Green Deal (European Commission, 2019).

If adopted, the AFIR would repeal and replace Directive 2014/19/EU on the Deployment of Alternative Fuels Infrastructure (AFID) from 2014 (Directive 2014/94/EU, 2014). The AFIR differs from the AFID both in terms of legal standing as well as content. From a legal perspective, and in contrast to the previous directive, this EU regulation would supersede national laws and would be binding and directly applicable in all EU Member States as soon as it enters into force. In terms of content, the AFIR takes a sophisticated approach by setting targets for power output and charging infrastructure coverage to be provided by individual Member States, in contrast to the AFID, which provided only suggestions regarding the ratio of electric vehicles per charge point. Though not discussed in this paper, the AFIR proposal also sets targets for heavy-duty vehicle charging (Basma & Rodríguez, 2021) and for the electronic payment systems, prices, and smart charging technology run by public charging station operators.

This white paper assesses publicly accessible power output per BEV and per PHV needed in every EU member state up to 2030 and compares the results to the current AFIR proposal. The first section of the paper examines how Member States are performing in terms of this novel metric through 2021. The next two sections provide an overview of the methodology, then describe the results in terms of total power output per BEV and per PHV in comparison to the AFIR proposal. It includes a case study for how this result could be translated into specific numbers of public charge points for one Member State, Poland. Finally, because the development of charging infrastructure to meet these targets will require significant investment in the coming years, the last section focuses on private stakeholder involvement and funds available at the EU level to finance this charging infrastructure deployment. The paper concludes with a summary of our findings and three policy recommendations.

1 Unless otherwise specified, "vehicle" in this paper refers to passenger cars and vans.

STATUS OF PUBLIC CHARGING THROUGH 2021

The proposed targets in the AFIR are simple (uniform requirements for all Member States across all years) and flexible in terms of the mix of slow and fast charge points used to meet the required capacity depending on local conditions. However, previous research on markets such as Germany (Nicholas & Wappelhorst, 2020), France (Rajon Bernard et al., 2021), Italy (Nicholas & Wappelhorst, 2022), Spain (Nicholas & Wappelhorst, 2021), and the United Kingdom (Nicholas & Lutsey, 2020) demonstrates that the required number of public charge points in future years will vary depending on electric vehicle market penetration (which impacts charge points' utilization) as well as local factors like the availability of private charging at home or workplaces and travel demand.

Based on charging infrastructure data from Eco-Movement (Eco-Movement, 2022) and estimates of electric vehicles on the roads, Figure 1 below displays the total publicly accessible power output in kilowatts (kW) per electric passenger car and van on the road for the 27 EU Member States except Slovenia, for which data was not available. Electric vehicles include both BEVs and PHVs. The yellow dashed line represents the EU average and the red dashed line represents the AFIR proposal (weighted according to the 53% BEV/47% PHV mix of electric cars and vans on the road through 2021 in the EU) (European Alternative Fuels Observatory, n.d.).

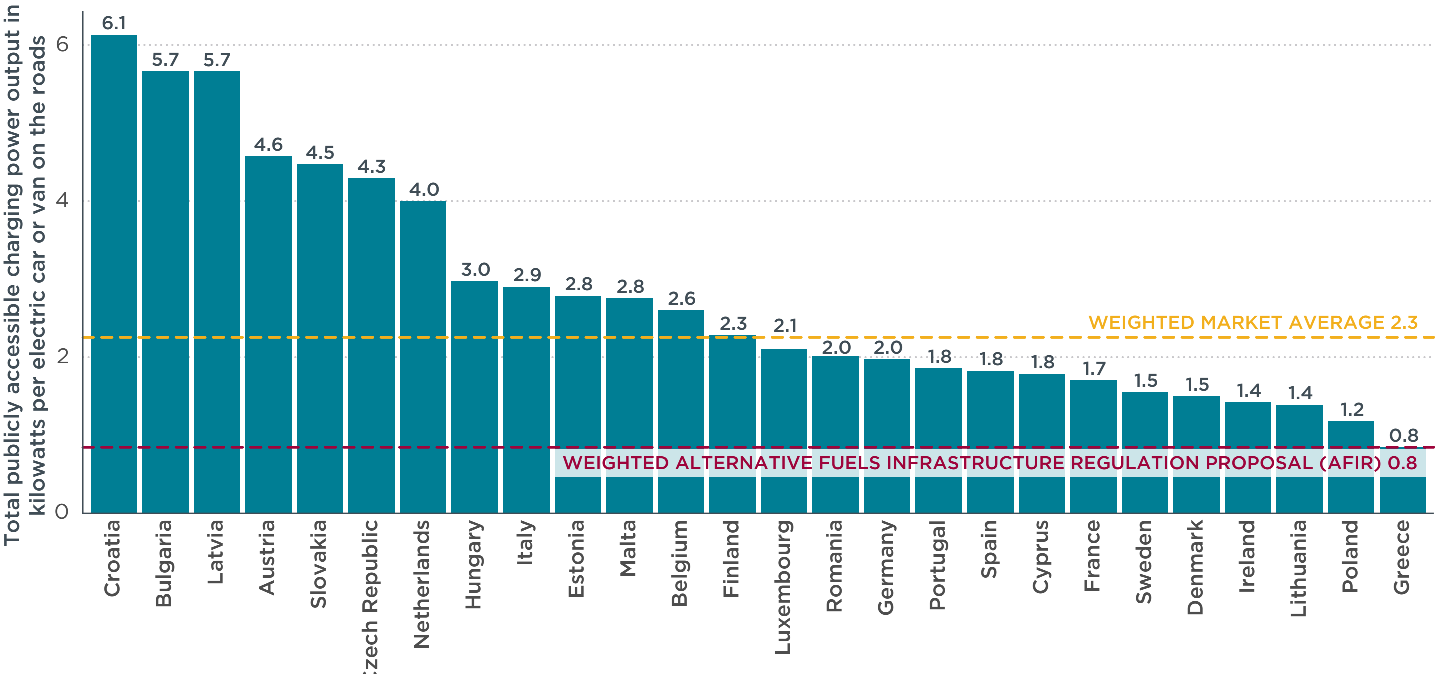

Figure 1. Total publicly accessible charging power output (in kW, data from (Eco-Movement, 2022)) per electric car and van on the roads at the end of 2021 for every European Union Member State (data not available for Slovenia).

The figure shows that every EU Member State complied with the AFIR proposal at the end of 2021, with more than three-fourths of Member States having more than twice as much power output per electric vehicle as required under this proposal. Many countries in the eastern part of the EU (e.g. Bulgaria, Latvia, and Slovakia) are performing particularly well compared to the AFIR target, and have more public charging capacity per vehicle than countries in the western and northern parts of Europe (e.g., Sweden, Denmark, and France) with higher electric vehicle uptake (Mock et al., 2022). As an example, Croatia and Bulgaria have 6.1 and 5.7 kW of power installed per electric vehicle compared to 1.5 for Sweden and Denmark. However, many of these countries have fewer charge points in absolute terms; for example, Croatia and Bulgaria had around 840 and 640 charge points in place at the end of 2021 compared to 17,950 and 5,650 for Sweden and Denmark respectively (Eco-Movement, 2022).

ASSUMPTIONS REGARDING CHARGING INFRASTRUCTURE NEEDS

This section describes the methodology and assumptions used to derive the suggested targets for power output requirements per BEV and per PHV in the European Union through 2030.

OVERVIEW OF METHODOLOGY

The methodology used to assess charging power output per BEV and per PHV in the EU for each year is illustrated in Figure 2 below. The blue rectangles represent the model steps, beginning at the top left. The yellow trapezoids indicate the data inputs and assumptions between the model steps, while the grey ovals explain what occurs at each step, in a more readable form. The top left rectangle shows that the model starts with a projection of vehicle sales, which, in turn, allows the stock of vehicles to be tracked over time. The next step allocates this stock to charging groups depending on the type of car (BEV vs. PHV), home charging availability, commuting status (car commuter vs. non-car commuter), and workplace charging availability. After this, the daily energy required is forecasted for each charging group. At the 4th step, this electricity demand is calculated for each charging setting and translated into the number of charge points required based on estimated daily utilization. Finally, the total number of public charge points needed is turned into a total public power output (step 5)— based on assumptions regarding the maximum power output of each public charge point—and divided by the electric vehicle stock, as defined in step 1, to obtain the maximum total power output per BEV and per PHV (step 6).

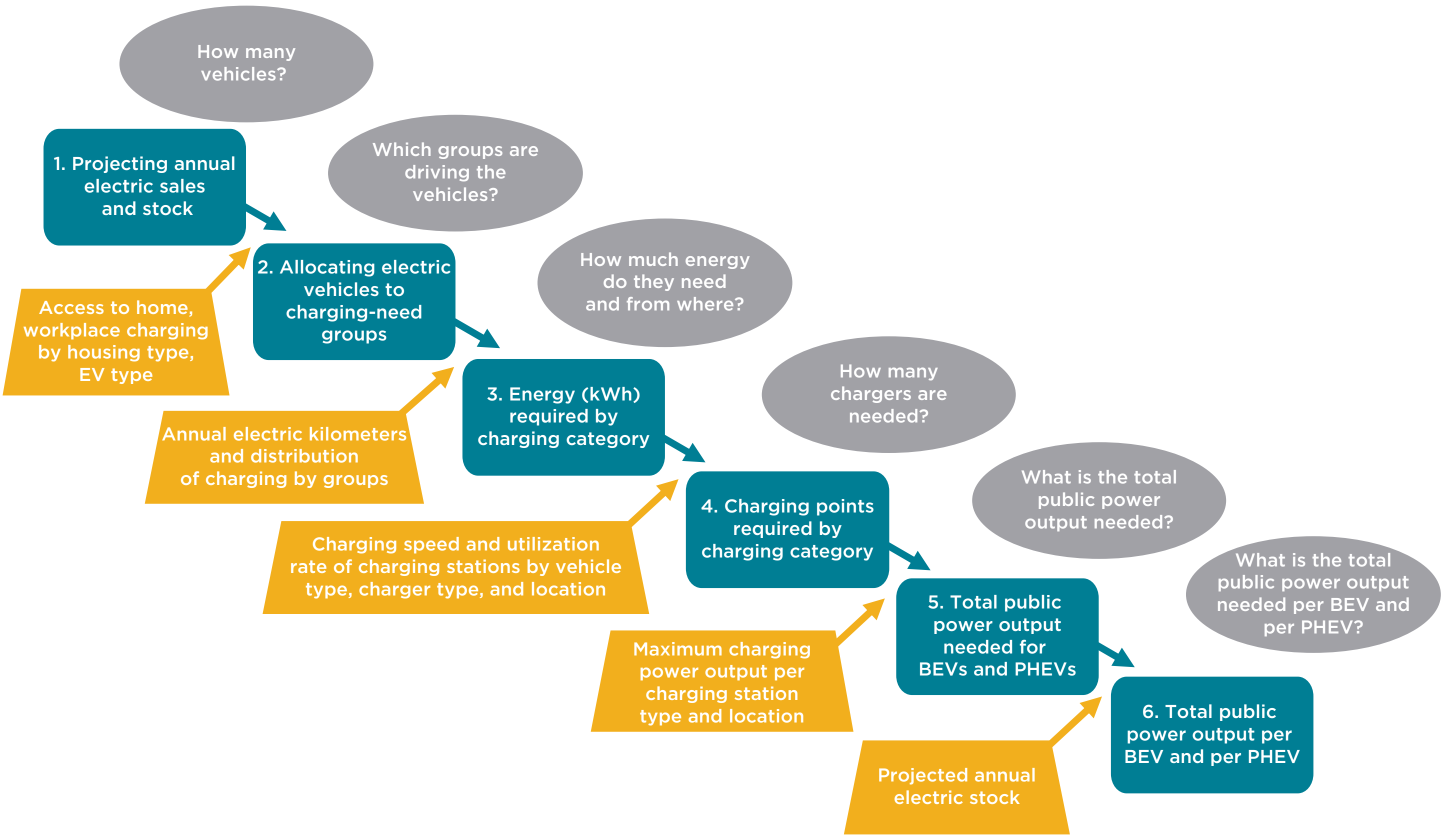

Figure 2. Key modeling steps to assess charging needs based on electric vehicle uptake

This analysis was conducted separately for 3 EU Member States: France, Germany, and Italy. These countries are the three largest car markets in the EU and collectively represent about 60% of new car registrations in the EU (Mock et al., 2022). They also represent a diversity of transportation and housing situations reflective of the EU more broadly, and they are at different stages of electric vehicle adoption. While the share of new BEV and PHV registrations in 2021 was 26% in Germany, it was 18% in France and only 10% in Italy. Therefore, an average of the power requirements for these three markets yields results that can be applied to the European Union as a whole. The methodology for steps 2-4 is based on previous studies for Germany (Nicholas & Wappelhorst, 2020), France (Rajon Bernard et al., 2021), and Italy (Nicholas & Wappelhorst, 2022) and developed in more detail in these reports.

ELECTRIC PASSENGER CAR AND VAN STOCK PROJECTIONS

Electric vehicle stock projections, the first modeling step shown in Figure 2, are based on the Progress Scenario of the ICCT Roadmap model (ICCT, 2021). Electric vehicles include both BEVs and PHVs. Figure 3 below illustrates the projected electric car and van stock share—i.e., the share of cars and vans on the roads that are electric—at the EU level (thick blue line) and for three selected countries: France, Germany, and Italy (light blue dashed lines) from 2021 to 2030. This Progress Scenario assumes that the EU will reach 100% zero-emission vehicle registrations by 2035 to meet the CO_2 targets proposed by the European Commission (European Commission, 2021).[2] France and Germany are ahead of Italy due to a higher electric share of new car and van registrations up to the end of 2021; this trend is projected to continue until at least 2030. Further assumptions behind the Progress Scenario of the ICCT Roadmap model can be found in the accompanying GitHub documentation (ICCT, 2021).

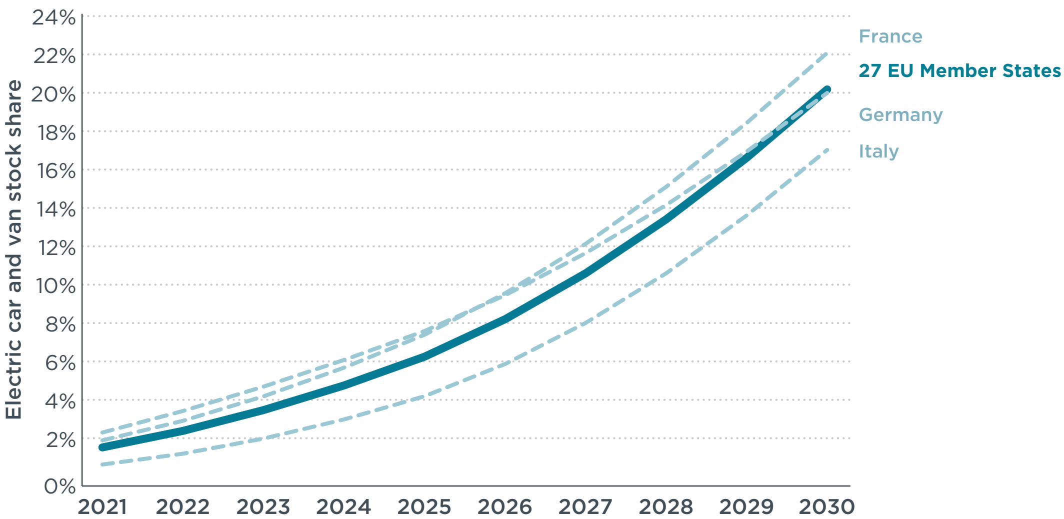

Figure 3. Electric car and van stock share at the European Union level (plain dark blue) and for France, Germany, and Italy (dashed light blue) from 2021 to 2030 based on the Progress Scenario of the ICCT Roadmap model (ICCT, 2021)

Figure 4 illustrates the projected electric vehicle stock, in terms of number of vehicles, differentiated by BEVs (blue) and PHVs (red), based on the Progress Scenario of the ICCT Roadmap model (ICCT, 2021). As shown, among the countries selected, Germany has the highest number of electric cars and vans on its roads up to 2030, followed by France and then Italy. This is explained by the early electric vehicle uptake and by the size of the car and van market of these countries: Germany is the largest EU car market followed by France, and then Italy. The total number of electric cars and vans on EU roads increases from 3.8 million in 2021 to more than 20 million in 2026 and over 50 million in 2030.

2 This Scenario also includes governments' commitments up to November 2021, which excludes the recently announced German government goal of 15 million EVs on their roads in 2030.

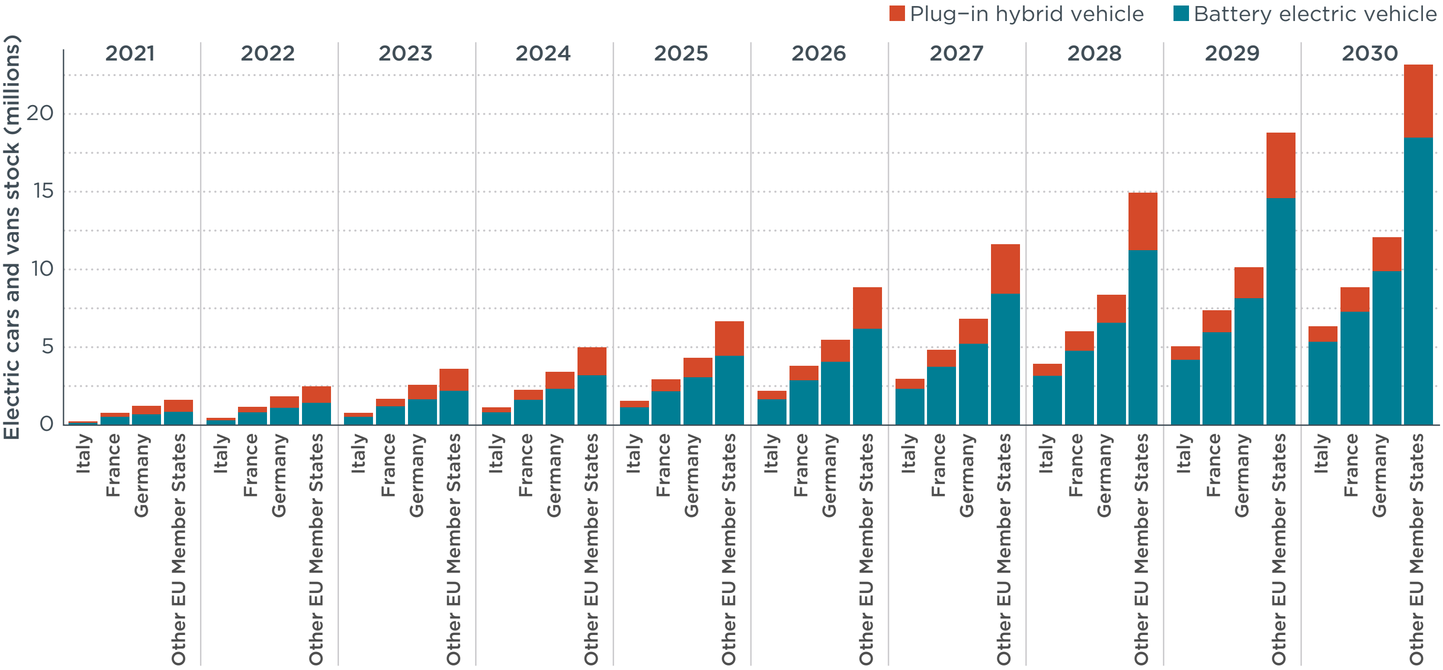

Figure 4. Projections for the number of electric cars and vans in the vehicle stock in Italy, France, Germany, and the rest of the European Union between 2021 and 2030

HOME CHARGING ACCESS ASSUMPTIONS

Access to private home charging has a considerable impact on public charging needs and is thus a key factor in our model—as shown in the first yellow trapezoid of Figure 2. Although data on drivers' access to private home charging are generally elusive, this can be estimated using more available statistics such as access to a dedicated parking spot and type of housing stock (detached houses, attached houses, low-rise buildings etc.). For the France charging infrastructure model, both housing stock and dedicated parking spot availability are used to estimate home charging availability. For Germany and Italy, housing stock is used to estimate home charging availability.

The aforementioned France, Germany, and Italy charging assessment studies forecast that home charging availability will decline by 2030. In France 75% of electric passenger car owners had access to home charging in 2021; the share will fall to 65% in 2030. The decline through 2030 is based on the shift from early EV adopters (who generally have dedicated private parking) to mainstream purchasers whose access to a dedicated parking spot eventually approaches the (lower) national average. In Germany, the shares are slightly higher, with an assumed 79% of electric vehicle owners having access to home charging in 2021, but only 72% in 2030. Home charging access in Italy falls between that of France and Germany, with an estimated 72% of electric vehicle owners having access to home charging in 2021, which drops to 67% in 2030.

CHARGE POINTS REQUIRED BY CHARGING CATEGORY

As shown at step 4 of Figure 2, translating electric vehicle energy demand, in kilowatt-hours (kWh), to an absolute number of charge points requires assumptions regarding the typical utilization of charge points, as measured in hours of active charging per day, and the typical charging speed, or power, measured in kW.

Charge point utilization

This analysis assumes that charge point utilization increases logarithmically with electric vehicle market penetration (share of electric vehicles on the roads) for both normal charge points (which run on alternating current (AC)) and fast charge points (which operate on direct current (DC)). The natural log (ln) function reflects best the assumption that the average number of charging hours per day will not exceed a practical threshold at high market penetration, but also increases rapidly in the nascent stages of an electric vehicle market. The increasing usage of normal charge points as a function of EV share of vehicle stock can be represented by the following equation:

$$\textit{Average daily hours of normal charge points' utilization} = a \times \ln(\textit{EV stock share}) + b$$

The *a* and *b* coefficients vary within countries depending on the area in question (mostly urban versus rural areas). The *a* coefficient represents the rate at which the utilization will increase, while *b* represents the maximum usage assumed once the EV stock share reaches 100%. These coefficients are determined based on 2021 charge point utilization data gathered from different sources and an assumed EU average maximum active utilization of around 6 hours per day for normal charge points and 5 hours per day for fast charge points (Rajon Bernard & Hall, 2022). A similar equation is used for the average daily utilization of fast charge points, but as a function of BEV share of vehicle stock, since most PHVs do not use fast charge points.

Charge point utilization is defined as the time during which power is actively drawn from the charge point. It does not include idling time. Because the power output of fast charge points is higher, the time to charge the car is lower, but the time spent to plug-in, pay, and scan a membership card remains the same regardless of charging speed. Because of this higher share of time not actively spent charging, the daily active utilization is assumed to be lower for fast charge points. As mentioned in the previous paragraph, for this analysis, we assume a maximum active utilization of 6 hours per day for normal charge points and 5 hours per day for fast urban and highway charge points. As an example, this results in 4.5 hours of active utilization per day for normal charge points in France in 2030 and 3.8 hours for fast urban and highway charge points.

Charging speed

This analysis assumes that charging speed—also called the rate of power drawn by vehicles—increases over the years to reflect technology improvements in the vehicles and greater availability of high-power charging. Table 1 displays the average rate of power draw for different charge points over the years. The average rate of power draw is the power delivered to a vehicle over one charging cycle, averaged across all vehicles.

Table 1. Average rate of power draw for different charge points and vehicles, selected years

	BEV: AC normal charge point	PHV: AC normal charge point	BEV: urban fast charge point*	BEV: corridor highway charge point*
2021	8.1 kW	3.7 kW	40 kW	72 kW
2026 (revision of the AFIR according to the proposal)	8.6 kW	3.9 kW	61 kW	100 kW
2030	9.0 kW	4.1 kW	80 kW	122 kW

* Fast charging is assumed to be used only by BEVs

Even though higher levels of power were already possible by 2021, in practice power sharing, battery management over an entire charge cycle, and the lower cost of lower power suggest that, on average, speeds will be lower than the maximum.

MAXIMUM POWER OUTPUT OF PUBLIC CHARGE POINTS

It is important to note that charge points' maximum power output, and the average power delivered to the car, differ substantially. The average power is lower than the maximum power of a charge point, also called rated power, because of vehicles' different rates of power acceptance and variations in power over the charge cycle. For example, power typically decreases as the battery approaches 100% charge.

Our assumptions regarding the maximum power output of charge points are shown in Table 2. Power output for 2021 is based on data from Eco-Movement and varies by country (Eco-Movement, 2022). This variation by country stems from the fact that, in early electric vehicle adoption stages, charging infrastructure deployment relies heavily on public subsidies, and strategies of subsidization differ between countries. As an example, while the average power output across all charge points in France is 20 kW, it is 28 kW for Italy, and 38 kW for Germany due to proportionally more 22 kW AC normal charge points and fast charge points in Italy and Germany than in France.

In 2030, we assume homogeneous maximum power output in all EU countries. This assumes that, by 2030, electric vehicles will reach mass adoption and charge point deployment will be led by the private market more than by governments, with charge point power determined by economics and vehicle technology rather than government incentives.

Table 2. Assumed average maximum power output by charge point type

Country	Charge point type	Maximum power output in kW	
		2021	2030
France	Normal AC charge points used by BEVs	13 kW	20 kW
	Normal AC charge points used by PHVs	8 kW	13 kW
	Fast urban DC charge points	100 kW	140 kW
	Fast highway DC charge points	140 kW	250 kW
Germany	Normal AC charge points used by BEVs	20 kW	20 kW
	Normal AC charge points used by PHVs	12 kW	13 kW
	Fast urban DC charge points	110 kW	140 kW
	Fast highway DC charge points	145 kW	250 kW
Italy	Normal AC charge points used by BEVs	19 kW	20 kW
	Normal AC charge points used by PHVs	12 kW	13 kW
	Fast urban DC charge points	110 kW	140 kW
	Fast highway DC charge points	140 kW	250 kW

DEFINITION OF TOTAL PUBLICLY ACCESSIBLE POWER OUTPUT

The total public power outputs mentioned in this analysis refer to the maximum simultaneously available power output that is publicly accessible. In reality, some charging pools have power sharing capabilities that can limit charging stations' power output due to grid capacity. For example, a charging pool may have a maximum grid connection of 300 kW and four 150 kW charging stations. If only two vehicles are charging at the pool, they could both charge at 150 kW, but if four vehicles charge, each would receive 75 kW. Likewise, this is interpreted as providing 300 kW of capacity in this analysis, even though there are four stations capable of charging at 150 kW.

The current AFIR proposal does not specifically reference this simultaneity requirement, nor does it specify what "total" means when setting "total power output" requirements per BEV and per PHV. This lack of specificity could lead to confusion in reporting and potentially less usable charging infrastructure compared to what is formally counted.

This study uses the same definition of "publicly accessible charge points" as the AFIR proposal: charge points located at a site open to the general public, whether on public or private property. These charge points can however be limited to certain users and applications.

RESULTS AND DISCUSSION: POWER OUTPUT PER ELECTRIC VEHICLE

Based on the methodology previously outlined, this section will derive generalizable targets for total publicly accessible power output per BEV and per PHV and compare these to the current AFIR proposal. The AFIR metrics of publicly accessible power output per electric vehicle are inherently flexible but are less intuitively understood than targets for number of charge points. This section therefore provides a case study, focused on Poland, to illustrate how this target can translate into a specific number of public charge points. We also present a brief sensitivity analysis to demonstrate the impact of private charging access on public power output requirements. Finally, this section ends with a comparison of this study's results to recommendations made by other groups.

GENERALIZABLE TARGETS FOR KW PER BEV AND KW PER PHV

Following the methodology outlined in the previous section, we arrive at an estimated total public power output in kW per BEV (plain lines) and per PHV (dashed lines) as a function of electric car and van market penetration for Germany, France, and Italy, which are presented in Figure 5. The lines on the Figure start and end at the respective 2021 and 2030 electric car and van stock shares.

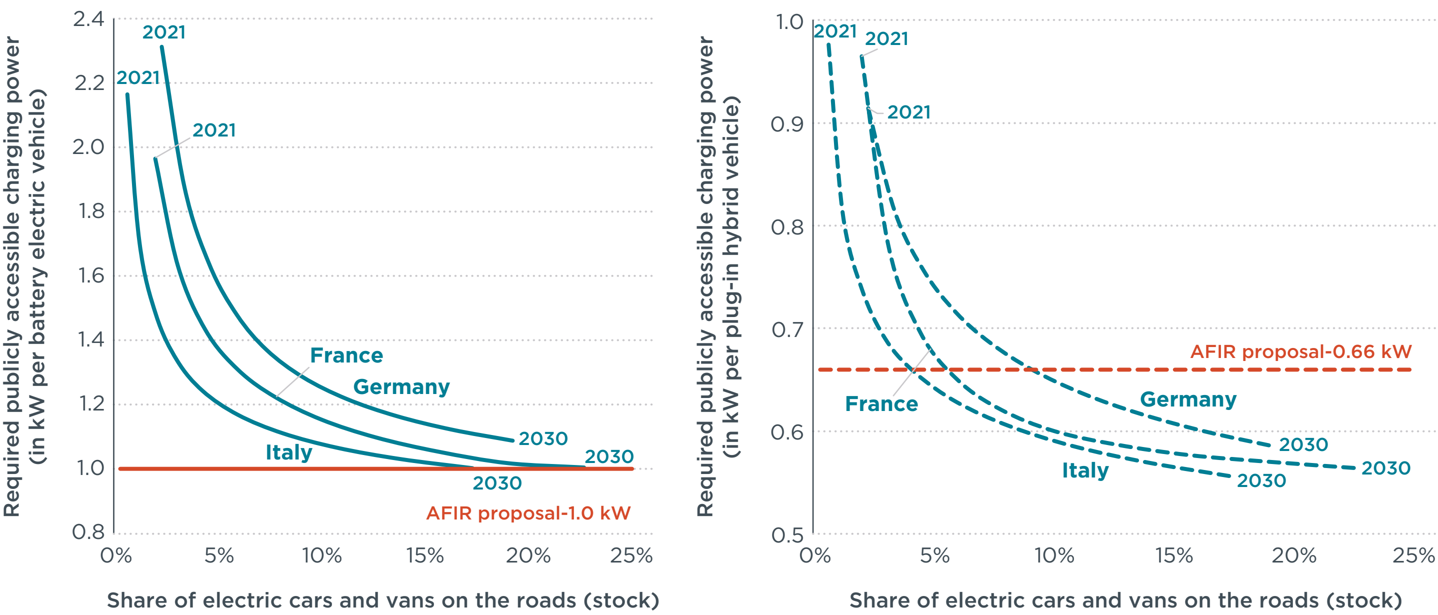

Figure 5. Total public power output in kW per BEV (left chart and plain lines) and per PHV (right chart and dashed lines) for France, Germany, and Italy as a function of electric car and van stock share.

The necessary publicly accessible power output per BEV, in kilowatts (left chart) decreases from 2.3 to 1.1 for Germany as the electric car and van stock share increases from 2% to 20% between 2021 and 2030. Similarly, in France, it decreases from 2.0 to 1.0 as the electric stock share increased from 2% to 23%. Finally, the charging power needs in Italy decrease from 2.2 to 1.0 kW per BEV as the electric car and van stock share increases from 1% to 17% between 2021 and 2030. The right chart shows a similar decrease for the necessary publicly accessible power output per PHV in Germany, France, and Italy. This decrease in power output requirement per electric vehicle is due to an assumption that charge point utilization will become more efficient over time. This more efficient utilization is a result of charge points being increasingly clustered in larger stations in areas with greater demand as the market matures after being more sparsely distributed in the early market to provide basic geographic coverage.

The differences among these three markets are primarily due to the difference in annual kilometers driven per electric vehicle across Germany, France, and Italy. Based on 2020 data, on average, German electric passenger car owners (following the trend for German car owners more broadly) drive 10% more than French electric vehicle owners, who in turn drive 18% more than Italian electric vehicle owners (Nicholas & Wappelhorst, 2020; Rajon Bernard et al., 2021; Nicholas & Wappelhorst, 2022). This explains the need for more power output per electric vehicle in Germany compared to France and Italy.

IMPLICATIONS FOR POWER REQUIREMENTS IN THE AFIR

France, Germany, and Italy are the three largest car markets in the EU, collectively accounting for about 60% of new car registrations (Mock et al., 2022), and represent a diversity of transportation and housing situations reflective of the EU more broadly. Therefore, an average of the power requirements for these three markets yields results that can be applied to the European Union as a whole. This average charging power requirement is presented in Figure 6 below, with the solid blue line representing power requirements per BEV and the dashed blue line power requirements per PHV. The red lines correspond to the AFIR proposals for BEVs (solid line) and PHVs (dashed lines).

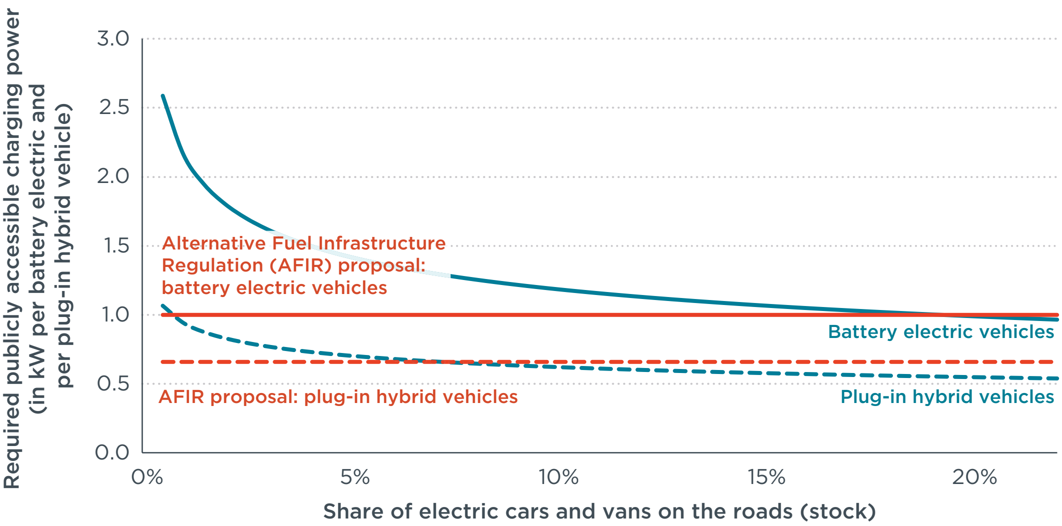

Figure 6. Total public power output in kW per BEV (solid line) and per PHV (dashed line) at the European Union level as a function of electric car and van stock share.

As shown in the Figure, our analysis suggests that the power output required per vehicle is highly dependent on the share of electric cars and vans on the roads. According to our model, in the early stages of electric vehicle adoption, when the share of electric cars and vans on the roads is below 5%, EU Member States would need at least 1.4 kW of publicly accessible power output per BEV and 0.7 kW per PHV. This 5% share of electric cars and vans on the roads is forecasted to be reached around 2024 for the EU as a whole. With more efficient utilization of deployed charging infrastructure, when Member States reach a 10% share of the on-road stock of electric cars and vans, the power requirements decrease to 1.2 kW per BEV and 0.62 kW per PHV. According to the model developed, in the long term (by 2030), this approach suggests charging infrastructure requirements would be close to 1 kW per BEV and 0.55 kW per PHV. This compares to 1 kW per BEV and 0.66 kW per PHV in the current AFIR proposal.

The different power requirements for BEVs and PHVs implies that these two vehicle types will not always use the same type of charge points. This analysis assumes that

PHVs will not use DC fast charging and that PHVs will be more likely to use lower-power AC charge points (3-7 kW).

RECOMMENDED POWER OUTPUT REQUIREMENTS PER BEV AND PER PHV

Based on the results presented in the previous subsection, the constant targets proposed by AFIR would underestimate the power output needs in the short term, potentially posing an obstacle for the electric vehicle transition by generating negative experiences for electric vehicle users. Raising the targets across the board would overestimate the public power needs in the long term, leading to unnecessary charging infrastructure at a significant expense. Ideally, power capacity targets would reflect the dependency on the share of electric car and van stock, as described in the analysis above. Based on an average of the continuous lines shown in Figure 6, we suggest a stepwise approach designed to respond to changing market dynamics while also allowing for simple implementation by governments. Table 3 and Figure 7 present this alternative proposal for publicly accessible power capacity requirements per BEV (blue line) and per PHV (red line) based on the electric share of car and van stock.

Table 3. Recommended total public power output per BEV and per PHV based on Member Sates' electric share of passenger car and van stock.

Electric share of car and van stock	Public power output per BEV	Public power output per PHV
≤ 2%	2.1 kW	0.95 kW
2% - 5%	1.6 kW	0.75 kW
5% - 10%	1.3 kW	0.65 kW
10% - 15%	1.1 kW	0.60 kW
>15%	1 kW	0.55 kW

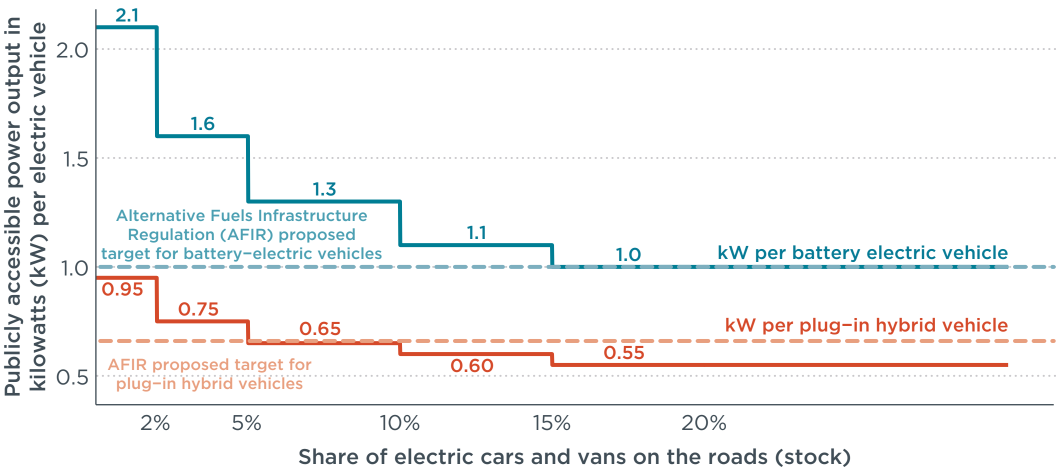

Figure 7. Recommended total public power output per BEV (blue) and per PHV (red) depending on Member States' electric share of car and van stock

CASE STUDY: TRANSLATING AFIR TARGETS INTO NUMBER OF CHARGE POINTS, IN POLAND

The AFIR metric of publicly accessible power output per electric vehicle is inherently flexible but less intuitive than targets for the number of charge points. This section provides a case study to illustrate how this target can translate into a specific number of public charge points. The case study focuses on Poland, one of the largest passenger car markets in Europe by new registrations but with a relatively low electric share of vehicle registrations to date (4% new BEV and PHV registrations in 2021 versus 18% in Europe) (Mock et al., 2022). Poland therefore represents how a EU market lagging in electric vehicle penetration would be impacted by the AFIR. The case study focuses on the period through 2026, at which point the AFIR, according to the European Commission proposal, will be reviewed and potentially revised.

This analysis first identifies public charging power capacity targets according to the recommendations identified above. Figure 8 restates these recommendations for power output per BEV and per PHV at different market stages, along with projections for Poland electric vehicle stock shares over the years (triggering different per-vehicle power capacity targets) according to the Progress Scenario of the ICCT Roadmap model. The figure presents the projected electric car and van stock share in Poland (left axis and purple) and the suggested power output per BEV (blue) and per PHV (red) to be met by Poland between 2022 and 2026.

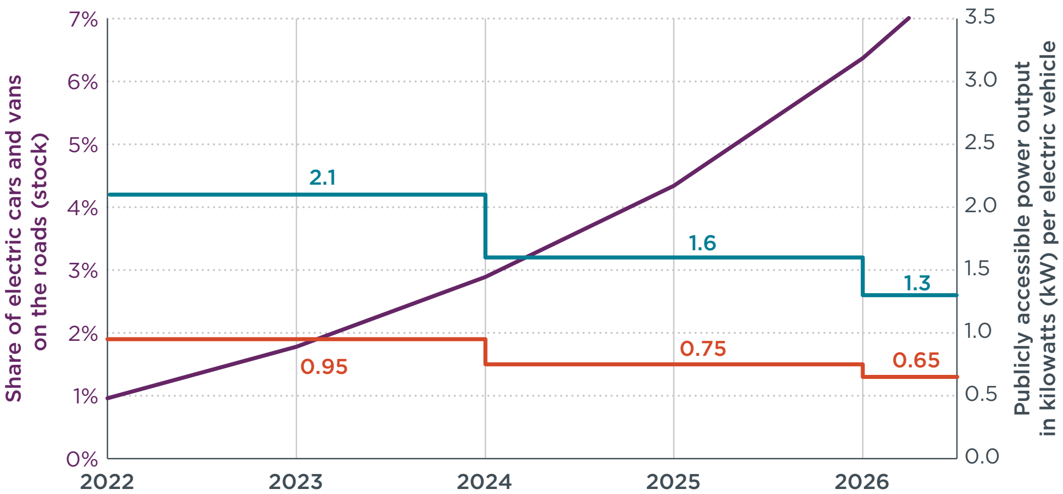

Figure 8. Share of electric cars and vans on the roads (purple and left axis) and recommended total public power output per BEV (blue) and per PHV (red) for Poland from 2022 to 2026.

After determining Poland's annual per-vehicle public charging capacity targets, these targets are multiplied by the number of BEVs and of PHVs on the road and summed to obtain the total power output needed for electric vehicles each year ("Outputs" column of Table 4). Table 4 illustrates the market growth assumptions (per the Progress Scenario of the ICCT Roadmap model), per-vehicle targets from Figure 8, and resulting charging capacity needed each year from 2022 to 2026. Values associated with BEVs are colored blue and those associated with PHVs are colored red.

Table 4. Electric car and van market in Poland 2022-2026 and the related power output needs in kW.

Inputs						Outputs	
Electric vehicle market projections (Progress Scenario of the ICCT Roadmap model)				Per-vehicle charging capacity targets			
Year	Electric cars and vans stock share	Estimated BEV stock	Estimated PHV stock	Recommended kW per BEV	Recommended kW per PHV	Total kW for BEV	Total kW for PHV
2022	1.0%	120,000	54,000	2.1	0.95	252,000 = 120,000 x 2.1	51,300 = 54,000 x 0.95
2023	1.8%	218,000	93,000	2.1	0.95	457,800	88,400
2024	2.9%	348,000	145,000	1.6	0.75	556,800	108,700
2025	4.3%	515,000	207,000	1.6	0.75	824,000	155,300
2026	6.3%	769,000	276,000	1.3	0.65	999,700	179,400

Since the number of charge points to be installed is contingent upon the power output of these charge points, this example assumes that charge points for BEVs will be a mix of 22 kW, 50 kW, and 150 kW, whereas all charge points for PHVs will be 7.4 kW. This example assumes that 25% of the power provided to BEVs will come from 150 kW charge points, 25% from 50 kW charge points, and 50% from 22 kW charge points.

The total kW for BEV and for PHV ("Outputs" column of the Table) are divided by the power capacity for each charge point category, explained in the previous paragraph, to obtain the number of charge points in each charge point category (7.4 kW, 22 kW, 50 kW, and 150 kW). For instance, using the example of PHVs in 2026, the 0.65 kW per PHV target is multiplied by a vehicle stock of 276,000 PHVs and divided by 7.4 kW to yield approximately 24,000 7.4 kW public charge points, presented in Figure 9 below.

Repeating this process for each charge point type and year according to the selected charging breakdown yields the absolute number of 7.4 kW, 22 kW, 50 kW, and 150 kW equivalent charge points recommended in Poland up to 2026. Those results are presented in Figure 9 below. This amounts to a total of 14,300 public charge points in 2022, 25,300 in 2023, 30,900 in 2024, 45,200 in 2025, and 53,600 in 2026. For reference, Poland had 2,293 public normal AC charge points (up to 22 kW) and 1,381 DC fast charge points (50 kW or greater) through the end of 2021. We emphasize that this is just one possible path to fulfilling the recommended targets; by using a different mix of charging speeds, Poland could achieve the same public charging power capacity with more or fewer total public charge points.

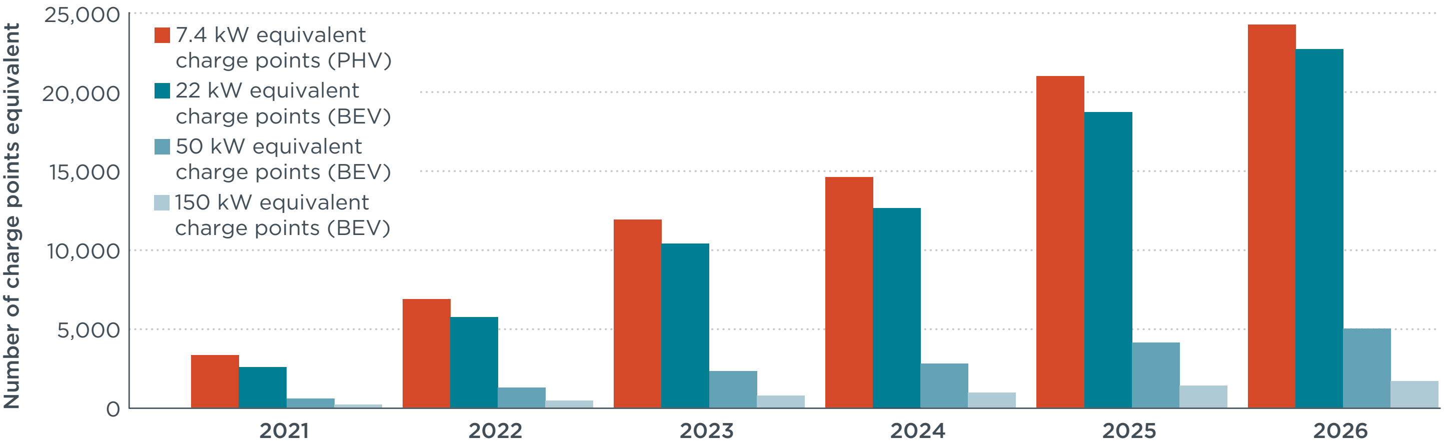

Figure 9. Absolute number of 7.4 kW (red), 22 kW (dark blue), 50 kW (blue), and 150 kW (light blue) equivalent public charge points to be installed in Poland up to 2026

IMPACT OF PRIVATE CHARGING AVAILABILITY ON PUBLIC CHARGING NEEDS

Access to private home and workplace charging impacts the amount of public charging needed. To show the importance of home and workplace charging access, a sensitivity analysis was conducted, illustrating a scenario where workplace and home charging access was reduced by 50%. Figure 10 shows the difference in public charging requirements under these scenarios using the same metric of public charging power output per electric vehicle. For more clarity, data is only shown for BEV. The blue line shows the total public power output needs for the baseline scenario and the purple one for the low home and workplace charging scenario. These results are derived using the same process outlined in Figure 2, only modifying the assumptions in step 3 to increase the number of drivers relying exclusively on public charging. A similar effect is observed for PHVs.

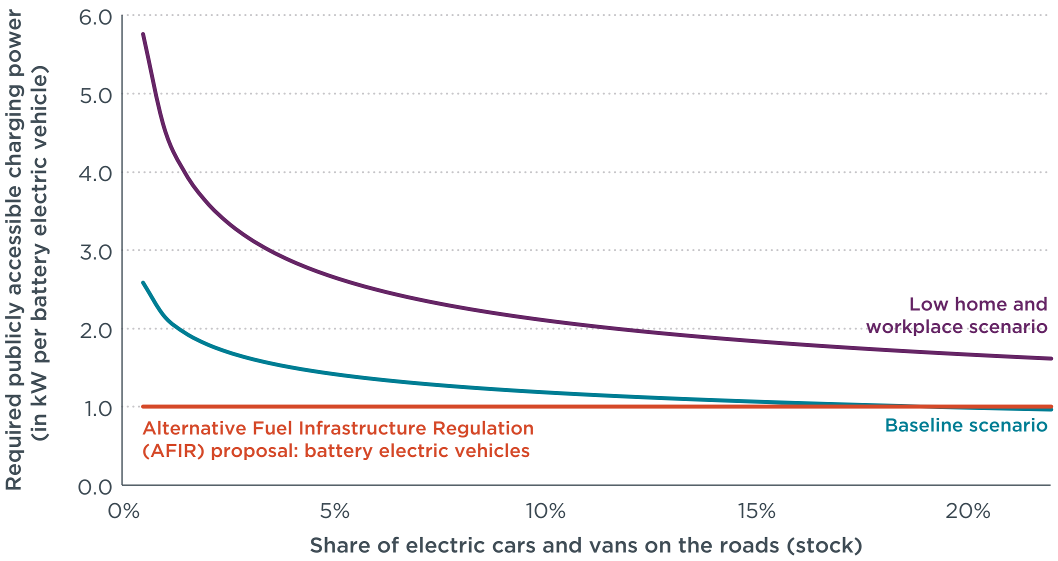

Figure 10. Total public power output in kW per BEV as a function of electric car and van stock share for the baseline scenario (blue) and the low home and workplace charging scenario (purple).

Depending on the share of electric vehicles, reducing home and workplace charging access by 50% increases the amount of public charging power needed per battery electric vehicle between 70% and 100%. As an example, based on this sensitivity analysis, for a market with 10% electric (BEV and PHV) stock share where 70% of electric vehicle owners have access to home charging, 1.1 kW per BEV of public charging capacity is needed. If only 35% of electric vehicle owners have access to home charging, 2.0 kW per BEV would be needed, nearly doubling the amount of public charging capacity required. Because public charging stations tend to cost much more than private charge points, such a shift would likely result in overall increased capital costs for the same number of vehicles (Nicholas, 2019).

Private home and workplace charging are likely to remain the most convenient and affordable ways of charging for most consumers and are therefore important for achieving the transition to electric vehicles. Although outside the scope of the AFIR, additional policies are necessary to ensure that private charging keeps pace with electric vehicle uptake, including electric vehicle-ready building codes and incentives for home and workplace charge points. Requirements for private charging in new and renovated residential buildings are included in the Energy Performance Building Directive (EPBD) proposal released in December 2021 by the European Parliament and the Council. The EPBD complements the AFIR by setting requirements for charging infrastructure in private buildings both at home and at the workplace (European Commission. (2021b).

COMPARISON TO OTHER ASSESSMENTS

This section compares the results of our analysis with three other publications that also assessed AFIR publicly accessible power output targets per light-duty BEV and PHV. The first publication was published by the NGO Transport & Environment in November 2021 (T&E, 2021), the second by AVERE (The European Association for Electromobility) in December 2021 (AVERE, 2021), and the third is an Amendment to the AFIR proposal put forward by Member of the European Parliament (MEP) Ismail Ertug, the AFIR Rapporteur of the Parliament's lead Transport Committee (Ertug, 2022).

Similar to this paper's recommendation, the three publications recommend higher public power output targets when markets have lower electric car and van stock shares. The AVERE study recommends adopting a minimum charging capacity commensurate to 10% electric share of vehicle stock. This means that every EU Member State whose electric share of car and van stock is below 10% would calculate their total power output requirements as if 10% of their car and van fleet was already electric. The other two publications recommend adopting a stepwise approach, similar to the one developed in this study.

Transport & Environment (T&E) and MEP Ertug both made the same recommendations in terms of public power output per BEV, depending on the electric car and van stock share, which can be found in the Figure below (blue and red lines). In addition, MEP Ertug also made recommendations about power output per PHV. Figure 11 compares the recommendations from T&E and MEP Ertug (blue and red lines) with AVERE recommendation (light blue and red lines) and our recommendations (dark blue and red lines). The left side shows the comparison for the publicly accessible power output recommendation per BEV and the right side per PHV.

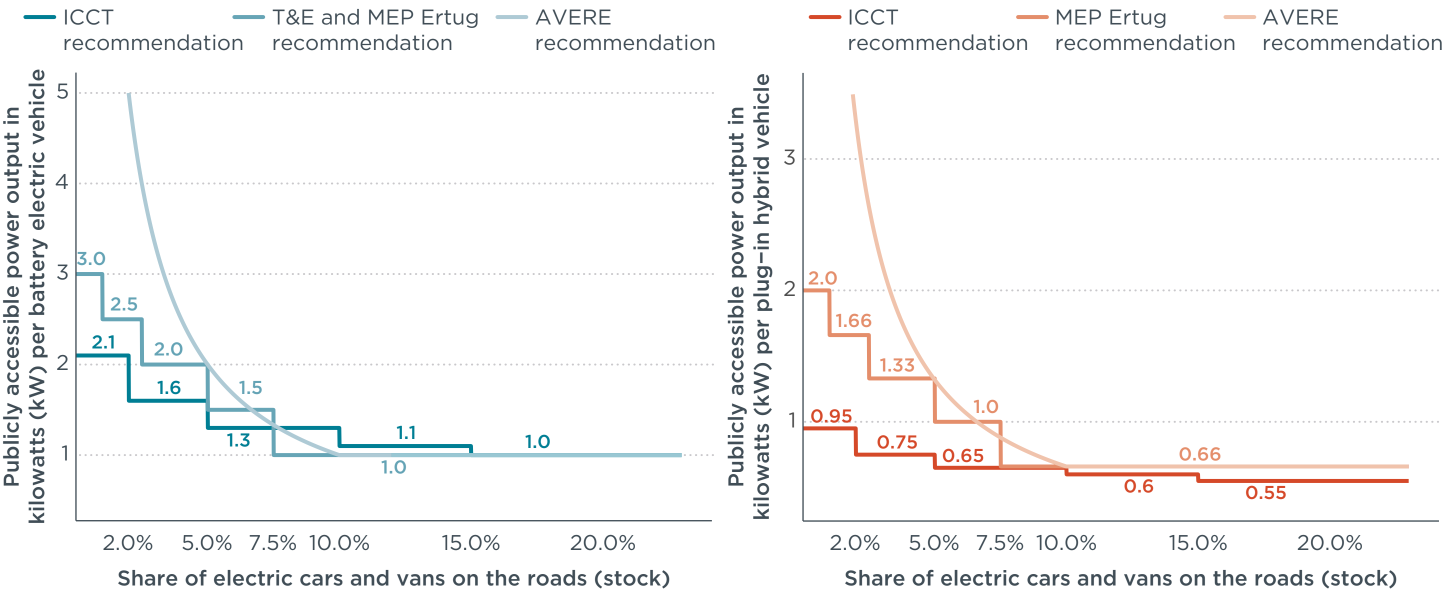

Figure 11. Comparison of this study's recommendations (dark lines) to AVERE recommendations (light lines) and Transport & Environment and MEP Ertug's recommendations in terms of total publicly accessible power output per BEV (left) and per PHV (right).

The figure shows that although these analyses are aligned in the recommendation for stronger targets at earlier market phases, they differ substantially in magnitude. Our analysis suggests a need for 15% - 40% less charging power output per BEV up to a 7.5% share of electric car and van stock compared to T&E and MEP Ertug's recommendations. For a share between 7.5% and 15%, our analysis then recommends more public power output per BEV than the compared studies, coinciding with the original AFIR proposal of 1 kW per BEV when the stock share exceeds 15%. The recommendations of our study for public power output per PHVs remain lower than the recommendations from MEP Ertug and AVERE for all electric vehicle market shares, with the largest gap at low shares of electric vehicle stock.

In addition to these electric car and van stock share-based targets, T&E and MEP Ertug both recommend putting a safeguard mechanism in place, similar to the one recommended by AVERE and shown on the graph: For all EU Member States with an electric car and van stock share below 2% in 2025, power output requirements would be calculated as if 2% of their car and van fleet were, indeed, electric. This threshold is increased to 5% in 2027 and to 10% in 2030.

PATHWAYS TO FUND CHARGING INFRASTRUCTURE ROLL-OUT

The previous sections suggest the need for a faster public charging infrastructure rollout than the original AFIR proposal would require. This implies a need for additional investment in charging infrastructure deployment in the near term. Many EU Member States have provided public funding for the rollout of charging infrastructure through 2021, but charging infrastructure is nonetheless projected to be the largest cost related to the zero-emission vehicle transition through 2050 (Slowik et al., 2019). This raises questions about the relative contributions of the public and private sectors in funding this charging infrastructure rollout, and how the EU can support its Member States.

PRIVATE SECTOR INVOLVEMENT

The profitability of operating public charging infrastructure tends to increase in proportion to electric vehicle penetration (Rimmer et al., 2021). While many charge points installed through early 2022 have received public subsidies, some countries are approaching a point where installing and operating charge points makes financial sense and could thus be pursued by the private sector without public funding. This trend is expected to continue: The impact assessment for AFIR suggests that 60% of costs for public charge points for cars and vans in Europe will be borne by the private sector through 2030, rising to 90% after 2030 (European Commission, 2021b).

A number of energy providers and car manufacturers have announced investments in public charging infrastructure, pointing to an improving business opportunity in this sector. For example, a senior executive of BP stated in January 2022 that selling DC fast charging may soon make as much business sense as selling conventional fuel (Bousso, 2022). Similarly, the CEO of EVBox, an electrical supply equipment company based in the Netherlands, stated that the entire electromobility ecosystem is already profitable in the Netherlands (Infos Auto, 2020).

Investment from private or public electricity producers and distributers may also be justified based on increased electricity sales for electric vehicles and benefits to all electricity ratepayers. For example, Hydro-Québec, the public utility for the province of Québec in Canada, estimates that each BEV sold results in an additional $300 CAD (approximately €210) per year in electricity consumption (both at home and in public), revenue that can be used to finance deployment of fast charge points (Rajon Bernard & Hall, 2022).

Vehicle manufacturers are also increasingly investing in charging infrastructure networks. In 2021, Stellantis[3] announced the launch of its own charging infrastructure network, called Atlante, in Southern Europe in response to the Fit for 55 package put forward by the European Commission in mid-2021 (Stellantis 2021). Tesla, which has constructed normal and DC fast charging stations for drivers of their own vehicles in Europe since 2013, began opening its DC fast charging stations to other vehicles in select markets in late 2021 (Tesla, 2021). As of early 2022, this program was in place in France, the Netherlands, and Norway, but the company intends to expand access worldwide as electric fleets expand. A consortium of automakers including BMW, Ford, Hyundai, Mercedes-Benz, and Volkswagen have set up more than 1,600 fast charge points in 24 European countries as part of the Ionity network, with plans to install approximately 7,000 fast charge points by 2025 (Ionity, n.d.).

3 Stellantis is the parent company of Alfa Romeo, Citroën, Fiat, Jeep, Lancia Opel and Peugeot

EUROPEAN UNION PROGRAMS AND INITIATIVES

Despite this increasing private investment in leading markets within the EU, public support will still be important in the short term for certain charging segments in almost all Member States. EU Member States have access to various support programs by the EU that help to deploy the necessary public charging infrastructure for the growing number of electric cars and vans. This section describes three of the most important EU co-funding initiatives to support charging infrastructure development as of February 2022.

The **Connecting Europe Facility (CEF)** infrastructure financing instrument was established by EU Regulation 1316/2013 in December 2013 (*Regulation (EU) No 1316/2013*, 2013). The aim is to support the development of an interconnected transport, energy, and communications infrastructure across Europe. The CEF Transport policy area supports projects with the aim to reduce the environmental impact of transport and enhance energy efficiency (European Commission, 2015).

Under CEF Transport, a call for proposals under the title "CEF 2 Transport - Alternative Fuels Infrastructure Facility – General envelope" was published in September 2021 (European Climate, Infrastructure and Environment Executive Agency (CINEA), 2021). Specifically, the call aims to support the deployment of alternative fuel supply infrastructure, encompassing electric, hydrogen, and liquefied natural gas vehicles, for light-duty and heavy-duty vehicles in an effort to decarbonize transport along the Trans-European Transport Network (TEN-T, the primary road connections linking the European Union). The available call (grant) budget is €1.2 billion, designed as a multiannual work program with five cut-off dates for the submission of proposals until the end of 2023.

For cars and vans, the call covers publicly accessible charging stations with a minimum power output of 150 kW and grid connection with a minimum power capacity of 600 kW to be located on TEN-T road sections or within 2 kilometers (km) of exits along the TEN-T network. To guarantee durability, the call suggests that supported charge points be operated and maintained for a minimum of five years. Companies and government agencies alike may apply for funding under the program. The program provides €20,000 for hardware and €20,000 for the grid connection per unit for light-duty charge points; the call encourages applications of no less than €1 million. At least 10% of the project cost must be financed by an implementing partner or another public or private financial institution.

The **Recovery and Resilience Facility (RRF),** which entered into force by EU Regulation 2021/241 in February 2021 (Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 Establishing the Recovery and Resilience Facility, 2021), is a temporary EU instrument providing financial support for EU Member States in the 2020 to 2026 timeframe. The overall aim of the initiative is to tackle the effects of the COVID-19 pandemic (European Commission, 2020). Under this regulation, Member States must prepare a National Recovery and Resilience Plan including reform and investment ambitions for various policy areas up to 2026 and submit it to the EU to receive co-funding as part of the RRF.

In September 2021, the EU issued a supplementary regulation specifying eleven measures to be included in member states' national recovery and resilience plans *(Commission delegated regulation (EU) 2021/2106, 2021),* one of which focuses on alternative fuels infrastructure. In addition, the original regulation from February 2021 states that electric vehicle charging can be supported as an element of overarching measures such as newly built or upgraded motorways and roads as part of the TEN-T core network and other reconstructed or modernized roads.

All 27 EU Member States except the Netherlands have submitted their National Recovery and Resilience Plans to the EU as of February 2022. About three quarters of the national governments aim to use some of the RRF funding to support the extension of the public charging infrastructure network for electric vehicles including Belgium, Bulgaria, Croatia, Czechia, Finland, France, Germany, Greece, Hungary, Italy, Lithuania, Luxembourg, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden (European Commission, 2020).

The **InvestEU Program** established in March 2021 aims to promote recovery, green growth, jobs, and prosperity across Europe in the 2021 to 2027 period (Regulation (EU) 2021/523, 2021). It is one of three pillars of the EU Just Transition Mechanism in the context of the European Green Deal. The Just Transition Mechanism is a key tool to ensure that the transition towards climate-neutrality is targeted at the most affected countries and regions (European Commission, (2019b).

The InvestEU program includes the InvestEU fund aimed at mobilizing public and private investment in four policy areas, including "sustainable infrastructure". Companies, public-private partnerships (PPPs), and non-profit organizations in the EU or selected other countries (e.g., Norway, Iceland, Liechtenstein) are eligible to apply (InvestEU, 2021).

The enabling regulation for the InvestEU Program lists "sustainable infrastructure" among the key performance and monitoring indicators and specifically highlights building and upgrading alternative fuel supply points. For sustainable infrastructure related to transport, the regulation suggests that investments should be particularly mobilized along the TEN-T network.

Table 5 summarizes key criteria of the three aforementioned EU programs open to all EU Member States that provide co-financing for publicly accessible charge points for electric cars and vans.

Table 5. Key EU funding programs to support public charging infrastructure including electric cars and vans

Funding initiative	Focus of funding	Funding period	Eligibility	Funding amount
Connecting Europe Facility (CEF) Call for proposal - CEF 2 Transport - Alternative Fuels Infrastructure Facility – General envelope	Publicly accessible charging stations along the TENT- road network with a minimum power output of 150 kW	January 2021 to September 2026	Legal entities (public or private bodies) in EU Member States and third countries associated with the CEF	€20,000 per unit (charging station)
	Grid connection with a minimum power capacity of 600 kVA			€20,000 per unit (charging station)
Recovery and Resilience Facility (RRF)	Alternative fuels infrastructure	February 2020 to December 2026	EU Member States	Not specified
	Electric vehicle charging as an element of the measure to build or upgrade motorways and roads in TEN-T			
	Electric vehicle charging as an element of the measure to reconstruct or modernize other roads (motorway, national, regional, or local)			
InvestEU Program	Alternative fuel supply points	2021 to 2027	Natural or legal persons established in an EU country or in an eligible third country (e.g., Norway, Iceland, Liechtenstein); acceding or candidate countries (Albania, Montenegro, North Macedonia, Serbia, Turkey); potential candidate countries; and countries covered by the European Neighbourhood Policy (Algeria, Armenia, Azerbaijan, Belarus, Egypt, Georgia, Israel, Jordan, Lebanon, Libya, Moldova, Morocco, Palestine, Syria, Tunisia, and Ukraine)	Not specified

CONCLUSIONS AND POLICY RECOMMENDATIONS

The EU's proposed AFIR provides a novel metric for future electric vehicle charging infrastructure targets: publicly accessible charging power capacity per electric car and van on the road. Building on in-depth analysis of charging infrastructure needs in Germany, France, and Italy, this paper assesses the implications of the proposed AFIR targets and examines opportunities for improvement. As a result of this analysis, we draw the following conclusions and accompanying recommendations to strengthen the AFIR proposal:

All EU Member States currently exceed the proposed AFIR target, suggesting an opportunity for greater ambition at early market stages. All 27 EU Member States met the proposed AFIR target (1 kW per BEV and 0.66 kW per PHV) for public charging power per electric car and van as of the end of 2021. 20 of the 27 states had more than twice the public charging capacity required, and 12 had more than three times. This suggests that the regulation as proposed would not compel additional charging infrastructure construction in most of the EU in the near future, including in many Member States where electric vehicle uptake is far below the EU average.

The AFIR could be strengthened by including targets that vary depending on the electric share of passenger car and van stock. Modeling of charging infrastructure needs suggests that the AFIR ratios of 1 kW per BEV and 0.66 kW per PHV may be sufficient for more advanced electric vehicle markets—once Member States surpass the 15% electric share of car and van stock, expected around 2028 for the EU on average. However, more ambitious targets are needed in the earlier market. For example, this analysis suggests that for early electric vehicle markets with an electric share of car and van stock below 5%—the case for all EU Member States but Sweden through 2021—public charging capacity of at least 1.6 kW per BEV and 0.75 kW per PHV is necessary. Adopting stepwise targets based on electric car and van stock share would promote geographic coverage and build consumer confidence during the early market but also allow for more efficient and profitable network design as the market evolves, consistent with the experience of leading electric markets.

- We recommend that the AFIR targets for total publicly accessible power output per battery and plug-in hybrid car and van be adjusted to **vary according to the electric share of car and van stock** through a **stepwise approach**. Our recommended targets start at 2.1 kW per BEV and 0.95 kW per PHV for markets with less than 2% electric car and van stock share and incrementally decline to 1 kW per BEV and 0.55 kW per PHV for markets above 15% electric car and van stock share.
- The AFIR could also clarify that power capacity targets refer to the charging capacity that can be used simultaneously, by introducing a **"total power output" definition** in *Article 2 Definition* of the AFIR, stating that 'total power output' means the maximum nominal power in kW that can be provided simultaneously to vehicles at one time. This does not preclude the implementation of smart charging to optimize consumption.

Beyond the AFIR, additional policies will be needed to ensure that home and workplace charging also keep pace with electric vehicle adoption. Public charging needs are highly sensitive to the level of access to private home and workplace charging, and the suggested targets for public charging capacity rely on broad access to private charging. If private charging access were decreased by 50%, the required total public power output would increase by 70% to 100%. Because private home and workplace charging are typically less expensive to install than public charge points and are also the most affordable and convenient charging option for drivers, this alternative scenario would likely result in greater system-wide costs.

» **The EU and national governments could support home and workplace charging, including by strengthening the Energy Performance Building Directive** (EPBD) with binding requirements that align with projected electric vehicle uptake resulting from CO_2 standards and the AFIR's targets for public power output.

The EU provides multiple funding sources to help finance public charging as private-sector investments increase. Public funding has been key to deploying the early public charging infrastructure network across Europe and will remain necessary for an equitable charging system, at least in the short term. The EU has established several initiatives to help finance public charging infrastructure for electric cars and vans. The Connecting Europe Facility Transport program specifically includes at least €1.2 billion for charging infrastructure for electric cars and vans. Member States can also apply funding from broader programs such as the Recovery and Resilience Fund and InvestEU toward public charging infrastructure, helping to meet the targets outlined in the AFIR. At the same time, private sector involvement and investments are increasing, including from energy providers and car manufacturers, and private sector charging installations are expected to grow further and become more profitable as the electric vehicle market matures.

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