WHITE PAPER

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# A REVIEW OF THE AFIR PROPOSAL: PUBLIC INFRASTRUCTURE NEEDS TO SUPPORT THE TRANSITION TO A ZERO-EMISSION TRUCK FLEET IN THE EUROPEAN UNION

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# EXECUTIVE SUMMARY

This white paper assesses the publicly accessible charging and refueling infrastructure required by zero-emission trucks in the European Union (EU) through 2030. The results are compared against targets put forward by the Alternative Fuel Infrastructure Regulation (AFIR) proposal of the European Commission. The proposed regulation sets targets for the minimum capacity and maximum distance between recharging and hydrogen refueling points along the Trans-European Network for Transport (TEN-T) to be met by Member States.

We quantify the level of infrastructure deployment required by the on-road fleet of zero-emission heavy-duty vehicles (ZE-HDVs) using a bottom-up assessment. First, we estimate the overall electricity and hydrogen consumption of the fleet. We then assess the charging power and hydrogen capacity along the Trans-European Network needed to satisfy these needs. Finally, we infer the infrastructure distribution across the Trans-European Network based on simulated truck traffic flows. The methodology, summarized in Figure ES 1, assumes a deployment of ZE-HDVs aligned with the EU's 2050 climate neutrality targets.

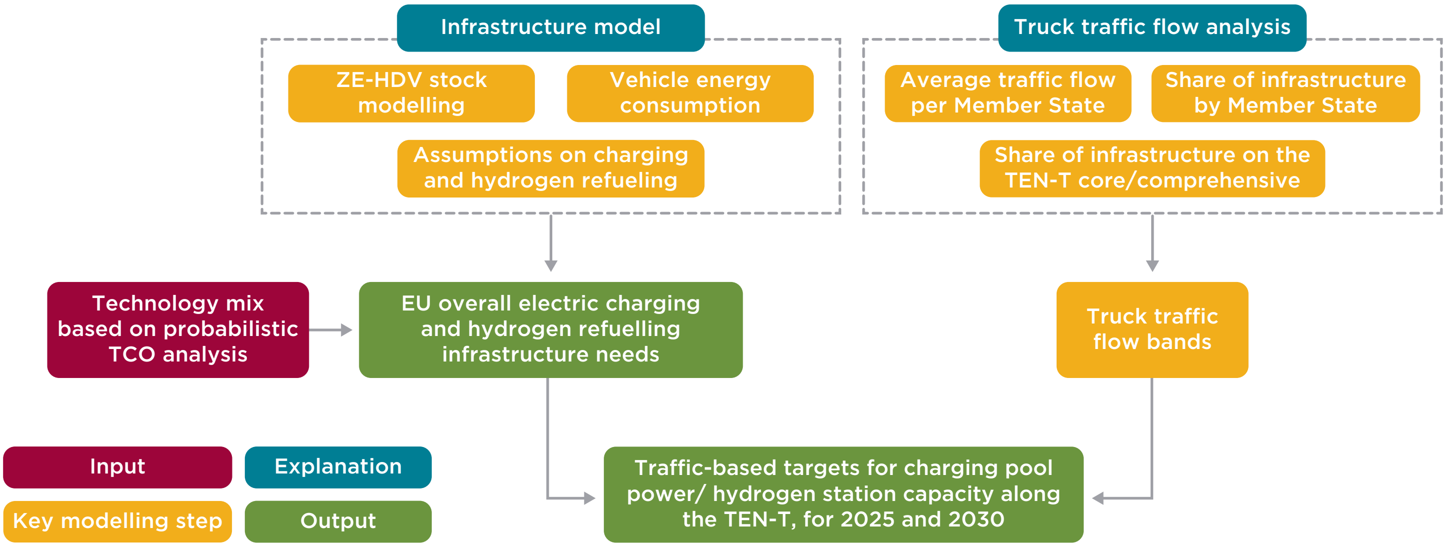


**Figure ES 1**. Main modelling steps used in this analysis to derive traffic-based targets for the rollout of electric charging and hydrogen refueling infrastructure along the Trans-European Network.

At the EU-27 level, we find that the AFIR targets are too high in the short term and too low in the longer term. The 2025 targets proposed in the AFIR are about 25% higher than we estimate is required to meet the projected public charging needs of the battery electric truck fleet. We do not consider this anticipation to be excessive, as early infrastructure rollout is critical to providing confidence to manufacturers and fleets in the early stages of electric truck adoption.

For 2030, our analysis indicates a need for about 80% more charging capacity than the AFIR proposal suggests. These overall results at the EU-27 level are summarized in Figure ES 2.

**Total installed power of public charging infrastructure (Gigawatts)**

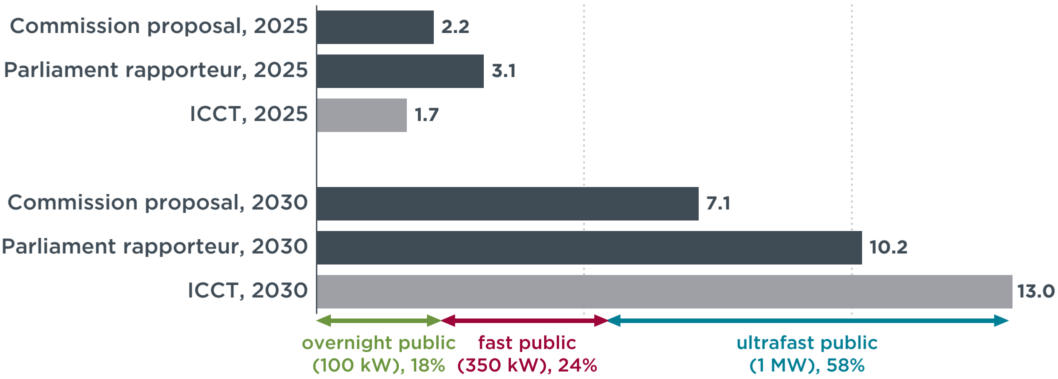


**Figure ES 2**. Total required installed power as calculated by the ICCT and compared to targets proposed by the European Commission and by the European Parliament's rapporteur

The techno-economic modeling of the electrification pathways suggests that battery-electric trucks will be the most cost-effective solution in the market for the majority of use cases. However, our analysis also shows that fuel-cell trucks may have the advantage in certain use cases featuring long range, high payload, and large day-to-day operating variability. We estimate that fuel-cell trucks can represent 9% of the long-haul truck market by 2050, and we find that the hydrogen refueling capacity proposed by the AFIR for 2030 would not be needed until 2035.

We find that the infrastructure rollout must not be homogeneous across Member States, due to the large differences in traffic volumes along their roads, but instead should be targeted to locations where the need is greatest. We identify four levels of average truck traffic flow that serve to group Member States into roughly even clusters, as shown in Table ES 1 for the core part of the Trans-European Network. Although each Member State has roads in all four traffic bands, this indicative clustering highlights the need for a more differentiated approach to target setting.

**Table ES 1**. Clustering of Member States based on the average traffic flow on their portions of the core Trans-European Network.

| Traffic band | Member States whose average traffic flow falls within the band |
|---|---|
| **> 9,000 HDV/day** | Germany, Poland, Belgium |
| **6,000 to 9,000 HDV/day** | Czech Republic, Luxemburg, Netherlands, Denmark, Austria, France, Italy |
| **3,000 to 6,000 HDV/day** | Slovakia, Hungary, Spain, Slovenia |
| **<3,000 HDV/day** | Estonia, Romania, Bulgaria, Finland, Greece, Latvia, Lithuania, Portugal, Croatia, Sweden, Ireland, Cyprus, Malta |

We propose to adjust the targets so that the total installed power is consistent with the results of our modelling, while still providing the flexibility to deploy lower levels of infrastructure on low volume roads of the Trans-European Network, based on these traffic flow bands. Member States seeking to meet these lower targets on some roads of their domestic Trans-European Network would need to apply to the European Commission for a derogation; otherwise the highest target would apply. Our recommendations are outlined here and summarized in Figure ES 3:

» Increase the nominal 2025 charging pool target for the core network to 2,000 kW every 60 km, and add low-volume flexibilities as traffic flow allows.

» Align the 2030 charging pool targets for the core and comprehensive networks.

» Increase the nominal 2030 charging pool target for the core and comprehensive networks to 9,000 kW every 60 km, adding low traffic volume flexibilities.

» Increase the nominal capacity target for hydrogen refueling stations to 3 tonnes per day every 150 km, postponing its application until 2035, avoiding setting sub-targets for liquid or compressed hydrogen, and adding low-volume flexibilities.

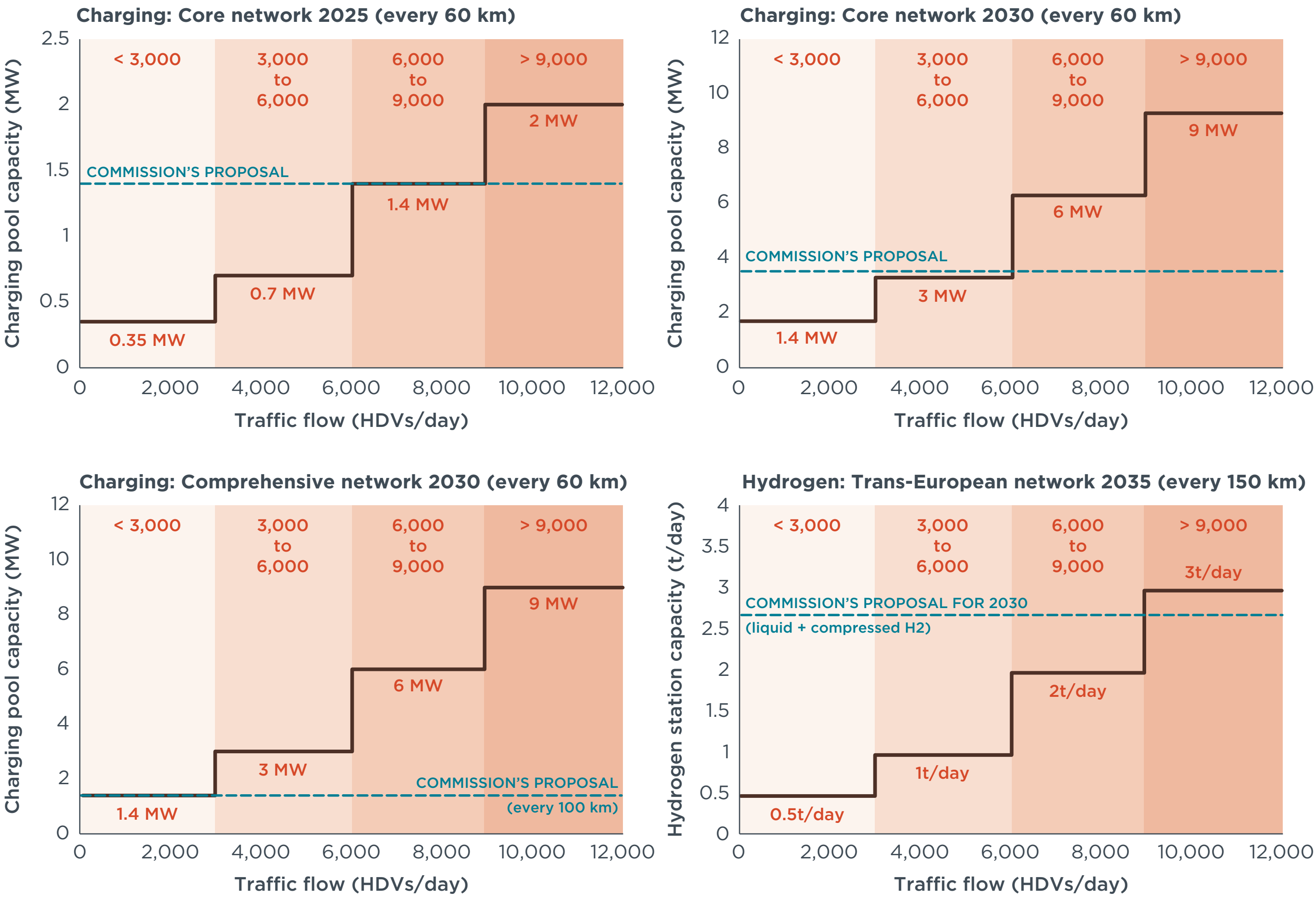


**Figure ES 3**. ICCT's proposal for traffic-based targets for the rollout of charging and hydrogen refueling infrastructure along the Trans-European Network for Transport, core and comprehensive networks.

# TABLE OF CONTENTS

# LIST OF FIGURES



# LIST OF TABLES

# INTRODUCTION

Meeting the objectives of the European Union (EU)'s Climate Law will require rapid decarbonization of the road freight sector, which is responsible for 26% of road transport-related $CO_2$ emissions (EEA, 2021). As the EU proposes to revise the stringency of its $CO_2$ standard for heavy-duty vehicles (HDVs) at the end of 2022, it has an opportunity to set targets that ensure the best pace of decarbonization.

Zero-emission HDVs (ZE-HDVs) are the only way to achieve this quickly and substantially, and ICCT studies have already shown the technical feasibility and potential economic viability of technologies such as battery electric trucks (BETs) and fuel cell electric trucks (FCET) (Basma et al., 2021; Basma & Rodríguez, 2022). Moreover, HDV manufacturers have clearly communicated their commitment to the decarbonization of the industry and made ambitious pledges to decarbonize their new-vehicle fleet by 2040 (ACEA & PIK, 2020). While this endeavor gathered significant momentum throughout 2021, the lack of electric charging and hydrogen refueling infrastructure remains a significant barrier, as perceived by both manufacturers and fleets, which threatens to slow the transition process. Without certainty on the future deployment of infrastructure, the EU will struggle to ensure consensus on a strict roadmap to decarbonization for its upcoming standard.

To this end, the EU's Alternative Fuels Infrastructure Regulation (AFIR) was proposed in July 2021 as part of the "Fit for 55" package of the European Commission. The proposed regulation would set mandatory targets for the deployment of infrastructure for charging and hydrogen refueling for both light-duty and heavy-duty vehicles. While the AFIR proposal is a first step in the right direction, the ICCT's preliminary assessment suggested a potential misalignment between the proposed targets (Basma & Rodriguez, 2021), and the capacity needed—given a growing fleet of ZE-HDVs—to help the EU meet its climate goals (Mulholland et al., 2022). This paper quantifies such infrastructure needs in detail and compares them against the Commission's targets and other proposals emerging as part of the co-decision process.

In this study, we estimate for each Member State the number of chargers and hydrogen refueling stations needed to fully transition to ZE-HDVs in the EU by 2040, and we provide recommendations for aligning the proposed targets with the goals of EU's Climate Law, taking into account differences in freight activity among EU countries.

# REGULATORY CONTEXT FOR HEAVY-DUTY VEHICLES

## EUROPEAN COMMISSION PROPOSAL FOR THE AFIR

On July 14, 2021, the European Commission released its regulatory proposal for the deployment of alternative fuels infrastructure. The provisions concerning heavy-duty vehicles would set minimum requirements for the rollout of infrastructure serving zero-emission HDVs across the Trans-European Network for Transport (hereafter the Trans-European Network or TEN-T), and the related urban nodes and overnight truck parking areas.

The Trans-European Network is composed of a core network gathering the most important corridors, mapped out in Figure 1, and a larger comprehensive network of roads**.** Nine corridors compose the bulk (70%) of the core network (CEDR, 2020). The Trans-European Network also includes 88 urban nodes connecting the various corridors.


**Figure 1.** Map of the TEN-T network (European Commission, 2021a). Core and non-core network are shown in thick and thin lines, respectively. Yellow dots represent urban nodes. Red dots represent capital cities.

The proposed regulation sets targets for the minimum capacity and maximum distance between recharging and hydrogen refueling points to be met by Member States. The key elements of the Commission's proposal are summarized in Table 1.

**Table 1.** Key elements of the Commission's proposal and tabled amendments by Parliament's rapporteur

| Scope | Metric | Commission's proposal | Rapporteur's draft report |
|---|---|---|---|
| **TEN-T core network** | Power of recharging pool every 60 km per direction | 1,400 kW by 2025<br>3,500 kW by 2030 | 2,000 kW by 2025<br>5,000 kW by 2030 |
| | Minimum charging speed of highest-power charging station per pool | 350 kW | 700 kW |
| **TEN-T comprehensive network** | Power of recharging pool every 100 km per direction | 1,400 kW by 2030<br>3,500 kW by 2035 | 2,000 kW by 2027<br>5,000 kW by 2032 |
| | Minimum charging speed of highest-power charging station per pool | 350 kW | 700 kW |
| **Urban nodes** | Aggregated power output at each urban node | 600 kW by 2025<br>1,200 kW by 2030 | 1,400 kW by 2025<br>3,500 kW by 2030 |
| | Minimum charging speed of highest-power charging station per pool | 150 kW | 350 kW |
| **Safe and secure parking areas** | Minimum number of charging stations with at least 100 kW | 1 station by 2030 | 2 stations by 2025<br>4 stations by 2030 |
| **Hydrogen refueling stations (HRS)** | Distance between HRS* (> 2 t/day) on TEN-T network | 150 km by 2030, 700 bar<br>450 km by 2030, liquid | 100 km by 2027, 700 bar<br>400 km by 2030, liquid |
| | Urban nodes | At least 1 HRS by 2030 | At least 1 HRS by 2027 |

## EUROPEAN PARLIAMENT DRAFT REPORT

On February 14, 2022, the rapporteur of the European Parliament Committee on Transport and Tourism (TRAN) released his draft report (Ertug, 2022). Compared to the Commission's proposal, the tabled amendments would increase the requirements for deployment of infrastructure for both battery electric and fuel-cell electric heavy-duty vehicles. The main amendments proposed by the rapporteur for heavy-duty vehicles are summarized, together with the Commission's proposal, in Table 1. Amendments from shadow rapporteurs are to be submitted by March 18, with a vote in the TRAN committee targeted for mid-May 2022.

## DEVELOPMENTS IN THE COUNCIL OF THE EUROPEAN UNION

At the time of writing, the Council had not adopted a response to the AFIR. Nevertheless, discussions are taking place at the working party level, as well as in the Permanent Representatives Committee and the Council of Ministers.

The Slovenian Presidency of the Council presented compromise drafts in fall 2021, the last of which preserved the Commission's charging targets—both in terms of capacity and distance—but removed the requirement to build infrastructure in both directions of travel for roads with fewer than 2,000 trucks per day. Regarding hydrogen refueling infrastructure, the Slovenian draft compromise text proposed to remove the capacity target of 2 tonnes of hydrogen ($H_2$) per day, eliminate the requirement to build infrastructure for both compressed and liquefied hydrogen, and increase the distance requirements to 180 km while keeping 150 km as the average target (General

Secretariat of the Council, 2021). No compromise could be found by the end of the Slovenian Presidency.

The AFIR—explicitly mentioned in the program for the French Presidency of the Council (PFEU, 2022)—is one of the files on which the French government will focus as part of the Commission's Fit for 55 climate package. In a recent note, the French Presidency proposes to other Council members to postpone a decision on the AFIR requirement for heavy-duty vehicles, on the grounds of technological uncertainty. Instead, the French Presidency proposes to include a review clause to first set the requirements in 2025 (Contexte, 2022), meaning that no infrastructure rollout would be mandated by the AFIR until the end of the decade. This poses a threat to the early market adoption of ZE-HDVs, which is widely understood to require sufficiently available charging and refueling infrastructure. The French Presidency also proposes to oblige Member States to begin planning the required upgrades of their domestic electric grid networks as soon as the regulation is adopted, to ensure that it does not prevent the rollout of charging infrastructure.

## METHODOLOGY AND ASSUMPTIONS

To estimate the level of infrastructure deployment required by the on-road fleet of ZE-HDVs in the coming years, we adopt a two-stage approach. First, we estimate the overall charging power and hydrogen capacity demand of the European truck fleet based on the deployment of ZE-HDVs needed to meet the EU's climate neutrality goal by 2050 (Mulholland et al., 2022). To do this, we use a newly developed infrastructure model based on the ICCT Roadmap framework (International Council on Clean Transportation, 2021). In the second stage, we distribute this charging power and hydrogen capacity along the Trans-European Network, accounting for portions of the network with different traffic flows, measured in number of trucks per day. This second stage is based on traffic flow data recently published by Fraunhofer ISI (Speth et al., 2022).

### ESTIMATING THE OVERALL FLEET CHARGING POWER AND HYDROGEN CAPACITY NEEDS

Figure 2 summarizes the key modelling steps used to assess the overall infrastructure needs. The following paragraphs detail the key assumptions.

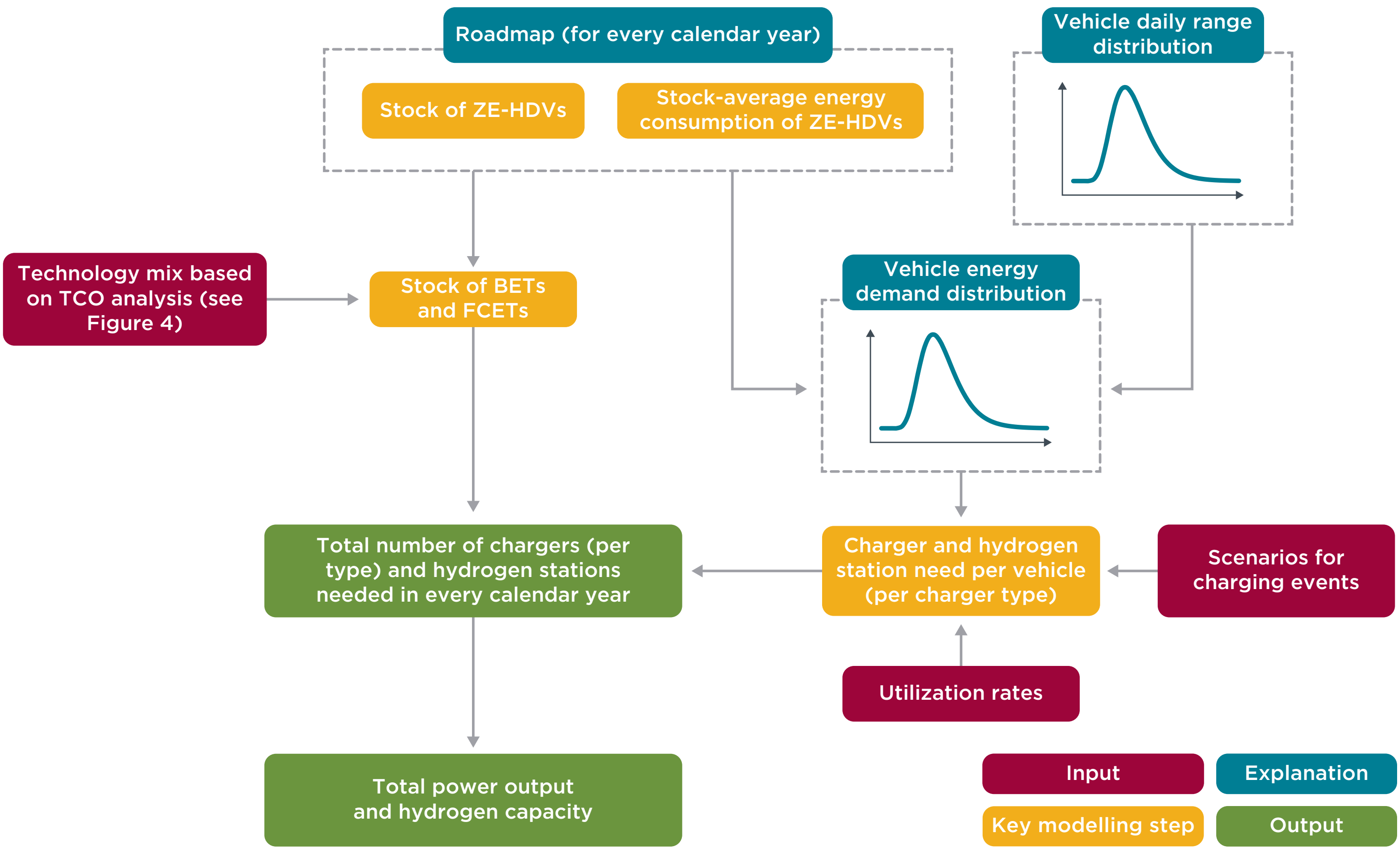


**Figure 2.** Key modelling steps to assess the overall electric charging and hydrogen refueling needs of the European truck fleet.

#### ZE-HDV sales and stock modelling

Using ICCT's Roadmap model, we project the sales, stock, and energy needs of ZE-HDVs in the EU until 2050. For this analysis, we modeled a policy scenario that would mandate a $CO_2$ emissions reduction target of at least 60% by 2030, at least 90% by 2035, and 100% by no later than 2040 for the upcoming review of the $CO_2$ standards

(Mulholland et al., 2022). We estimate this would result in a ZE-HDV sales share of 38% in 2030 and a 7% share of the total stock for ZE-HDVs in 2030.

Setting such standards would closely align the EU's HDV sector with the reductions required by the European Climate Law, the EU's legal framework for aligning European industry with the Paris agreements (Mulholland et al., 2022). The scenario also aligns with pledges made by manufacturers to ramp up the production of ZE-HDVs. Although these commitments vary in ambition for 2025 and 2030, all major HDV manufacturers have signed a declaration with the European Automobile Manufacturers' Association (ACEA) pledging to sell only fossil-free commercial vehicles by 2040 (ACEA & PIK, 2020).[1] Targets announced by individual manufacturers are shown in the Appendix.

Figure 3 shows the projected stock of ZE-HDVs out to 2035.

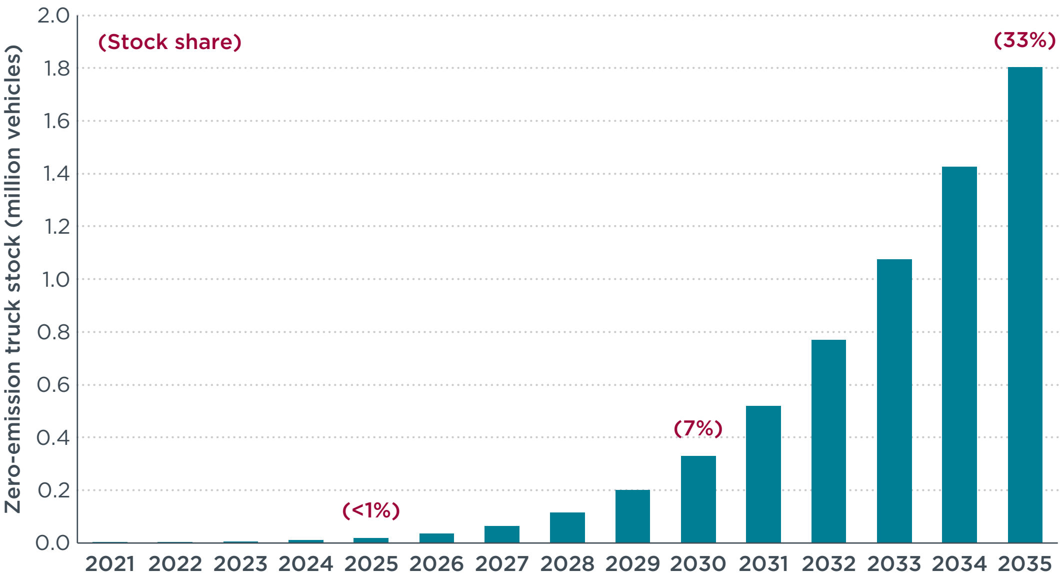


**Figure 3.** Assumed evolution of the stock of ZE-HDVs in the EU.

We classify HDVs by their propensity for ZEV deployment, classifying buses and light trucks as fast-transition vehicles, regional and urban delivery trucks as medium-transition, and long-haul transport and construction trucks as slow-transition. Based on industry commitments, we assume that medium-transition vehicles will have a 50% greater sales share of ZE-HDVs than slow-transition vehicles. The evolution of the ZE-HDV stock for the different truck segments is shown in the Appendix.

### Technology mix

For a given stock of ZE-HDVs, the split between battery-electric and fuel cell trucks largely determines the needs for charging and hydrogen refueling infrastructure. The consumer technology choices are assumed to be driven by differences in the techno-economic performance. Thus, we conducted a Monte Carlo analysis (probabilistic modeling) of the total cost of ownership (TCO) of both electrification pathways for a variety of truck applications. The model considers the truck purchase price and operational expenses from a first-user perspective over a 5-year period of ownership. The levelized cost of energy—for both electricity and hydrogen—captures the infrastructure costs reported in the AFIR's impact assessment study (European Commission, 2021b). The modeling also accounts for the costs of financing, depreciation, and maintenance, as well as the impacts of reduced payload capacity

1 We apply the optimistic assumption that fossil-free here refers to zero-emission vehicles, rather than an internal combustion engine fueled by advanced biofuels or synthetic fuels, which still have tailpipe emissions.

resulting from the increased weight of the powertrain. More details on the TCO model can be found in Basma et al. (2021).

The probabilistic analysis combines the impact of uncertainties that arise when forecasting technology and energy costs. The main input variables to the TCO model are determined as probability distribution functions that are defined based on data collected from the literature and truck fleet operators. The main variables considered in this analysis are the average daily driving range, driving range variability,[2] payload, battery cost, fuel cell unit cost, hydrogen storage tank cost, electricity, and hydrogen fuel prices. The energy storage systems—namely the battery and the hydrogen tank—are sized based on the truck use case, its energy efficiency, and in the case of battery electric trucks, the available charging technology. Figure 4 presents a schematic of the probabilistic approach used to estimate the TCO of the trucks.

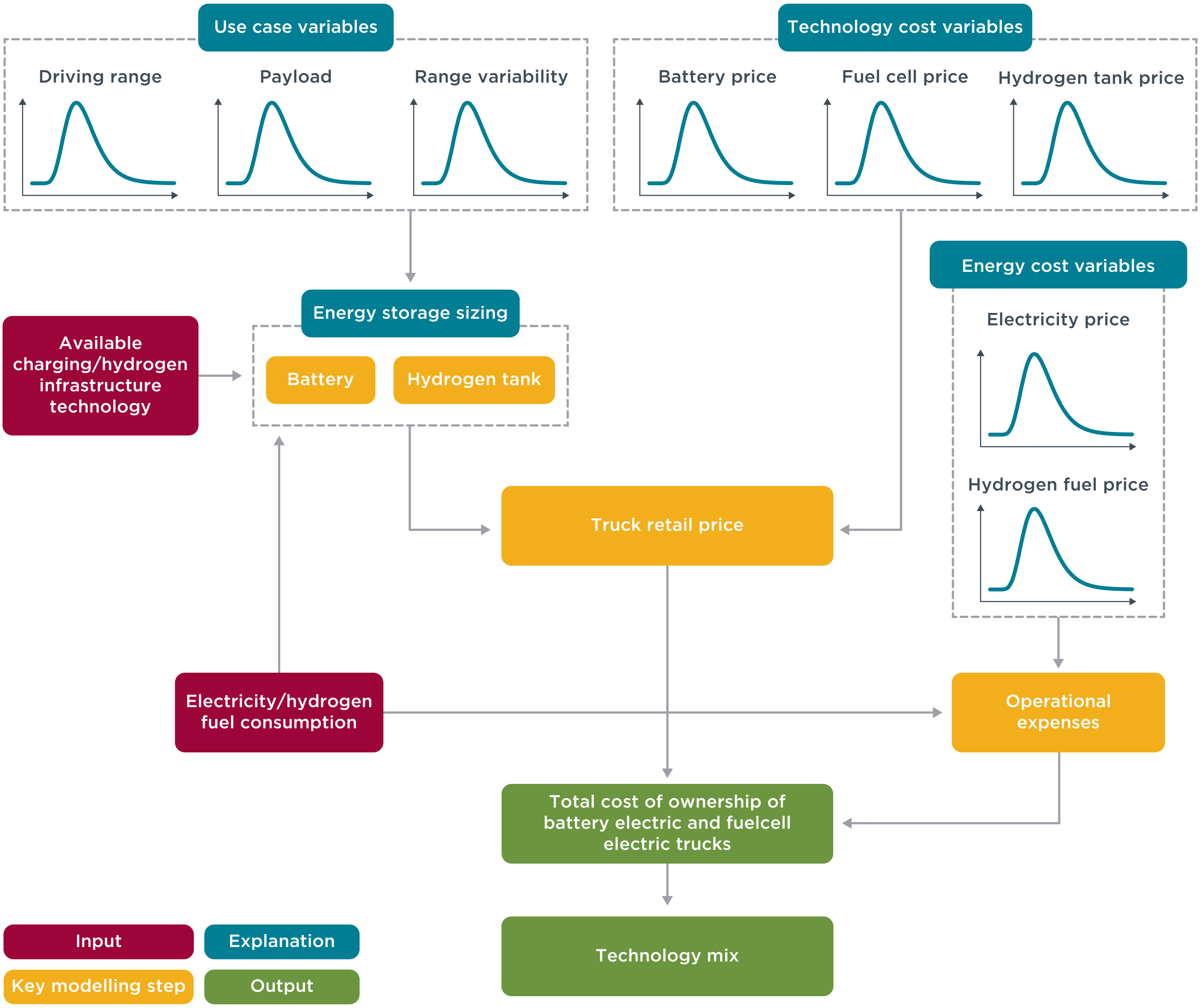


**Figure 4.** Schematic of the stochastic approach used to estimate the trucks TCO

2 For trucks with high range variability, the daily distances can deviate significantly from the average value. The energy storage system is then dimensioned based on the maximum experienced daily range. In contrast, the TCO calculation is performed using the average daily driving range.

The assumptions regarding energy prices have a large impact on the resulting TCO. Electricity prices in 2022 are adopted from official EU databases (Eurostat, 2022), resulting in an average price of ¢12.7 per kWh. By 2030, we assume that the share of renewable electricity will reach at least 50%[3] for every member of the EU-27, resulting in an average electricity price of ¢11.76 per kWh. In 2050, we assume 100% renewable electricity with an average price of ¢7.3 per kWh. More details on the renewable electricity price projection can be found in (Zhou et al., 2022). On top of these electricity prices, additional fees will be charged by charging station operators to recuperate their initial investment. These charges are dependent on charger cost and utilization. More details can be found in Basma et al. (2021).

We forecast at-the-pump hydrogen prices out to 2050, which includes the levelized cost of production, fueling costs, and varying levels of subsidies. Projections for 2030 and 2050 depend on several key variables. These include technological progress, electricity prices, and policy support resulting from Fit for 55 regulatory proposals whose outcomes are not yet known—such as the revision of the Renewable Energy Directive (RED II). Therefore, we derive three scenarios—pessimistic, mid-level, and optimistic—for hydrogen prices, using different combinations of the cost of production, fueling costs, and level of subsidy. The probabilistic approach adopted here is meant to capture this uncertainty. Furthermore, the assumptions used in this analysis are in line with previous assessments done by the ICCT (Searle & Christensen, 2018; Zhou et al., 2022).

We give greater weight to the optimistic hydrogen price scenario, which uses our lower estimate for the costs of production and refueling, ranging from €3 per kg to €5 per kg (which in turn is based on an assumption of high rates of infrastructure utilization, and high levels of subsidies out to 2050). This weighting generates optimistic results regarding the TCO performance of fuel cell trucks, and provides an upper bound for their market uptake. It also captures the fact that the market acceptance of fuel cell vehicles depends not only on their TCO performance compared to battery electric vehicles, but also on other consumer behavior elements not captured in this model.

We model prices for hydrogen produced from natural gas with carbon capture and storage (“blue hydrogen”) and hydrogen produced from electrolysis using renewable electricity (“green hydrogen”). We assume all hydrogen used in transport applications today is blue hydrogen, at an average at-the-pump price of €7.2 per kg. As of 2023, we assume a growing share of hydrogen is green hydrogen. In 2030, we assume a 50-50% mix of green and blue hydrogen, at an average at-the-pump price of €5.6 per kg. With 100% green hydrogen in 2050, the at-the-pump price falls to €2.9 per kg.

Table 2 summarizes the technology split between battery electric and fuel cell vehicles resulting from 10,000 runs of the Monte Carlo analysis. This split is applied to long-haul vehicle groups only. Battery-electric trucks dominate the market with a 99% sales share in 2030 based on their TCO performance relative to fuel-cell trucks. The market share of fuel-cell trucks is expected to increase slightly, reaching 4% by 2040 and 9% by 2050. Applications in which fuel-cell trucks are more economically viable than their battery-electric counterparts are mainly associated with cases that combine high driving range variability, high payloads, low hydrogen fuel prices and high electricity prices. Based on manufacturers’ announcements regarding their development plans (Basma & Rodriguez, 2021), we assume that urban and regional delivery trucks will rely on battery electric powertrains only. The techno-economic constraints on range and payload are less significant for these use cases. A detailed report on this analysis will be published soon.

3 The renewable electricity share in 2022 already exceeds 50% in some Member States. It is assumed that those member states will retain this renewable electricity share until 2030.

**Table 2**. Modeled new sales shares of battery-electric and fuel cell electric trucks from 2025 to 2050, based on the technology total cost of ownership

| Truck use case | Technology | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| **Long-haul** | Battery-electric | 99% | 99% | 96% | 91% |
| | Fuel cell | 1% | 1 % | 4% | 9% |
| **Regional delivery** | Battery-electric | 100% | 100% | 100% | 100% |
| | Fuel cell | 0% | 0 % | 0% | 0% |
| **Urban delivery** | Battery-electric | 100% | 100% | 100% | 100% |
| | Fuel cell | 0% | 0 % | 0% | 0% |

### Vehicle energy demand

The daily driving range of a truck, or vehicle kilometers travelled (VKT), is assumed to follow a lognormal probability distribution (Basma et al., 2021). The distribution used in this analysis is based on data gathered from truck fleets in the EU, representing a total of 13,400 long-haul trucks and 1,600 regional delivery trucks.[4] Long-haul trucks are modeled to have a mean daily range of 500 km, with 25% of them covering daily distances greater than 590 km on average and just 5% of them averaging more than 800 km. Regional delivery trucks have a mean daily range of 300 km, with 25% of them traveling more than 375 km and 5% more than 675 km.

The probability distribution of a truck's daily energy demand is estimated based on its driving range probability distribution and energy consumption. The distance-specific energy consumption assumed for each HDV segment is shown in the Appendix.
The stock-average energy consumption of a typical BET or FCET for each group is obtained from the ICCT's Roadmap model. The stock modeling accounts for the energy consumption of newly introduced vehicles in each calendar year, as well as that of remaining vehicles introduced in previous years, weighted by the share of kilometers travelled by each age group. As shown in Figure 5, long-haul tractor-trailers—belonging to group 5-LH in the official EU segmentation—have a mean daily energy demand of 700 kWh, with 10% of trucks having energy needs greater than 1050 kWh. For regional delivery trucks (i.e., group 4-RD), the mean daily energy demand is 280 kWh with 10% of trucks having an energy demand above 625 kWh.

4 Data from a survey of members of the European Clean Trucking Alliance, conducted by ICCT.

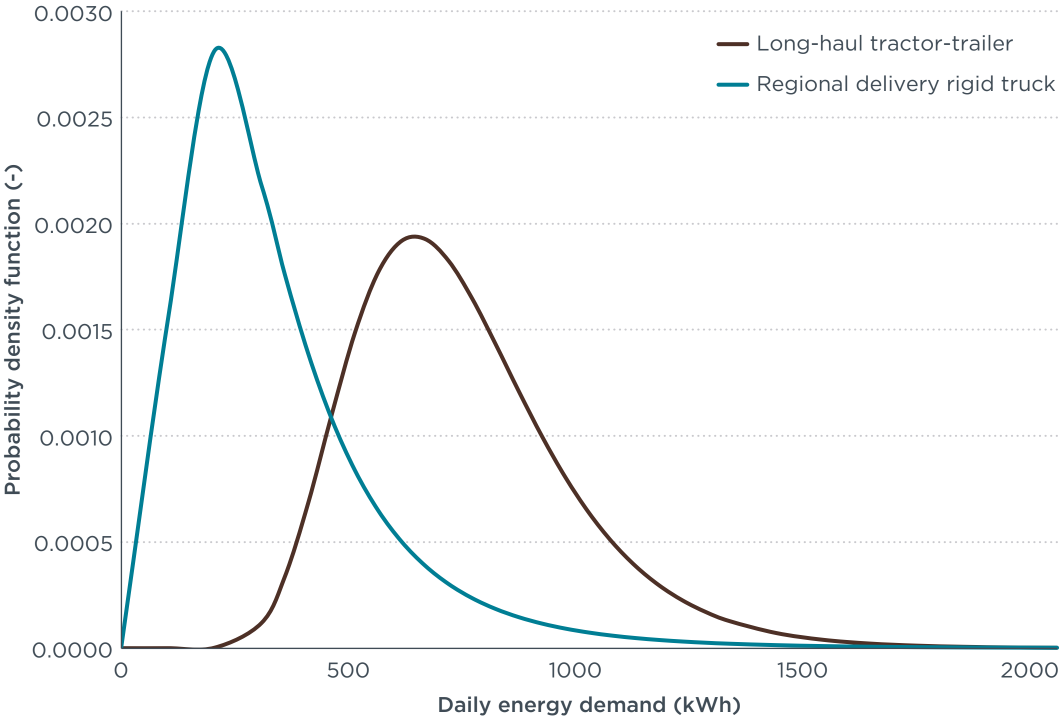


**Figure 5**. Probability density function for the energy demand of a long-haul tractor-trailer (group 5-LH) and regional delivery rigid truck (group 4-RD).

### Assumptions regarding electric charging and hydrogen refueling

The AFIR sets targets for the minimum power installed at charging pools, as well as a minimum for the power output of a single charging station. A charging pool is defined as a grouping of one or more charging stations at a specific location. A charging station is defined as a standalone physical installation and may consist of one or several charging points, or dispensers. Charging points are the physical interfaces that allow for the transfer of electric energy between the charging station and the vehicle. Here, when referring to "chargers," we mean charging station as defined by the AFIR.

The energy demand of battery-electric trucks is satisfied by three different types of direct current (DC) chargers. Overnight chargers, whether publicly accessible or at private locations such as depots and logistics hubs, are modeled to have a nominal power of 100 kW. Fast chargers are modeled as Combined Charging Systems (CCS) that can deliver up to 350 kW of nominal power. Finally, ultra-fast chargers are defined as Megawatt Charging Systems (MCS) delivering up to 1 MW of nominal power. We assume that all charger types operate, on average, at 85% of their nominal power, and that they have a charging efficiency of 85%. This accounts for power losses in the charging hardware of both the charging station and the vehicle. Table 3 summarizes the different types of chargers considered.

**Table 3**. Types of chargers and charging parameters considered in this analysis

| Type of charger | Nominal power | Average power | Charging time per event | Max. energy delivered per event | Charger efficiency** |
|---|---|---|---|---|---|
| **Overnight charger** | 100 kW | 85 kW | 8 hours | 680* kWh | 85% |
| **Fast charger (CCS)** | 350 kW | 298 kW | 0.5 hours | 150 kWh | 85% |
| **Ultra-fast charger (MCS)** | 1,000 kW | 850 kW | 0.5 hours | 425 kWh | 85% |

*For medium lorries and heavy rigid trucks with a 4×2 axle configuration, we cap the energy available from an overnight charging event to the maximum storage capacity of the battery—300 kWh and 400 kWh, respectively. These numbers are based on current market developments.
**Accounts for energy losses in the charger

We assume that it is cost-effective for truck operators to maximize the use of overnight charging for two reasons. First, the hardware cost of overnight chargers is lower (Basma et al., 2021). Second, charging at night enables access to cheaper power. Therefore, we assume that each electric truck is charged overnight and starts the day with a full battery. As a result, one overnight charger per electric truck is needed. As a simplifying assumption, we assume that trucks operate an average of 250 days per year.[5] Hence, we assume that on an average day, 0.68 overnight chargers per truck in the fleet is needed.

Because urban and regional delivery trucks usually return to their depots at the end of their shifts, we assume that they would charge overnight at private depot chargers, a circumstance not covered in the scope of the AFIR. For long-haul trucks, the number of public overnight chargers required is adjusted to match the estimated number of truck drivers engaged in long-haul transport on an average weekday.

The AFIR sets targets to install publicly accessible overnight chargers at safe and secure truck parking areas (SSTPAs). The standardization of SSTPAs is still under development and only 7 truck resting areas are certified as SSTPAs to date, while 57 parking sites are certified to other standards (European Commission, 2019). However, we assume that a growing number of truck resting areas will become certified and therefore be subject to the AFIR target for SSTPAs. The consortium responsible for the development of the standard on behalf of the European Commission estimates that about 5,000 parking areas are dedicated to trucks in the EU, providing 300,000 parking spaces per night (European Commission, 2019). They further estimate that 400,000 of these parking spaces would be required to accommodate all drivers engaged in long-haul transportation on an average weekday. This number is then adjusted to account for the expected 50% increase in freight activity between 2020 and 2050, as estimated in the PRIMES-TREMOVE model used for the EU Reference Scenario 2020 (European Commission et al., 2021).

We assume that the targets for urban nodes and SSTPAs are covered by the charging power and hydrogen capacity installed on the TEN-T, both core and comprehensive.

When trucks are not able to cover their daily range with a single overnight charge, fast and ultra-fast chargers along the TEN-T network are used to top-up the batteries. Truck drivers are legally required to take 45-minute breaks every 4.5 hours of driving. To account for the operations required before and after the charging event, we conservatively estimate that the charging duration would last 30 minutes only. The different charging scenarios required to meet a vehicle's energy needs are based on the energy demand distribution described above. Figure 6 shows the cumulative distribution function for the energy demand of a typical long-haul truck (segment 5-LH) and the respective charging scenarios it can experience.

5 Data from a survey of members of the European Clean Trucking Alliance, conducted by ICCT.

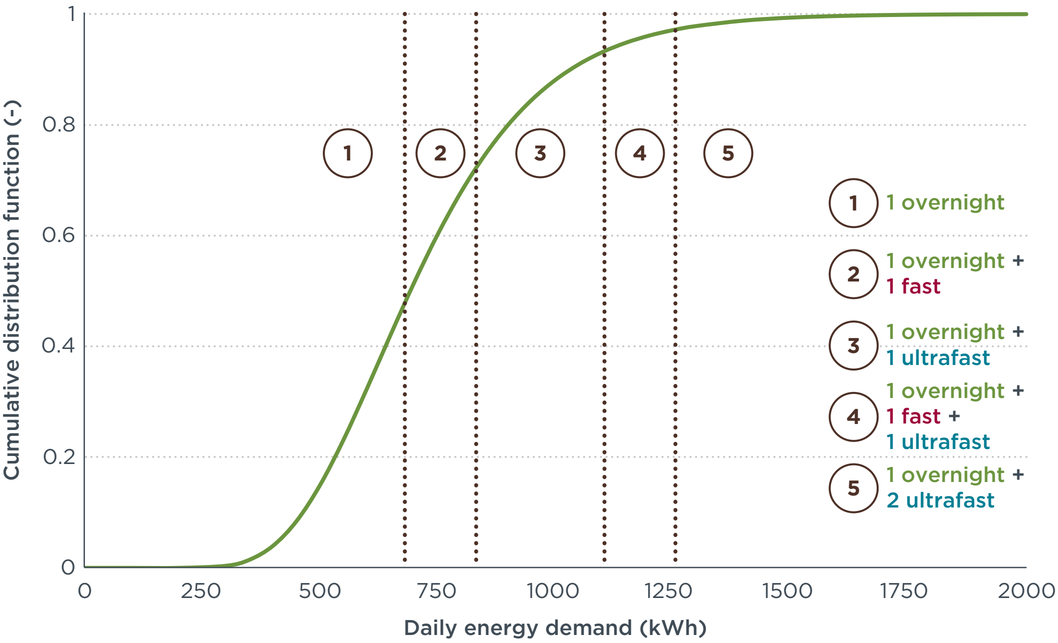


**Figure 6**. Cumulative distribution function for the energy demand of a long-haul tractor-trailer (segment 5-LH), and the respective charging event scenarios.

As shown in Figure 6, close to 50% of long-haul tractor-trailers have daily energy needs of less than 680 kWh, which can be satisfied by a single overnight charging event. 70% of trucks in this segment can meet their daily needs by adding one charging event at a 350-kW charger, which increases to 90% if that charging event occurs at a 1-MW charger. That is, only 10% of long-haul tractor-trailers would require more than one fast-charging event per day. Truck segments with lower energy demand, typically urban and regional delivery trucks, would rely even less on fast charging.

The modeling of hydrogen supply does not depend on assumptions about the capacity and type of the infrastructure. We model the total amount of hydrogen per day (tonnes/day) needed by the fuel cell truck fleet, regardless of whether it is delivered as liquid or compressed hydrogen. The resulting total hydrogen demand is converted to an indicative number of stations based on the distances specified in the AFIR proposal and assuming a constant station capacity of 2 tonnes per day. However, in the second part of the analysis, we analyze truck traffic flows to recommend different minimum capacity requirements for the refueling stations in different traffic bands. Because previous ICCT research shows that fuel cell powertrains, from a societal perspective, are much less beneficial than battery electric powertrains in light-duty vehicle applications (Mock & Díaz, 2021), we assume that the AFIR's targets for $H_2$ stations are driven by the needs of fuel cell trucks only.

### Infrastructure utilization

Infrastructure utilization is calculated separately for public fast and ultra-fast chargers, public overnight chargers, and hydrogen refueling stations. To capture the increase in utilization as the market matures, we assume that the utilization rate grows logarithmically, relying on a method that has been applied and validated in several ICCT assessments (Hsu et al., 2021; Minjares et al., 2021; Rajon Bernard & Hall, 2022). As a result, we model a low utilization of the infrastructure in early years, when the aim is to ensure base coverage of the network, and an increasing, and eventually plateauing, utilization as the ZE-HDVs market matures.

The final utilization is capped at a maximum value to avoid congestion. According to (Rajon Bernard & Hall, 2022), the maximum for DC fast chargers is 5 hours per day of active utilization time, not accounting for idling time for related operations such as plugging, unplugging, and paying. We therefore use 5 hours as the maximum for fast and ultra-fast chargers. While we refer to the publicly accessible 100 kW chargers as overnight chargers, we take the view that these chargers will also be used for day charging during long dwell periods, increasing the utilization rate of the infrastructure. Thus, for publicly accessible overnight chargers, we set the initial utilization rate at one charging event of 8 hours every 10 days, increasing logarithmically to 1.5 charging events per day by 2050.

We also assume that some fast and ultra-fast chargers can be used for overnight charging for several vehicles, using power-sharing. That is, the nominal power of the charging station is shared among more than one vehicle through separate charging points, instead of being used for a single vehicle.

The technology for power-sharing is already commercially available for electric bus fleets (Proterra, 2021). Hence, a 1-MW charger can, in principle, be used to meet the overnight needs of charging 10 vehicles at a nominal power of 100 kW. Similarly, a 350-kW charger can be used to charge 3.5 vehicles at a nominal power of 100 kW. We assume that some of the fast and ultra-fast chargers can be used for power-sharing. In the absence of better estimates, we assumed that 15% of fast and ultra-fast chargers are used in overnight power sharing. This effectively reduces the number of stand-alone 100 kW public overnight chargers required, while also increasing the utilization of fast and ultra-fast chargers during the night, when they are not expected to be used for fast top-ups.

Finally, for hydrogen refueling, we assume that the maximum utilization starts at 10% today and reaches 75% of the station's capacity by 2050, following the same logarithmic growth methodology. Given the expected smaller market size of fuel cell trucks compared to battery electric powertrains, base coverage of the network would likely dominate over optimized utilization, so that the utilization does not increase to 100% of the station's capacity.

## MEMBER STATE ALLOCATION BASED ON TRAFFIC FLOW DATA

The targets for infrastructure rollout in the AFIR's proposal do not differentiate between high- and low-traffic areas. The proposal suggests a uniform distribution of the total installed power and hydrogen capacity across the TEN-T road network. The aim is to provide basic coverage of the network to support the early ZE-HDV market developments, assuming that the market for ZE-HDV infrastructure will develop as more vehicles enter the market. However, this uniform distribution could result in overutilization of infrastructure in some portions of the network if Member States fail to voluntarily expand it—which could lead to poor user experience and hinder the ZE-HDV market uptake. Or it could lead to underutilization in other areas of the network and a waste of investment funds by some Member States.

Therefore, we examined the infrastructure development required as a function of freight activity and showed how different TEN-T corridors—and Member States—could deploy the required infrastructure in differentiated ways. We use traffic flow data recently published by Fraunhofer ISI (Speth et al., 2022) to identify portions of the TEN-T road network where higher-than-average and lower-than-average infrastructure rollout is required. The total power output and hydrogen capacity calculated in the first stage of the modeling is then split across these traffic bands, yielding a set of traffic-dependent targets. We still account for a certain level of base coverage of the network through the low utilization assumed in the early years of market development.

The dataset from Fraunhofer ISI uses results from the European Commission's ETISplus project (European Commission, 2012) to map truck traffic flows among 1,700 European regions onto the TEN-T network—which is divided into 16,000 portions, or links. The 2019 traffic is calibrated to align with official statistics on freight activity reported by the European Union (Eurostat, 2020). Using these results, we use the lengths and proportions of traffic on the TEN-T network, core and comprehensive, to split the total installed power and hydrogen capacity between both TEN-T sections for each Member State.

We calculate the total number of charging pools and refueling stations in each Member State based on the domestic length of the network and the minimum distance requirements set out in the AFIR proposal. Hence, we obtain an average requirement for power per charging pool, and hydrogen station capacity, for each Member State.

Finally, we define four bands of average traffic flow (HDVs/day) so that the average traffic values of all Member states are distributed roughly equally across all bands. We then propose a set of targets—one for each band—that would satisfy the average needs of Member States while aiming to maintain the total installed power aligned with the needs of the fleet identified in our modelling. This method is applied to charging infrastructure needs along the TEN-T core in 2025, and to both charging and refueling infrastructure needs along the core and comprehensive networks in 2030.

Figure 7 summarizes the methodology described above.

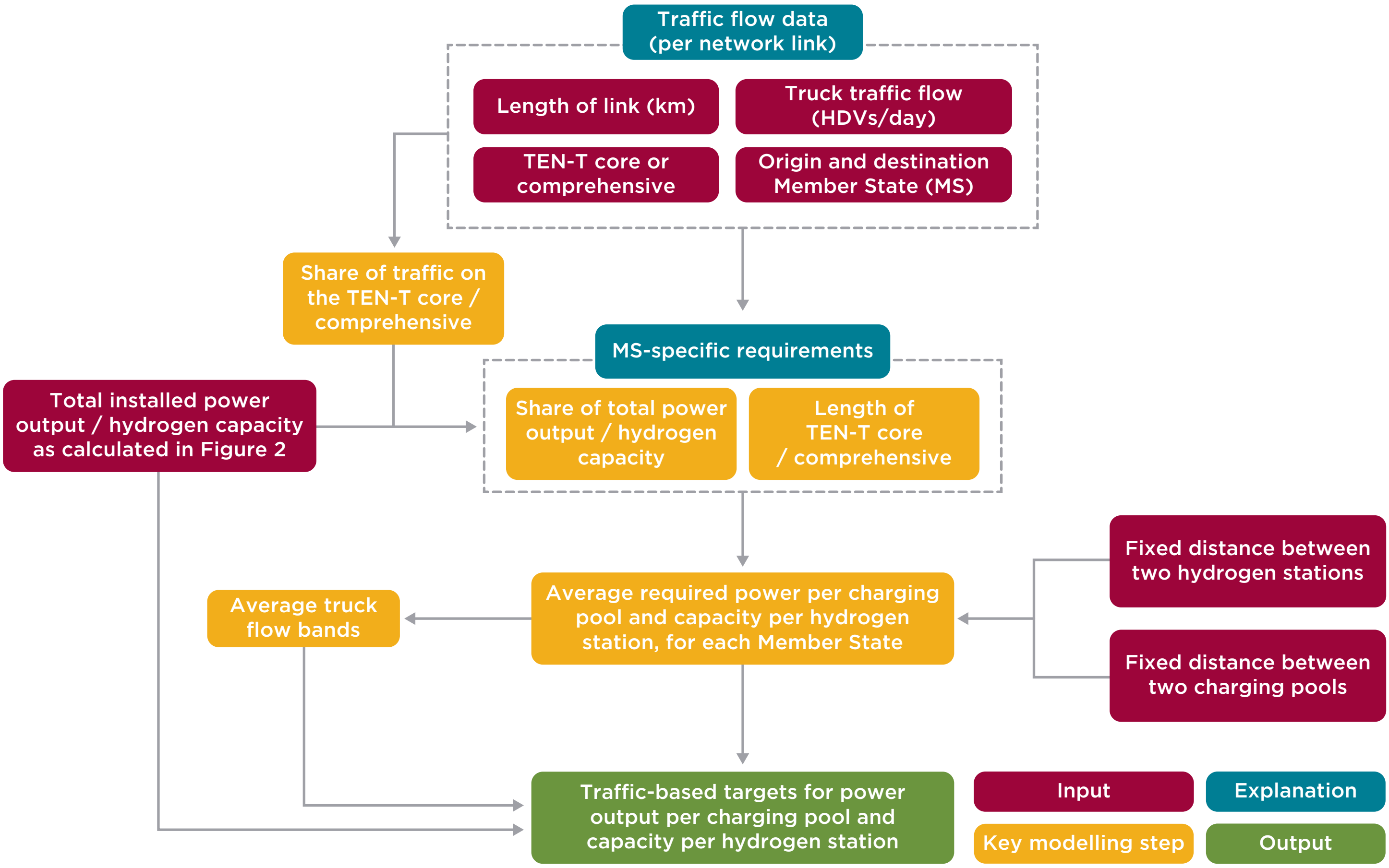


**Figure 7.** Key modelling steps to distribute the total power output and hydrogen capacity across traffic bands

# RESULTS AND DISCUSSION

## OVERALL INFRASTRUCTURE NEEDS

### Electric charging

Based on the method highlighted in Figure 2, we estimate the total public charging infrastructure needs to satisfy the demand from the growing battery-electric truck fleet out to 2035. As shown in Figure 8, we find that the infrastructure rollout needed by 2025 will be modest, as the stock of ZE trucks across the EU is expected to be less than 20,000 units for the truck segments modelled in this analysis. However, the needs start growing rapidly in the second half of this decade, as the modelled stock of electric vehicles increases to more than 330,000 units by 2030.

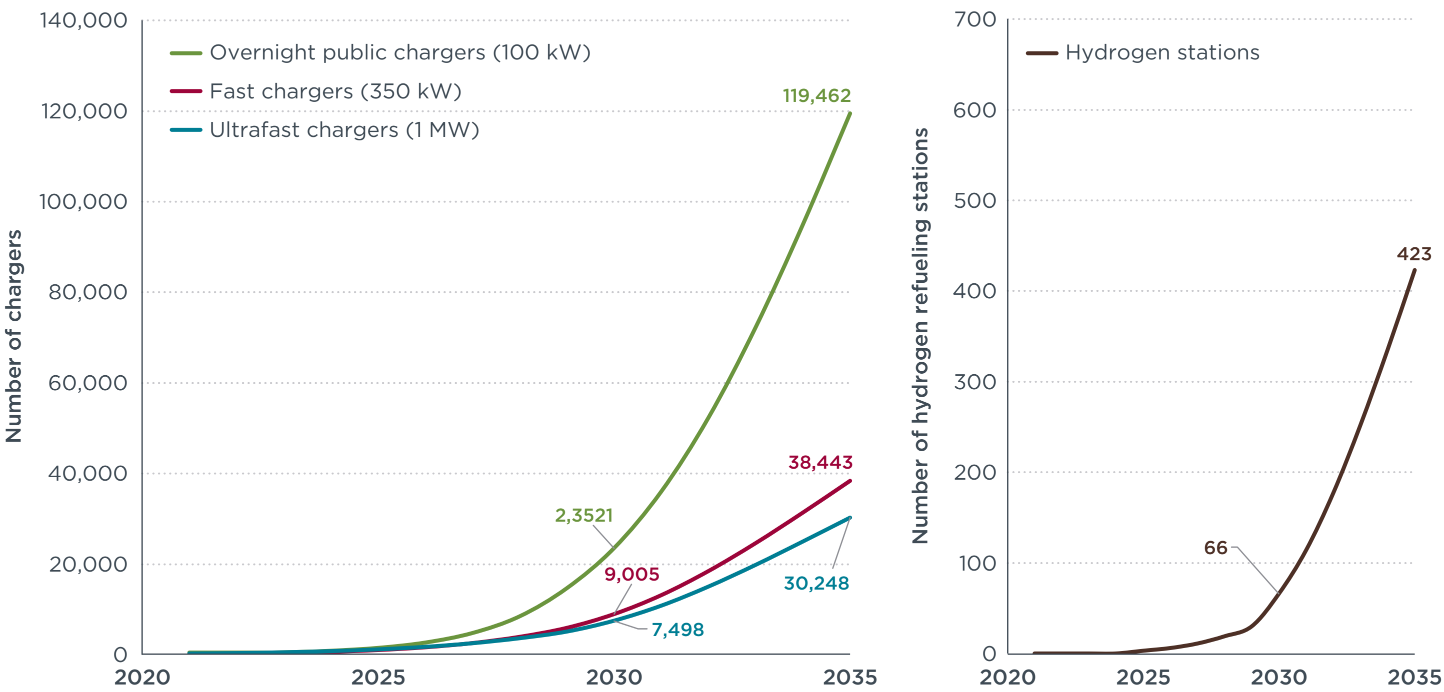


**Figure 8.** Total number of electric chargers (per type) and hydrogen refueling stations required to satisfy the needs of the EU truck fleet out to 2050. We assume an average hydrogen station capacity of 2 tonnes per day.

About 40,000 public charging stations are needed in 2030 to satisfy the needs of the electric truck fleet, increasing to 190,000 in 2035. In this study, we maximize the use of overnight chargers, as we expect that the lower associated electricity prices will make it a more attractive option for truck operators. As a result, close to 60% of all charging stations are public overnight chargers. However, these chargers represent a much lower share of the total installed power, as shown in Figure 9, as fast and ultrafast chargers have much higher energy throughputs. Additionally, close to 90% of all overnight chargers would be privately owned and installed at depots, and therefore do not fall under the scope of the AFIR. Public overnight chargers would mostly be used by truck drivers engaged in long-haul freight transport with trips longer than the daily maximum driving range.

Compared to a scenario where truck fleets would rely more heavily on fast opportunity charging, this leads to a lower level of total installed power, and in turn less ambitious targets for the installed power per charging pool. However, based on the cost estimates provided in the AFIR's impact assessment study, we estimate that relying on a smaller number of high-power chargers could be a more cost-effective option from the infrastructure deployment perspective.

If 15% of the fast chargers are also used in power-sharing for overnight charging, the required deployment of overnight chargers is reduced by 40% in 2030—from 39,000 to 24,000 chargers. We expect that the deployment of most of these overnight chargers will be driven by the targets for trucks in safe and secure truck parking areas (SSTPAs) under the AFIR. If all the 5,000 dedicated parking areas for trucks that exist today in the EU were converted into SSTPAs by 2030, our results would translate to about 4 public overnight chargers per parking area—in line with the European Parliament's Rapporteur recommendations.

Figure 9 shows our model's output of total installed power required on the Trans-European Network. We compare this to the targets proposed by both the European Commission and the European Parliament (EP) Rapporteur. This is calculated based on the length of the TEN-T, core and comprehensive—about 40,000 km and 100,000 km, respectively—and the fixed distance between two charging pools, 60 km and 100 km, respectively. We assume that the total installed power calculated from the targets for the TEN-T, core and comprehensive, would also cover the requirements for urban nodes and parking areas.

**Total installed power of public charging infrastructure (Gigawatts)**

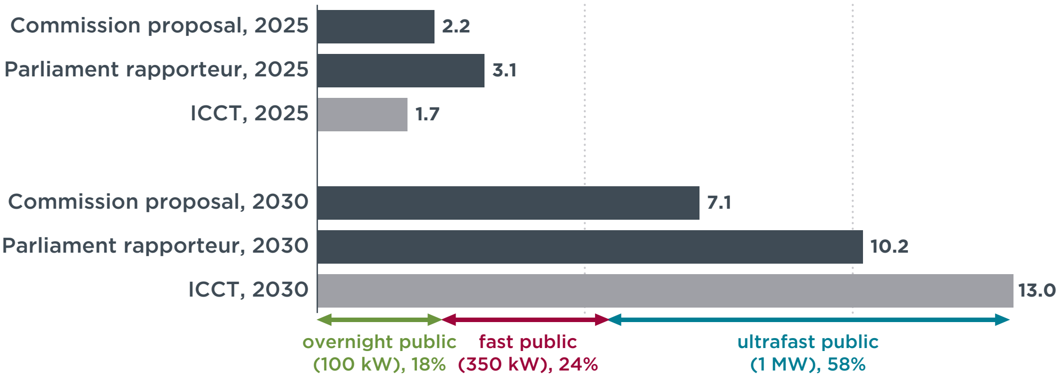


**Figure 9.** Total installed power required for the EU truck fleet as calculated by the ICCT (split by charger type) and resulting from the targets proposed by the European Commission and the European Parliament rapporteur's draft report.

For 2025, we estimate that 1.7 GW of installed power would be required to meet the needs of battery electric trucks in the EU—less than that proposed by the European Commission, around 2 GW, and by the European Parliament rapporteur, about 3 GW. However, starting in 2030, we expect the market for ZE-HDVs to become more robust, which will require higher levels of installed power than the levels proposed by the Commission and recommended by the Parliament's rapporteur—13 GW, compared to 7 GW and 10 GW, respectively. For context, the installed capacity of the electric grid in the EU has expanded over the past decade at an average rate of 11.6 GW per annum between 2011 and 2020. Thus, the total required power to be installed by 2030 to meet the battery-electric heavy-duty vehicles market uptake will amount to about 14% of the annual growth in installed grid capacity. This is an upper bound, as charging can be done largely with existing grid capacity during periods of low electricity demand.

Looking at the different types of chargers, we estimate that public overnight chargers would supply 9% of the installed capacity by 2025, 18% by 2030 and 21% by 2035, despite representing most charging points as shown in Figure 8. 350-kW chargers (CCS) would represent 55% of the fast and ultrafast charging stations, and 30% of the installed fast-charger power by 2030. Hence, this technology can provide a significant portion of the energy demand of the fleet. By 2030, a standard for megawatt charging systems (MCS) will likely be developed and we assume that such systems would deliver about 58% of the publicly accessible charging energy for battery-electric trucks in the EU.

### Hydrogen refueling

As shown in Figure 8, we estimate that even under the optimistic scenario modelled for the uptake of fuel cell trucks, just 66 hydrogen refueling stations across the EU would suffice to meet the needs of the fleet by 2030. This increases to 423 stations in 2035.

The European Commission's AFIR proposal sets maximum distances of 150 km and 450 km between any two compressed and liquid hydrogen refueling stations, respectively. This applies to the entire Trans-European Network—including its core and non-core sections. At the proposed fixed station capacity of 2 tonnes per day, this would result in a total installed hydrogen capacity of about 1,900 tonnes per day in 2030. In our analysis, we find that just 130 tonnes per day would be required in 2030, and that required capacity would reach the level proposed by the European Commission late into the next decade. Therefore, we apply the traffic-based analysis to the hydrogen capacity required at a later stage than the year proposed, 2030. To remain consistent with the timeline proposed by the Commission, we look at the requirements for 2035.

We use the approach laid out in Figure 7 to derive a set of four traffic-based targets for the capacity of hydrogen refueling stations that would align with the needs of the fleet identified in our modelling.

## REQUIREMENTS PER MEMBER STATE, BASED ON TRAFFIC FLOWS

### Electric charging

We allocate the overall infrastructure needs described in the previous section to the different Member States, based on their share of truck traffic. Then, based on the number of charging pools on their territory—determined by the length of the Trans-European Network in each Member State and the distances specified in the AFIR proposal—we determine the average required power output per charging pool for each Member State.

Results are shown in Figure 10 for the core network in 2025 and in Figure 11 for both the core (top graph) and comprehensive (bottom graph) networks in 2030.[6] In general, for a fixed charging pool density (i.e., the maximum distance between two charging locations), the average needed power capacity per charging pool in each Member State is roughly proportional to the average traffic flow. The grey dotted regression lines represent the resulting relationship. Figure 10 through Figure 12 also show our recommendations for the different traffic flow bands (different colors) and associated targets, as described below.

6 Traffic flow data for Cyprus and Malta were not available, therefore they are excluded from the analysis.

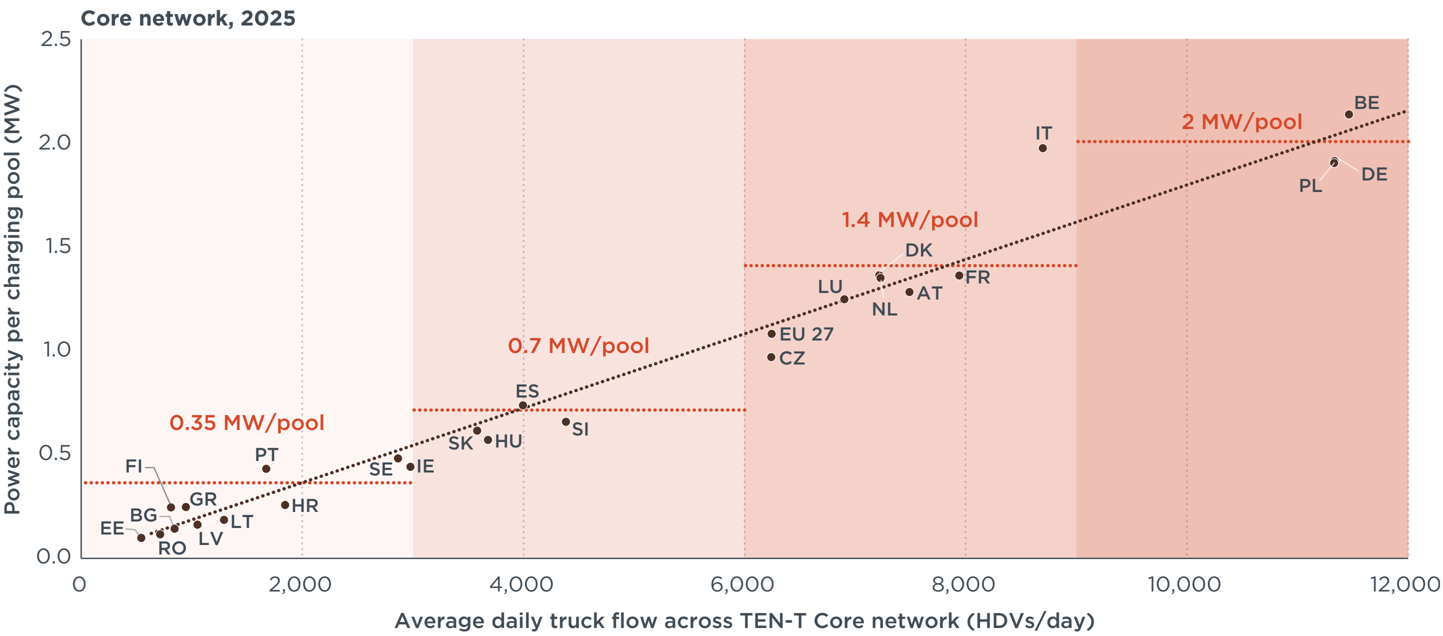


**Figure 10**. Required average power output per charging pool for each Member State in 2025, based on average daily truck flows, and ICCT's recommendation for traffic-based targets.

As shown in Figure 10, an average of 1 MW/pool on the core network would be needed for the EU 27. However, a uniform target is not appropriate due to the large discrepancies in the average needs of different countries. The Commission's proposed uniform target of 1,400 kW per charging pool for the core network in 2025 is higher than our estimate of what is needed, on average, in most Member States (see Figure 10)—which suggests the need for traffic-based targets as early as 2025. This result is in line with our finding that the total installed power should be lower than suggested by the Commission.

Member States like Germany, Belgium and Poland would require, on average, a high power output per charging pool on the core network, as their sections of the Trans-European Network are more densely utilized by freight operators. Together, these three Member States would gather 42% of the total power installed on the core network. Conversely, Member States like Estonia, Bulgaria and Romania would need much lower average power for their charging pools, due to the lower average traffic density on their share of the core network. Importantly, all Member States would have network links lying in the different traffic bands.

For 2030, the Commission proposes a uniform target of 3,500 kW for the core network. As shown in Figure 11 (top graph), this target lies close to the average of all Member States, despite some having much higher average needs, and others much lower needs. For the comprehensive network, the proposed uniform target of 1,400 kW is insufficient to cover the average needs of 18 Member States, in some cases by several megawatts. Hence, we estimate that most of the installed power gap identified in Figure 9 for 2030 results from the targets set out for the comprehensive network. As shown in Figure 11 (bottom graph), the average traffic flow in each Member State is significantly different for the comprehensive network.


**Figure 11.** Required average power output per charging pool for each Member State in 2030, based on average daily truck flows, and ICCT's recommendation for traffic-based targets.

To incentivize the deployment of a well-utilized charging infrastructure, different minimum power requirements can be considered depending on the observed traffic flow on the roads of the Trans-European Network. We identify four bands of traffic flow: (1) more than 9,000 HDVs per day, (2) between 6,000 and 9,000 HDVs per day, (3) between 3,000 and 6,000 HDVs per day and (4) fewer than 3,000 HDVs per day. The traffic bands are indicated by shaded areas in Figure 10 and Figure 11. Table 4 shows the clustering of Member States if they were to be grouped based on their average traffic flow on the Trans-European Network.

**Table 4.** Clustering of Member States based on the average traffic flow on their portion of the Trans-European Network. This is indicative only, as Member States would have roads in all traffic bands.

| Traffic band | Member States with an average traffic flow falling in that band (Core) | Member States with an average traffic flow falling in that band (Comprehensive) |
|---|---|---|
| **> 9,000 HDV/day** | Germany, Poland, Belgium | |
| **6,000 to 9,000 HDV/day** | Czech Republic, Luxemburg, Netherlands, Denmark, Austria, France, Italy | Netherlands, Poland |
| **3,000 to 6,000 HDV/day** | Slovakia, Hungary, Spain, Slovenia | Czech Republic, France, Slovakia, Italy, Denmark, Austria, Belgium, Germany |
| **<3,000 HDV/day** | Estonia, Romania, Bulgaria, Finland, Greece, Latvia, Lithuania, Portugal, Croatia, Sweden, Ireland, Cyprus[1], Malta[1] | Romania, Greece, Estonia, Bulgaria, Lithuania, Finland, Portugal, Latvia, Ireland, Croatia, Hungary, Luxemburg, Slovenia, Sweden, Spain, Cyprus[1], Malta[1] |

[1]Cyprus and Malta were not included in this analysis as data for these countries were not available. However, we expect that the average traffic in these Member States would lie in the lowest traffic band, for both the core and comprehensive networks.

To account for these differences across Member States, we propose to set the infrastructure requirements for the Trans-European Network based on these traffic flow bands, while aiming to maintain the total installed power aligned with the needs of the fleet identified in our modelling. By default, Member States would have to comply with the highest target, but by derogation based on having lower traffic flows across parts of their domestic network, they could be bound by the associated lower target for those areas. The targets we recommend for 2025 and 2030 are also shown in Figure 10 and Figure 11. The resulting number of charging pools and hydrogen stations per traffic band in each Member State is shown in the Appendix.

Understanding that the MCS standard has not yet been finalized, we consider that 350 kW of power (CCS standard) for at least one charging station would be sufficient. Charging stations with 350 kW of power will play an important role as they can provide 150 to 250 km[7] of additional driving range during a 45-minute charging session, enabling daily ranges of up to 660 km (Basma et al., 2021). We estimate that 24% of the installed power by 2030 will be delivered by these charging stations (see Figure 9).

Along the core network, by 2030, for roads with a high daily traffic flow exceeding 9,000 HDV/day, the minimum required charging pool power capacity would be in the range of 9,000 kW, meeting the average needs of the Member States with the highest traffic flows. This would decrease to 6,000 kW, 3,000 kW and 1,400 kW for the lower traffic bands. By 2030, the MCS standard will have been finalized, warranting the increase in power requirements for individual charging stations to at least 700 kW.

As most of the charging gap identified in 2030 arises from the target levels for the comprehensive network, we recommend applying the same targets as the core network. Aligning both sets of targets would close the charging gap—to within 1%. We also recommend adjusting the charging pool density on the comprehensive network to match the 60 km distance proposed for the core network. This leads to a single set of traffic-based targets for both the core and comprehensive network in 2030.

### Hydrogen refueling

We apply a similar rationale to allocate the hydrogen refueling infrastructure required in 2035 across the Trans-European Network roads with varying traffic flows. The

7 The actual additional driving range gained during charging depends on the truck energy efficiency in kWh/km, which is driven by the truck mission profile and technical specifications.

resulting minimum hydrogen station capacity required for each Member State, on average, is shown in Figure 12. Traffic-based targets are then obtained based on the previously defined bands of traffic flow (see Table 4).

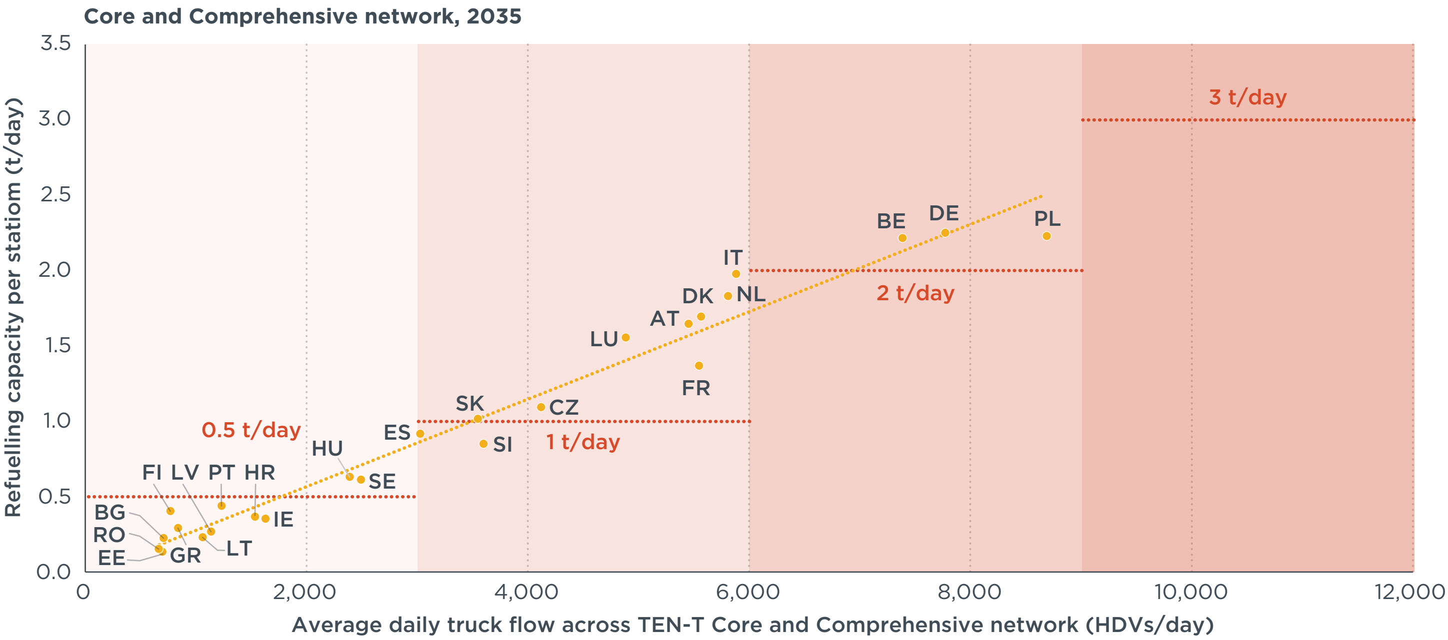


**Figure 12**. Required hydrogen capacity per station for each Member State, based on average daily truck flows, and ICCT's recommendation for traffic-based targets.

The European Commission proposes a fixed hydrogen capacity of 2 tonnes per day throughout, with separate distance requirements for compressed and liquid hydrogen. When aggregating both sets of requirements, this results in an effective average station capacity of around 2.7 tonnes per day across the Trans-European Network. This is higher than the average needs of all Member States, although some road sections might still exhibit this need.

Due to the technological uncertainty, we recommend eliminating the simultaneous requirement for liquid and compressed hydrogen, resulting in a single target for the capacity of all types of hydrogen stations, with a maximum distance requirement of 150 km. For roads belonging to the highest traffic flow band, we propose the minimum required hydrogen refueling station capacity to be 3,000 kg/day. Only very few road sections in some Member States would have to comply with this target. For the lower traffic flow bands, we propose lower minimum capacities of 2,000 kg/day, which further decreases to 1,000 kg/day and 500 kg/day.

# SUMMARY AND POLICY RECOMMENDATIONS

The successful adoption of the AFIR will be a key enabler of the rapid transition to zero-emission trucks and, consequently, of the decarbonization of the EU economy. Using a portfolio of modeling tools, this study provides a detailed bottom-up assessment of the infrastructure needs for zero-emission trucks over the next decade, compares the results with the targets proposed in the AFIR, and suggests ways to improve them. The key findings of our analysis are summarized below.

- **Early rollout of infrastructure will be crucial, to give manufacturers and fleets confidence regarding the technical feasibility of electric trucks.** The proposed 2025 AFIR targets exceed the fleet's charging needs. The 19,000 zero-emission trucks expected to be on EU roads by 2025 will require a public charging infrastructure with an installed capacity of 1.7 GW. This is about 25% less than our estimate of what the Commission's proposal would require. However, setting ambitious targets as early as 2025 will be crucial to ensure the market uptake of ZE-HDVs, especially in the more densely used parts of the Trans-European Network.
- **The proposed 2030 AFIR targets largely underestimate the fleet's charging needs.** The 330,000 zero-emission trucks that are expected to be on EU roads by 2030 will require a public charging infrastructure with an installed capacity of 13 GW. This is about 70% more than we estimate would result from the Commission's proposal. Such a charging gap could create difficulties for the industry to commit to the transition to ZE-HDVs.
- **Battery-electric trucks are a certain decarbonization pathway.** The techno-economic modeling of the electrification pathways shows that battery-electric trucks will be the most cost-effective solution in the transition to zero-emission trucks, with most manufacturers planning their series production before 2025. However, our analysis also shows that fuel-cell trucks may have the advantage in certain use cases featuring long range, high payload, and large day-to-day operating variability. In line with manufacturers' announcements, we expect—with some uncertainty—that this technology will start deployment towards the end of the decade, and only for long-haul trucks. We estimate the market share of fuel cell powertrains to reach about 9% of this segment by 2050.
- **The proposed 2030 AFIR targets overestimate the hydrogen refueling needs.** By 2030, we estimate that the fleet of fuel cell trucks will consume around 130 tonnes of hydrogen per day, which can be supplied by nearly 70 hydrogen refueling stations with an average capacity of 2 tonnes per day. This is about 90% less than the capacity requirement we estimate would result from the Commission's proposal. However, the level of hydrogen infrastructure rollout proposed by the Commission would be required later into next decade. Hence, we propose to shift the hydrogen requirements from 2030 to 2035.
- **The infrastructure needs are not uniform across the Trans-European Network.** Corridors on which a larger number of trucks travel every day require a more important rollout of charging and refueling infrastructure than roads with low traffic volumes. Uniform targets along the entire Trans-European Network are not well suited for the regulatory design, as they could unnecessarily burden Member States with low-volume portions of the network.

Based on our findings, we propose to adjust the targets to match the fleet's needs, while still providing the flexibility to deploy lower levels of infrastructure on low volume roads of the Trans-European Network. Member States seeking to meet these lower targets on some roads of their Trans-European Network would need to apply to the European Commission for a derogation, otherwise the highest target would apply. Our recommendations are outlined below and summarized in Table 5 and Table 6.

» Increase the nominal 2025 charging target for the core network to 2,000 kW every 60 km and add low-volume flexibilities through the use of traffic bands.

» Align the 2030 charging targets for the core and comprehensive networks.

» Increase the nominal 2030 charging target for the core and comprehensive networks to 9,000 kW every 60 km, adding low traffic volume flexibilities.

» Increase the nominal capacity target for hydrogen refueling stations to 3 tonnes per day every 150 km, postponing its application until 2035, avoiding setting sub-targets for liquid or compressed hydrogen, and adding low volume flexibilities.

**Table 5.** ICCT's recommendations for the AFIR's targets for heavy-duty vehicle charging infrastructure based on the bottom-up infrastructure assessment.

| Traffic band | TEN-T core | | TEN-T comprehensive | |
|---|---|---|---|---|
| | European Commission | ICCT | European Commission | ICCT |
| > 9,000 HDV/day | Every 60 km; 2025: 1,400 kW; 2030: 3,500 kW | Every 60 km; 2025: 2,000 kW; 2030: 9,000 kW | Every 100 km; 2030: 1,400 kW; 2035: 3,500 kW | Every 60 km; 2030: 9,000 kW |
| 6,000 to 9,000 HDV/day | | Every 60 km; 2025: 1,400 kW; 2030: 6,000 kW | | Every 60 km; 2030: 6,000 kW |
| 3,000 to 6,000 HDV/day | | Every 60 km; 2025: 700 kW; 2030: 3,000 kW | | Every 60 km; 2030: 3,000 kW |
| < 3,000 HDV/day | | Every 60 km; 2025: 350 kW; 2030: 1,400 kW | | Every 60 km; 2030: 1,400 kW |

**Table 6.** ICCT's recommendations for the AFIR's targets for hydrogen refueling infrastructure based on the bottom-up infrastructure assessment.

| European Commission | ICCT (per traffic band) | | | |
|---|---|---|---|---|
| | > 9,000 HDV/day | 6,000 to 9,000 HDV/day | 3,000 to 6,000 HDV/day | < 3,000 HDV/day |
| Every 150 km | Every 150 km | Every 150 km | Every 150 km | Every 150 km |
| 2.7 t/day | 3 t/day | 2 t/day | 1 t/day | 0.5 t/day |
| 2030 | 2035 | 2035 | 2035 | 2035 |

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# APPENDIX

**Table A11.** Assumptions regarding ZE-HDV stock and energy consumption, based on the ICCT's Roadmap model (International Council on Clean Transportation, 2021).

| Vehicle group | ZE-HDV stock in 2025 (trucks) | ZE-HDV stock in 2030 (trucks) | ZE-HDV stock in 2035 (trucks) | ZE-HDV stock in 2050 (trucks) |
|---|---|---|---|---|
| **1** | 1,058 | 13,554 | 48,222 | 154,488 |
| **2** | 1,104 | 19,749 | 90,822 | 301,419 |
| **3** | 1,177 | 19,896 | 89,441 | 290,517 |
| **4-UD** | 5 | 205 | 946 | 3,194 |
| **4-RD** | 1,912 | 32,456 | 147,830 | 527,805 |
| **4-LH** | 799 | 14,228 | 76,823 | 284,275 |
| **5-RD** | 96 | 1,793 | 8,116 | 26,263 |
| **5-LH** | 9,132 | 167,782 | 1,023,962 | 4,270,853 |
| **9-RD** | 1,469 | 21,140 | 90,195 | 297,268 |
| **9-LH** | 2,140 | 32,778 | 180,961 | 709,732 |
| **10-RD** | 0 | 45 | 222 | 665 |
| **10-LH** | 359 | 7,504 | 47,140 | 185,152 |

| Vehicle group | BET energy consumption in 2021 (kWh/km) | BET energy consumption in 2030 (kWh/km) | FCET energy consumption in 2021 (kWh/km) | FCET energy consumption in 2030 (kWh/km) |
|---|---|---|---|---|
| **1** | 0.85 | 0.64 | 1.71 | 1.28 |
| **2** | 1.02 | 0.76 | 2.06 | 1.53 |
| **3** | 0.98 | 0.74 | 2.29 | 1.71 |
| **4-UD** | 0.80 | 0.59 | 1.22 | 0.79 |
| **4-RD** | 0.94 | 0.72 | 2.50 | 2.00 |
| **4-LH** | 1.35 | 0.99 | 2.73 | 2.00 |
| **5-RD** | 1.31 | 1.00 | 2.67 | 2.14 |
| **5-LH** | 1.34 | 0.98 | 2.70 | 1.98 |
| **9-RD** | 1.05 | 0.80 | 2.13 | 1.71 |
| **9-LH** | 1.49 | 1.09 | 3.01 | 2.21 |
| **10-RD** | 1.29 | 0.99 | 2.63 | 2.11 |
| **10-LH** | 1.38 | 1.01 | 2.78 | 2.04 |

**Table A 2.** Manufacturer announcements for the phase-in of zero-emission and fossil-free HDVs

| Manufacturer | 2025 | 2030 | 2039 | 2040 | Source | 2019 Sales Share |
|---|---|---|---|---|---|---|
| **DAF** | - | - | - | 100% | (ACEA and PIK, 2020) | 18% |
| **Iveco** | - | - | - | 100% | (ACEA and PIK, 2020) | 6% |
| **MAN** | - | 40% LH<br>60% RD | - | 100% | (MAN, 2021); (ACEA and PIK, 2020) | 15% |
| **Daimler Trucks** | - | 60%* | 100% | 100% | (Daimler AG, 2021); (ACEA and PIK, 2020) | 18% |
| **Renault Trucks** | 10% | 35% | - | 100% | (Renault Trucks, 2020); (Renault Trucks, 2021); (ACEA and PIK, 2020) | 9% |
| **Scania** | 10% | 50% | - | 100% | (Scania, 2021); (ACEA and PIK, 2020); (Dutch Ministry for the Environment and CALSTART, 2021) | 18% |
| **Volvo Trucks** | 7% | 50% | - | 100% | (Volvo Trucks, 2021); (ACEA and PIK, 2020) | 16% |

*Note:* LH = Long-Haul, RD = Regional Delivery. *The 2030 announcement by Daimler is worded as “up to 60%”.

**Table A 3**. Number of charging pools and hydrogen stations per Member State and per traffic flow band

| Member State | Number of charging pools per traffic band | | | | | Number of $H_2$ stations per traffic band | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | <3,000 HDV/day | 3,000 to 6,000 HDV/day | 6,000 to 9,000 HDV/day | >9,000 HDV/day | Total | <3,000 HDV/day | 3,000 to 6,000 HDV/day | 6,000 to 9,000 HDV/day | >9,000 HDV/day | Total |
| **Austria** | 8 | 24 | 20 | 13 | **65** | 2 | 6 | 4 | 4 | **16** |
| **Belgium** | 15 | 11 | 10 | 29 | **65** | 4 | 3 | 3 | 7 | **17** |
| **Bulgaria** | 87 | 0 | 0 | 0 | **87** | 19 | 0 | 0 | 0 | **19** |
| **Cyprus** | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| **Czech Republic** | 20 | 26 | 11 | 11 | **68** | 5 | 6 | 3 | 3 | **17** |
| **Germany** | 52 | 75 | 83 | 173 | **383** | 11 | 16 | 17 | 35 | **79** |
| **Denmark** | 18 | 18 | 7 | 14 | **57** | 5 | 5 | 3 | 3 | **16** |
| **Estonia** | 48 | 0 | 0 | 0 | **48** | 11 | 0 | 0 | 0 | **11** |
| **Spain** | 259 | 78 | 27 | 39 | **403** | 52 | 17 | 6 | 8 | **83** |
| **Finland** | 166 | 2 | 8 | 0 | **176** | 34 | 1 | 2 | 0 | **37** |
| **France** | 143 | 206 | 59 | 81 | **489** | 30 | 42 | 13 | 17 | **102** |
| **Greece** | 147 | 2 | 0 | 0 | **149** | 31 | 1 | 0 | 0 | **32** |
| **Croatia** | 46 | 8 | 0 | 0 | **54** | 10 | 3 | 0 | 0 | **13** |
| **Hungary** | 67 | 12 | 8 | 1 | **88** | 15 | 3 | 2 | 1 | **21** |
| **Ireland** | 62 | 10 | 5 | 1 | **78** | 13 | 3 | 2 | 1 | **19** |
| **Italy** | 170 | 69 | 61 | 65 | **365** | 35 | 14 | 13 | 14 | **76** |
| **Lithuania** | 57 | 1 | 0 | 0 | **58** | 12 | 1 | 0 | 0 | **13** |
| **Luxemburg** | 2 | 0 | 1 | 2 | **5** | 2 | 0 | 1 | 1 | **4** |
| **Latvia** | 67 | 7 | 0 | 0 | **74** | 14 | 2 | 0 | 0 | **16** |
| **Malta** | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| **Netherlands** | 10 | 24 | 20 | 14 | **68** | 3 | 5 | 5 | 4 | **17** |
| **Portugal** | 94 | 3 | 0 | 0 | **97** | 20 | 1 | 0 | 0 | **21** |
| **Poland** | 38 | 31 | 85 | 106 | **260** | 9 | 7 | 17 | 22 | **55** |
| **Romania** | 162 | 0 | 0 | 0 | **162** | 34 | 0 | 0 | 0 | **34** |
| **Sweden** | 142 | 50 | 20 | 4 | **216** | 29 | 10 | 4 | 1 | **44** |
| **Slovenia** | 10 | 10 | 4 | 1 | **25** | 3 | 3 | 1 | 1 | **8** |
| **Slovakia** | 26 | 10 | 20 | 1 | **57** | 6 | 3 | 5 | 1 | **15** |
| **EU27** | 1,916 | 677 | 449 | 555 | **3,597** | 409 | 152 | 101 | 123 | **785** |