Flicking the switch on truck charging

Why connecting truck charging stations to the grid is technically and economically feasible

January 2022

Executive summary

There is increasing consensus among European truck manufacturers and industry stakeholders that battery electric trucks (BETs) will play a dominant role in the decarbonisation of the road freight sector. Most truck makers including Daimler, MAN, Scania and Volvo are now focusing on bringing battery-powered trucks to the mass market for all vehicle segments, and including long-haul starting from 2024. For this, a network of public high-power and overnight charging points needs to be rolled out across Europe no later than 2025.

Transport & Environment commissioned *RE-xpertise* and *ef.Ruhr* to examine the techno-economic feasibility of charging stations for long-haul trucks and their connection to the electricity grid. The technical study evaluates possible charging and grid connection configurations for three scenarios: a high- and a low-traffic motorway station, as well as a logistics hub.

This policy briefing summarises the findings of the technical study and provides concrete recommendations for EU and national policy-makers to plan the roll-out of truck charging infrastructure in a cost-effective manner and streamline the planning and permitting process.

Connecting truck charging stations to the grid is feasible

The model *e.mission* developed by RE-xpertise and ef.Ruhr calculates the power requirements of the truck charging stations and indicates how they should be connected to the grid based on the truck traffic flows, the BET market uptake, the charging behaviour as well as the applied charging management.

Based on real-world traffic data, a high- and a low-traffic motorway station were analysed in the study. The high-traffic station represents the highest traffic flows in Germany, whereas the low-traffic motorway station illustrates a less frequented section of the network. With more than 22,000 trucks passing by per day, the high-traffic station can be considered representative for the most extreme traffic flow cases across the EU.

In the case of the low-traffic station, its 5,000 trucks per day are comparable to the upper average traffic intensity at EU level. For comparison, half of the TEN-T network length is frequented by less than 3,000 HGVs per day and three quarters by less than 6,000. For the logistics hub, a mixed business area with a size of about 125 hectare was considered.

The findings show that high-power truck charging is technically and economically feasible and would not pose any fundamental challenges with respect to the grid connection:

- For the high-traffic motorway station (22,000 trucks per day), a connection to the medium-voltage grid is necessary from the 2020s and sufficient until 2035. From 2040, when almost 90% of the local long-haul fleet is assumed to be electric, the station needs to be directly connected to the high-voltage grid.
- For the low-traffic motorway station (5,000 trucks per day), a connection to the medium-voltage grid is likely sufficient until 2040.
- For the logistics hub, a capacity of around 60 MW and a dedicated connection to the high-voltage grid is necessary by 2040 when more than 90% of the local truck fleet is electric.

The technical study builds on the most common voltage levels in Germany for medium-voltage (10 and 20 kV) and high-voltage lines (typically 110 kV). Electricity lines with these or similar voltage steps are common across the EU and are often located in proximity to the motorway network for larger industrial companies and commercial facilities. Connecting to these medium- and high-voltage lines is common practice and does not pose technical challenges. Although the power demand of a high-power truck charging point is higher than for an electric passenger car, the electricity grid is already designed in a way that can cope with such requirements.

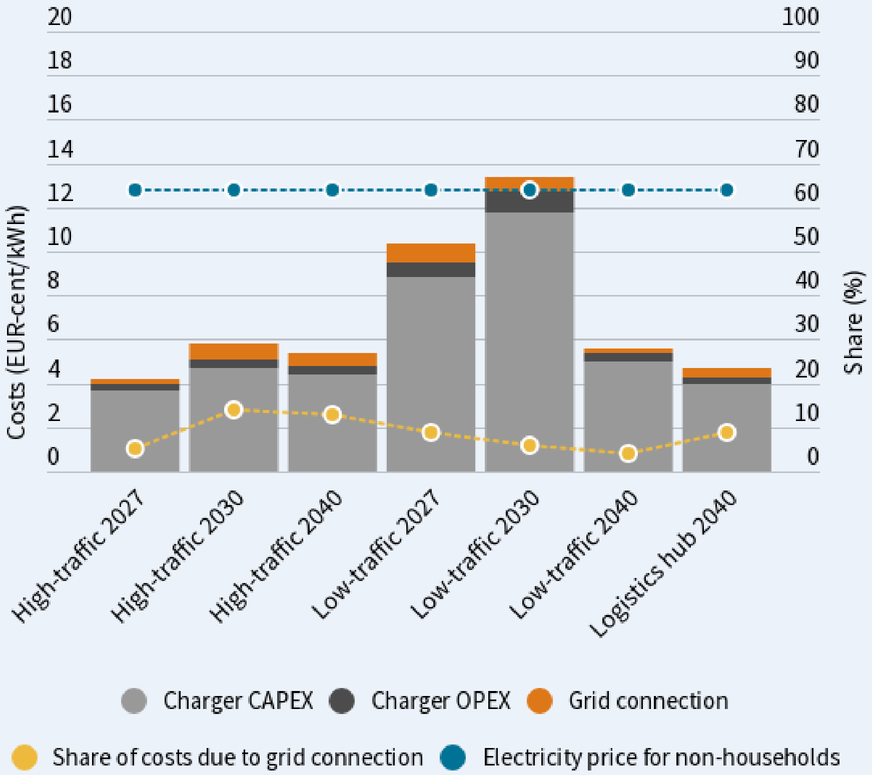
Charging point costs dominate, grid connection costs are marginal

The installation and operational costs for the chargers and for the grid connection were included in the analysis. Costs for electricity generation, taxes, levies or network tariffs were not taken into account. Overall, the costs to install and operate the chargers and the grid connection is low.

Depending on the scenario, the costs required for refinancing the chargers and the grid connection is about 4 - 6 EUR-cent per kWh of electricity charged for the high-traffic station and the logistics hub. Higher utilisation rates at these stations explain the relatively lower cost. In the case of the low-traffic charging station, the cost of the infrastructure is higher (10 - 14 EUR-cent per kWh). This can be explained by the lower utilisation rates at less frequented stations.

In the case of all examined scenarios, the costs of the charging infrastructure are dominated by the costs for the chargers. In most scenarios they represent about 90% of total infrastructure costs. In other words, the costs related to the grid connection are, in most cases, less than 10% of the infrastructure-related costs.

For comparison, the EU average electricity price for non-household consumers similar to haulage companies was around 13 EUR-cent/kWh in the first half of 2021. The charger and grid connection costs are therefore the equivalent of 50% of the non-household electricity price in the high-traffic and logistics hub scenario. In the low-traffic scenario, the costs are roughly the same as the electricity price.



Making the Alternative Fuels Infrastructure Regulation fit for electric trucks

As the first series production of long-haul BETs is expected for 2024, an initial network of high-power charging stations will need to be installed no later than 2025. The proposed distance-based charging infrastructure targets under AFIR are underestimating the expected market deployment of BETs. It is therefore necessary to increase the ambition along the TEN-T network as well as at the urban nodes and safe and secure truck parking areas:

- The TEN-T core network: a charging pool of at least 2,000 kW (2025) power output and 5,000 kW (2030) every 60 km
- The TEN-T comprehensive network: a charging pool of at least 2,000 kW (2030) power output and 5,000 kW (2035) every 100 km
- Urban nodes: at least 1,200 kW (2025) power output and 3,500 kW (2030) per node
- Safe and secure truck parking: at least two 100 kW stations by 2025 and at least five by 2030
- For logistics centres and depots at least one (semi-)public charger of at least 350 kW by 2025.

Shortening permitting procedures through the National Policy Frameworks

Cumbersome and lengthy procedures to install charging stations are often cited as a key barrier by business. The planning, permitting and procurement procedures need to be streamlined, any administrative obstacles removed and development times shortened. As part of AFIR, the so-called National Policy Frameworks should require Member States to ensure that obtaining the final permit and building authorisation for a publicly accessible charging station does not take longer than six months from the date of the initial permitting request by the company.

Coordination with grid operators, public authorities and industry

The planning process needs to begin well before the infrastructure needs materialise and be coordinated between all involved authorities and stakeholders, including improved coordination between EU-, national and local authorities.

Due to the long development times, transmission and especially distribution grid operators need to incorporate the roll-out of truck charging infrastructure early in their grid extension planning. Public authorities should coordinate the deployment of charging infrastructure to ensure that it is deployed in an efficient and integrated manner. Following best practices in Germany and in collaboration with grid operators, public authorities should map appropriate locations for site development with sufficient grid capacity and make this information publicly available.

Electric long-haul trucks are coming - it is time to start planning

This study shows that, just as battery-powered trucks are about to hit the market, their high-power charging infrastructure does not pose technical or economic challenges with respect to the grid connection. But preparing and planning for these charging stations must start now so as to not delay the transition to zero-emission trucking and the climate benefits they bring.

Further information

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1. Introduction

Road haulage is the preferred transport mode to move goods across Europe. Due to their flexibility and adaptability, heavy-goods vehicles (HGVs) fulfill a broad range of operational requirements for transport operators. To ensure that long-haul freight movements can be done by battery electric trucks (BETs), a network of public high-power and overnight charging stations needs to be rolled out across Europe. Battery-powered trucks will need to be charged during the driver's mandatory breaks and daily rest periods. Due to the significant power levels, truck charging stations will require a dedicated and adequate connection to the electricity grid in the medium- and high-voltage range.

*Transport & Environmen*t commissioned *RE-xpertise* and *ef.Ruhr* to examine the techno-economic feasibility of charging stations for long-haul trucks and their connection to the electricity grid.[1] The technical study evaluates possible charging and grid connection configurations for three archetype charging locations based on the expected market uptake and fleet penetration of BETs. The charging locations include a high- and low-traffic motorway station as well as a logistics hub. The technical study also analyses the resulting infrastructure-related costs which are due to the grid connection and examines the potential of charging management and stationary battery storage.

This policy briefing summarises the findings of the technical study and puts them into context with the infrastructure needs of transport operators. In addition, the briefing provides concrete policy recommendations for EU and national regulators to plan the roll-out of truck charging infrastructure in a cost-effective manner and to streamline the planning and permitting process.

2. Electric long-haul trucks are coming

There is increasing consensus among European truck manufacturers and industry stakeholders that BETs will play a dominant role in the decarbonisation of the road freight sector. Truck makers have made voluntary commitments for zero-emission vehicle (ZEV) sales over the coming decade. Based on their public announcements, an estimated 4 - 9 % of total truck sales will be zero-emission by 2025, rising to 41 - 47 % by 2030.[2]

Most of them including Daimler, MAN, Scania and Volvo are now focussing on bringing battery-powered trucks to the mass market for all vehicle segments, and including long-haul starting from 2024. For example, Daimler is readying its *eActros LongHaul* truck with a 500 km range for series production in 2024.[3] MAN is also initially planning with 500 km ranges from 2024.[4] Scania intends to enter the long-haul market by the same year with vehicles capable of running four and a half hours between breaks.[5]

Whereas some observers still think that batteries would only be suitable for urban and regional deliveries and competing technologies such as hydrogen fuel cell trucks, or even e-fuels, would excel

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[1] Burges and Kippelt (2021). Grid-related challenges of high-power and megawatt charging stations for battery-electric long-haul trucks. Study on behalf of Transport & Environment. Link.

[2] Transport & Environment (2021). Easy Ride: why the EU truck CO2 targets are unfit for the 2020s. Link.

[3] Daimler Truck (2021). Strategy Day. Link.

[4] Handelsblatt (2021). Abschied vom Diesel – MAN kündigt Serienproduktion von Elektro-Lastwagen an. Link.

[5] Scania (2021). Scania's commitment to electrification – our initiatives so far. Link.

over long distances, European truck makers now expect BETs to play a dominant role in the long-haul segment too.[6]

This is mainly due to the economics of trucking: Purchasing the vehicle is only one part of the total cost of ownership (TCO) equation, the other being the cost to fuel and maintain it.[7] Energy efficiency differences mean that batteries require half as much electricity than fuel cells powered by renewable hydrogen. Battery-powered trucks also require less maintenance and repairs than any other technology. With trucks being heavily used capital goods, the advantage of BETs in terms of operating costs grows with increasing mileage, making them particularly competitive for long-haul haulage.

2.1. Infrastructure coverage is needed from 2025

With a view to the expected market uptake of BETs, charging infrastructure will need to be rolled out across Europe from the early 2020s in lockstep with a rapidly growing number of battery-powered trucks. As the first series production of long-haul BETs is expected for 2024, an initial network of high-power charging stations along Europe's main transport routes will need to be installed by 2025 already. From 2030, BETs will increasingly dominate the sales mix and, in a subsequent step, the vehicle fleet on the road. This will require the charging network to be further extended and its capacity increased.

To ensure a European-wide infrastructure coverage, the European Commission has proposed mandatory distance-based targets for heavy-duty vehicles (HDVs) as part of the Alternative Fuels Infrastructure Regulation (AFIR).[8] The proposed targets are underestimating the expected market deployment of BETs and the level of ambition needs to be significantly increased by co-legislators in the Council and European Parliament.[9] Nonetheless, the proposal represents a good starting point and would ensure a much needed basic coverage of truck charging stations along the TEN-T core network by 2025.

The spatial distribution and capacity of truck charging infrastructure will need to take into account the respective road freight volumes, route and driving patterns, the driving times and rest periods as well as the size and expected electric driving range of the vehicle fleet. From the perspective of the electricity grid, existing medium-voltage or high-voltage lines as well as corresponding substations should be in close proximity to the planned location of charging stations.[10]

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[6] TRATON (2021). Why the future of trucks is electric. Link.

[7] Transport & Environment (2021). Why the future of long-haul trucking is electric. Link.

[8] European Union (2021). Proposal for a Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council. Link.

[9] Transport & Environment (2021). AFIR: How can the EU's infrastructure law make Europe 'fit for 55'? Link.

[10] ENTSO-E (2021). Position Paper. Electric Vehicle Integration into Power Grids. Link.

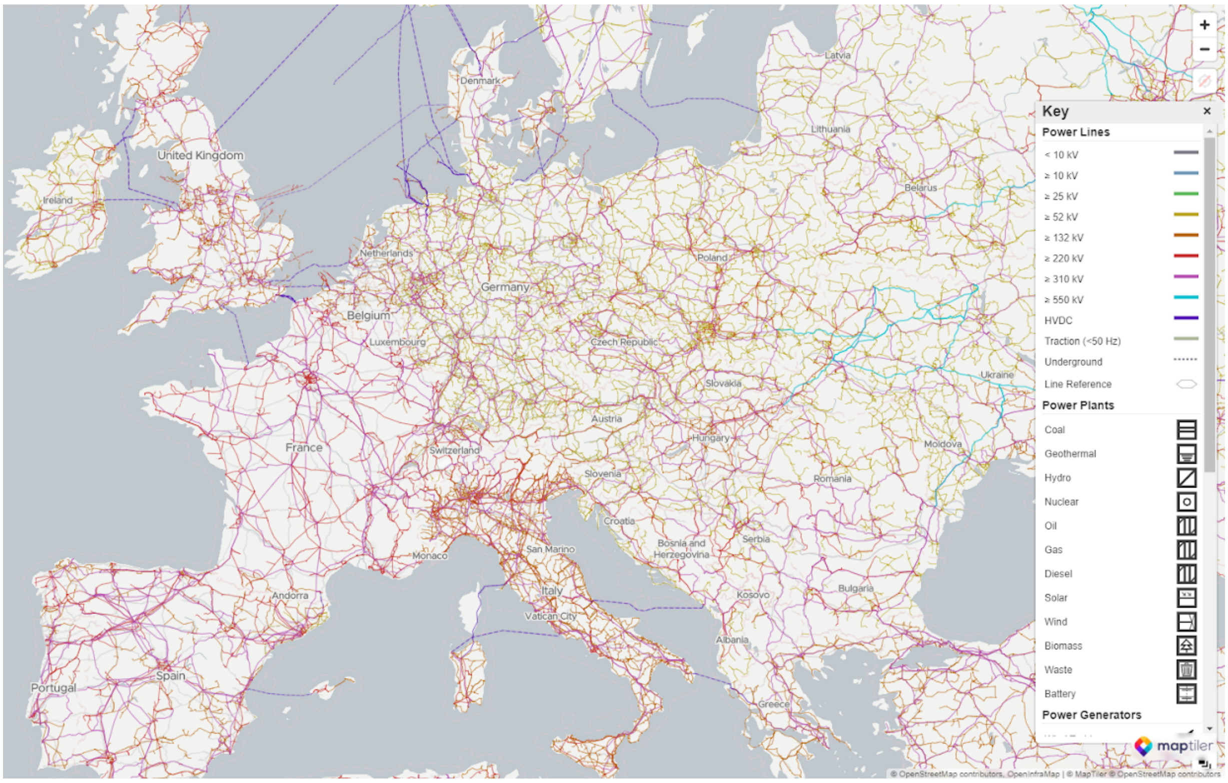

Figure 1. Transmission and distribution grid in the EU[11]

The electricity grid can be subdivided into the transmission and distribution grid. Transmission lines facilitate the transport of electricity over large distances within and between countries directly to the areas where a lot of power is consumed. Although the definitions differ from country to country, at the distribution grid level, high-voltage lines typically transmit power between 36 and 220 kV to population centres and large industrial clusters whereas medium-voltage lines are defined as between 1 and 36 kV.[12]

The technical study by RE-xpertise and ef.Ruhr builds on the most common voltage levels in Germany for medium-voltage (10 and 20 kV) and high-voltage lines (110 kV). Medium- and high-voltage lines with these or similar voltage steps are common across the EU and are often located in proximity to the motorway network (see Figure 1).

2.2. Charging can be aligned with driving times and rest periods

Battery-powered long-haul trucks will need to be charged during the driver's mandatory breaks and daily rest periods in order to avoid operational downtime. The European regulation foresees maximum daily driving periods of 9 hours (10 hours up to 2 times per week) and minimum rest periods of 11 hours (9 hours up to 3 times per week).

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[11] Open Infrastructure Map (no date). View of the EU's power line infrastructure mapped in the OpenStreetMap database. Link.

[12] Eurelectric (2020). Power Distribution in Europe. Facts & Figures 2020. Link.

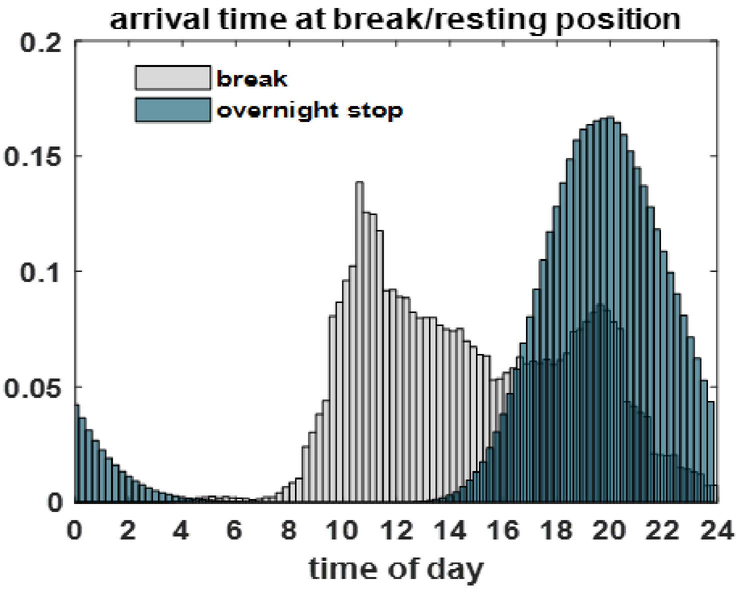

Figure 2. Distribution of truck arrival times at break/rest location. Y-axis represents frequency.

During the day, mandatory breaks of 45 minutes after every four and a half hours of driving are legally required which can be split into two breaks of 15 minutes followed by a break of 30 minutes.[13] These breaks and rest periods are the preferred time window to recharge the vehicle either rapidly during the day or slowly overnight. The technical study by RE-xpertise and ef.Ruhr assumes a given distribution of these breaks and rest periods (see Figure 2).

2.3. Driving ranges are feasible

Based on the driving times and rest periods and assuming an (upper bound) 80 km/h average vehicle speed, a single driver can drive a distance of up to 360 km between the mandatory breaks and a total distance of up to 720 km per day. The long-haul BETs which are expected to go into series production by 2024 by Daimler, Man, Scania and Volvo will initially feature ranges between 300 and 500 km and be able to charge the energy required for a four and a half hours drive during the 45 minutes mandatory rest break (see Section 2).

Long-haul road haulage is commonly defined as freight movements which are performed on single vehicle trips above 400 km. Close to 80 % of total EU road freight activity measured in tonne-kilometres is performed on vehicle trips below 800 km (see Figure 3).[14] Long-haul BETs will therefore require onboard batteries for a daily range of 500 to 800 km which can be extended through opportunity charging during the 45 minutes rest break.

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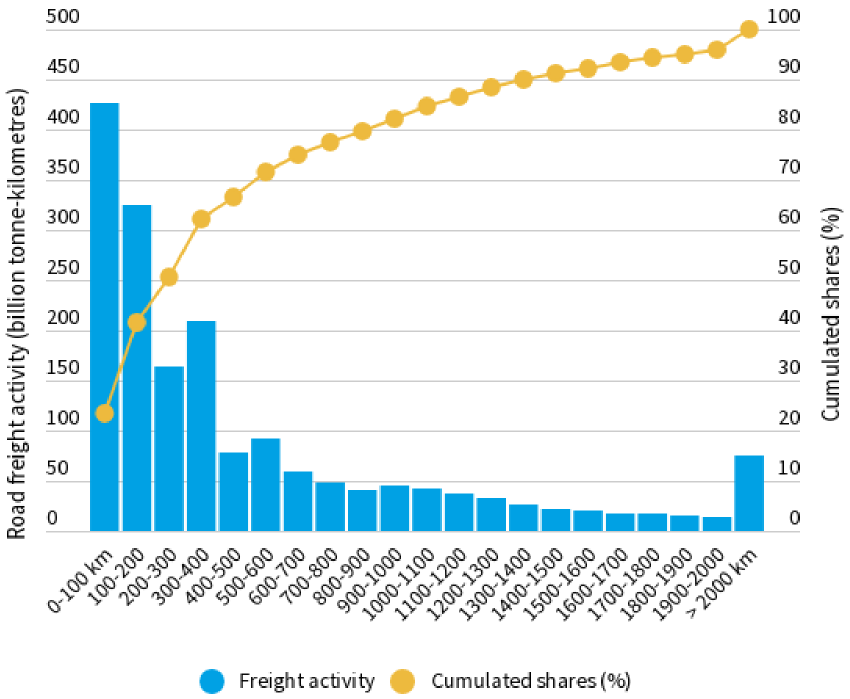
[13] European Union (2019). Regulation (EC) No 561/2006 of the European Parliament and of the Council of 15 March 2006 on the harmonisation of certain social legislation relating to road transport. Link.

[14] Transport & Environment (2021). Unlocking electric trucking in the EU: recharging along highways. Link.



Notes: Distribution of road freight activity in the EU across vehicle trip distance bands. Trips can last multiple days.

Sources: T&E calculations based on ETISplus (2010) and calibrated based on Eurostat (2018).

Figure 3. Distribution of road freight activity in the EU across trip distances

These long-haul trucks, whose routes can involve multi-day intercity travel, will rely on a comprehensive network of public charging stations along the road network and at freight hotspots across Europe. The driving range and battery size will be optimised based on the daily requirements and any potential variability in daily range. Payload losses due to the battery weight are not expected to be relevant anymore from the second half of the 2020s.[15] Notwithstanding, downsizing the battery size may be cheaper from a TCO and wider economic perspective if the transport operator can rely on a good charging network.

3. Summary of the technical study

Charging infrastructure for trucks will require a dedicated connection to the electricity grid in the medium- and high-voltage range. The technical study by RE-xpertise and ef.Ruhr evaluates possible charging and grid connection configurations for three archetypical charging stations based on the expected market uptake and future fleet penetration of BETs. The examined charging locations include a high- and low-traffic motorway station as well as a medium-sized logistics hub. The technical study also analyses the resulting infrastructure-related costs which are due to the grid connection and examines the potential of charging management and stationary battery storage.

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[15] Transport & Environment (2021). How to decarbonise long-haul trucking in Germany. An analysis of available vehicle technologies and their associated costs. Link.

3.1. Methodology

The charging infrastructure locations of long-haul BETs trucks will be diverse, depending on the individual requirements of haulage companies such as typical freight movements, trip distances, loading and unloading times as well as driving shifts. Charging opportunities include:

- Public megawatt charging (MCS) points
- Public overnight combined charging (CCS) points for longer rest periods
- (Semi-)public MCS and CCS points at the place of (un)loading
- Private overnight CCS points for truck returns to the depot

Those charging locations were examined as part of the technical study, with the exception of private depot charging. It should be noted that some of these charging locations will to some extent also serve urban- and regional-delivery trucks, especially in the case of depot and destination charging locations. For the purpose of modelling the infrastructure needs of the archetypical motorway stations, it was assumed that these stations are only used by long-haul trucks.[16] In order to realistically estimate the infrastructure needs of the archetypical logistics hub, a parallel electrification scenario of the local urban- and regional delivery fleet was assumed.

The modelling framework *e.mission* developed by RE-xpertise and ef.Ruhr simulates the dimensioning of the necessary infrastructure based on the traffic flows, the charging behaviour as well as the applied charging management (see Figure 4). The number of customers, their distribution throughout the day and the supplied energy determine the number of chargers and their power needs. For example, a concentration of many vehicles within a short time period would require a higher number of chargers compared to a more even distribution throughout the day. The energy supplied per charging event also affects the overall demand for charging points. Longer charging times would result in a higher number of chargers required.

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[16] This was solved by isolating articulated tractor trailers from the traffic counting data. Given that some tractor trailers operate on urban- and regional-delivery duty cycles, this can be considered to be a conservative estimate.

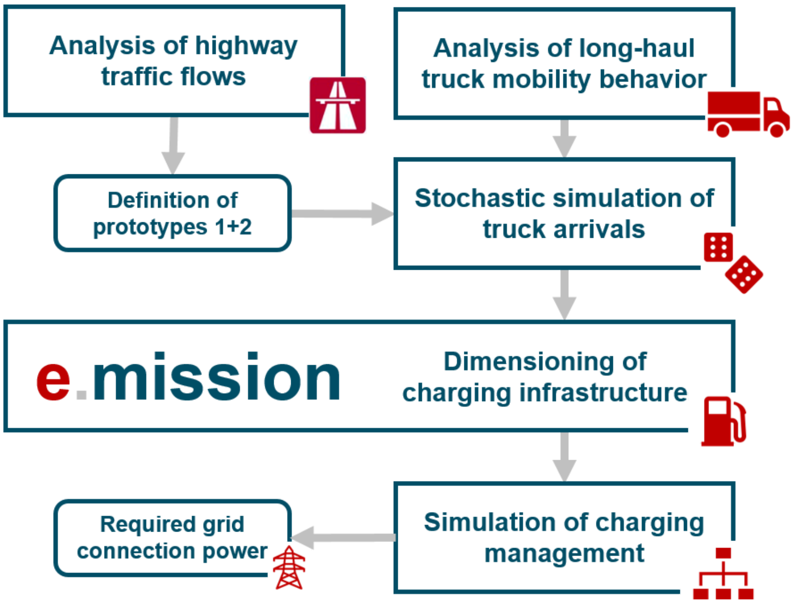

Figure 4. Modelling framework *e.mission*

The truck flows were evaluated based on the automated traffic counting system of the German motorway network to select the location of the two archetypical motorway stations and model their respective infrastructure needs (see Figure 5). The high-traffic motorway station represents the case with the highest real-world truck traffic flows in Germany counting more than 20,000 HGVs passing by each day, whereas the low-traffic motorway station assumes around 5,000 HGVs per day (lower quartile of traffic flow cases).[17] The high-traffic archetype can be considered representative for the most extreme traffic flow cases across the EU, whereas the low-traffic station is comparable to the upper average traffic intensity at EU level. For comparison, half of the TEN-T network length is frequented by less than 3,000 HGVs per day and three quarters by less than 6,000.[18]

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[17] The numbers include urban and regional delivery trucks which were not taken into account to model the charging needs.

[18] Conference of European Directors of Roads (2020). Trans-European Road Network, TEN-T (Roads): 2019 Performance Report. Link.

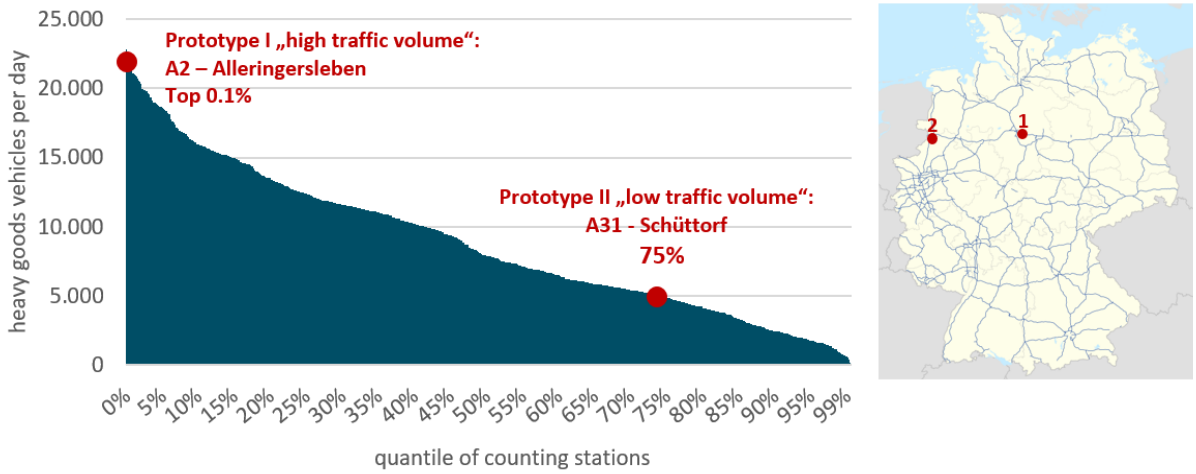

Figure 5. Average daily number of HGVs at German motorway traffic counting stations (sorted)

The modelled long-haul fleet consists of trucks with different driving ranges and battery sizes. Differences in the vehicle range and the driving pattern explain why not all trucks need to always charge at a public charging station. For example, long-haul trucks with a maximum range of 700 km but which operate only 500 km per day will likely be mostly charged at the depot or place of (un)loading in order to reduce charging costs. In contrast, trucks with longer daily trips will more often require high-power charging at a public charging station.

Trucks are thus assumed to only charge at MCS charging points if their remaining trip distance is higher than the remaining battery capacity. Charging behaviour is modelled in a way to ensure that the truck always reaches its final trip destination with a remaining safety margin corresponding to a 20% battery state of charge (SoC). Nominal charging power of the MCS charging point is assumed to be 1.2 MW.

There is also a trade-off between MCS charging during the day and CCS charging overnight. If MCS charging points are used more frequently, the charging energy of overnight charging can be reduced (and vice versa). Trucks are charging at MCS charging points with the fully rated charging power until the battery reaches 80% SoC. At overnight CCS charging points, trucks always charge during the night until a 100% SoC is reached. The maximum charging power at CCS amounts to 150 kW, the rated power can vary depending on the applied charging management.

3.2. Fleet assumptions

The study considers quickly rising fleet penetration rates of long-haul BETs at the given locations. These rates may be associated with the years 2027, 2030, 2035 and 2040 but could also refer to earlier or later dates depending on how the market uptake will evolve. In the examined scenarios different average distances between stations are assumed depending on the given year. Even in an early stage with initially low fleet penetration, the maximum allowable distance between two charging stations along the motorway should not be higher than 100 km.

The BET penetration levels shown in Table 1 may differ from expected EU averages. Initially, the fleet size of long-haul BETs trucks will be small. The early market uptake will happen at different speeds across Europe. Even within individual countries and regions, charging infrastructure will be rolled out first at more frequented motorways and at busier freight hotspots. The early availability of charging opportunities at these selected locations will attract more long-haul BETs more quickly than elsewhere due to a 'gravitational pull effect'.

Archetypical charging station	Year	Assumed local BET fleet share (long-haul)
High-traffic motorway station	2027	8 %
	2030	20 %
	2035	50 %
	2040	88 %
Low-traffic motorway station	2027	3 %
	2030	7 %
	2040	60 %
Logistics hub	2040	80 %[19]

Table 1. Assumed fleet penetration of long-haul BETs depending on the scenario

Motorways with lower traffic volume will initially experience a lower local fleet share of long-haul BETs for some time. The low-traffic motorway station therefore assumes a local fleet share which is slightly below the expected EU-wide average. With increasing sales and fleet shares of long-haul BETs, charging stations will need to be rolled out across all regions more evenly and the gravitational pull effect of the high-traffic locations will become less relevant over time.

A similar development can be expected in the case of logistics hubs. A mixed business area with a size of about 125 hectare net was considered for the archetypical logistics hub (see Figure 7). The traffic flow profile combines long-haul trucks with urban and regional distribution activity. Short-haul BETs will be introduced sooner than their long-haul counterparts and will therefore mainly determine the charging needs initially. For that reason, the analysis for this archetype is restricted to a high-penetration scenario across the urban, regional delivery and long-haul segment which may (but does not necessarily have to) be associated with the year 2040.

3.3. Resulting grid connection capacity

The different configurations of the public charging stations cover a broad range of grid connection power levels and thus require different grid connection concepts. In practice, the choice of the voltage level and the specific point of connection to the public power grid depends on numerous factors, such as:

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[19] Also assuming a 95 % BET fleet share of the local urban- and regional delivery truck fleet at the logistics hub.

- The available grid capacity of the pre-existing power grid infrastructure
- Costs of different connection alternatives
- Spatial and environmental aspects including the space for new substations
- Construction costs as well as regionally applicable and diverging network tariffs
- The development of future truck flows and peak power requirements

The design of the grid connection is therefore always a trade-off between these factors and a universally valid concept does not exist. For the sake of simplicity, a broad set of universal grid connection concepts was developed (see Figure 6).

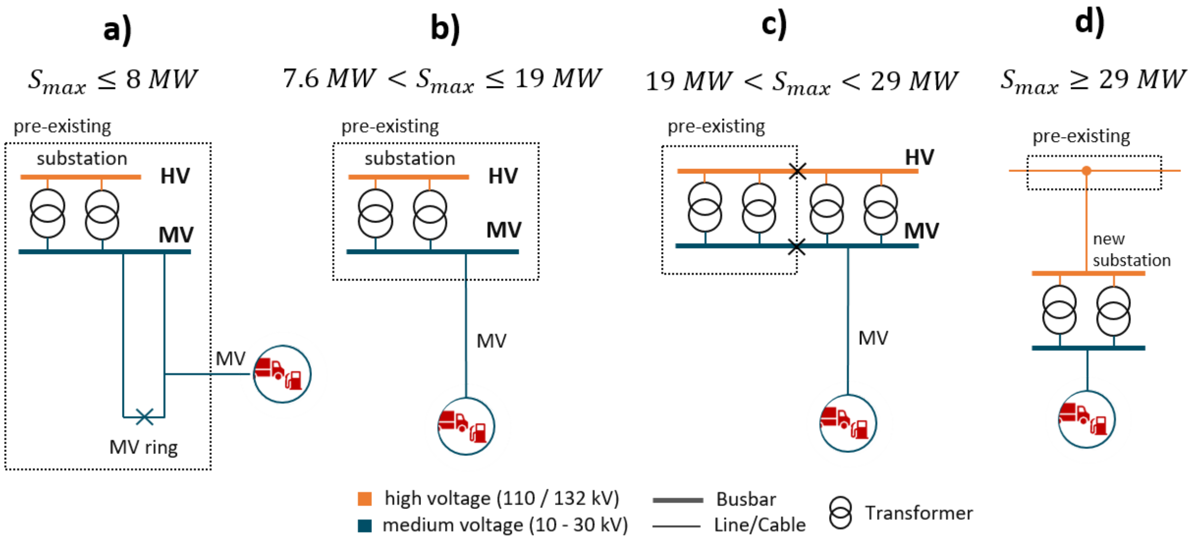

Figure 6. Grid connection concepts[20]

Charging stations with a necessary connection capacity below 8 MW are connected to a nearby medium-voltage ring (a). Above 8 MW, a distinct connection to the closest substation is needed. If the preexisting high- to medium-voltage transformers of this substation have sufficient reserve capacity, no further investment is necessary and the maximum available grid connection capacity is assumed to be 19 MW (b). If the substation does not have enough reserve capacity and above 19 MW up until 29 MW, the expansion of the nearby high-voltage substation becomes necessary (c). For connection capacities above 29 MW, the charging station needs to be directly connected to the high-voltage grid (d). This involves the installation of a new substation, either in the vicinity of the high-voltage grid or located next to the charging station.[21] It should be noted that the conditions can differ depending on the concrete situation.

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[20] The rated power is shown here in megawatt (MW) which excludes reactive power and charger efficiency losses. These losses are assumed to be 5%. Subtracting them from the rated power determines the connection capacity measured in MW.
[21] It should be noted that these are average values and differences may occur depending on the individual case.

High- and low-traffic motorway station

The design of the public charging stations is assumed to be similar to today's motorway service stations. MCS are offered at special parking stands that can only be used for the duration of the charging process. Overnight parking stands are available at separate charging bays.

Standing times for the overnight charging process are determined by the mandatory rest period and not by the duration of the charging process. It is also assumed that a similar density of overnight parking facilities for trucks to the one existing today will be needed. For an estimation of the required number of overnight CCS charging points, the available parking opportunities along the relevant German motorway sections were manually counted based on satellite data. Together with the local fleet share of battery-powered long-haul trucks and the average distance between charging stations, the required number of CCS points is then estimated.

Archetypical charging station	Year	Average distance between stations	Number of charging points		Cumulative power output	Required grid connection capacity (concept)	
			MCS 1.2 MW	CCS 150 kW	1 direction	1 direction	2 directions
High-traffic motorway station	2027	100 km	3	41	9.8 MW	3.6 MW (a)	7.2 MW (a)
	2030	50 km	4	54	12.9 MW	4.8 MW (a)	9.7 MW (b)
		100 km	7	108	24.6 MW	8.4 MW (b)	16.7 MW (b)
	2035	50 km	8	136	30.0 MW	9.6 MW (b)	19.2 MW (c)
	2040	50 km	13	217	48.2 MW	15.6 MW (b)	31.2 MW (d)
Low-traffic motorway station	2027	100 km	1	4	1.8 MW	1.2 MW (a)	2.5 MW (a)
	2030	50 km	2	5	3.2 MW	2.4 MW (a)	4.8 MW (a)
		100 km	2	10	3.9 MW	2.4 MW (a)	4.8 MW (a)
	2040	50 km	3	43	10.1 MW	3.8 MW (a)	7.2 MW (a)

Table 2. Required grid connection capacity and concept for the different scenarios

The results of the modelled grid connection capacity for the different scenarios is illustrated in Table 2. For two co-located high-traffic motorway stations for both directions, a distinct connection to the medium-voltage grid with the expansion of the nearby high-voltage substation is sufficient until 2035. From 2040, the two charging stations need to be directly connected to the high-voltage grid in order to cope with the significant share of long-haul BETs among the local fleet. For two low-traffic motorway stations in both directions, a connection to the nearby medium-voltage ring would be sufficient until 2040.

These results can vary to some extent depending on the charging duration, the charging power, the number and ratio between high-power and overnight chargers as well as the possible co-location of charging stations for passenger cars and light-duty vehicles (LDVs) which were not further considered here. Depending on this, a direct connection to the high-voltage grid may already become necessary much sooner than 2040.

Logistics hub

A large share of HGVs leaves the logistics hub one or two hours after arrival, i.e. after loading or unloading goods. This dictates the time window for charging. Together with the traffic flows and their distribution throughout the day, this determines the required number and capacity of (semi-)public MCS and CCS charging points.

For the considered logistics hub, the demand from both urban and regional delivery as well as long-haul trucks in 2040 can be satisfied by 150 MCS with a maximum power output of 450 kW and 500 CCS at 90 kW. This on-site charging infrastructure results in a necessary grid connection capacity of around 60 MW and, hence, a dedicated connection to the high-voltage grid. Larger logistics hubs may need even more powerful grid connections.

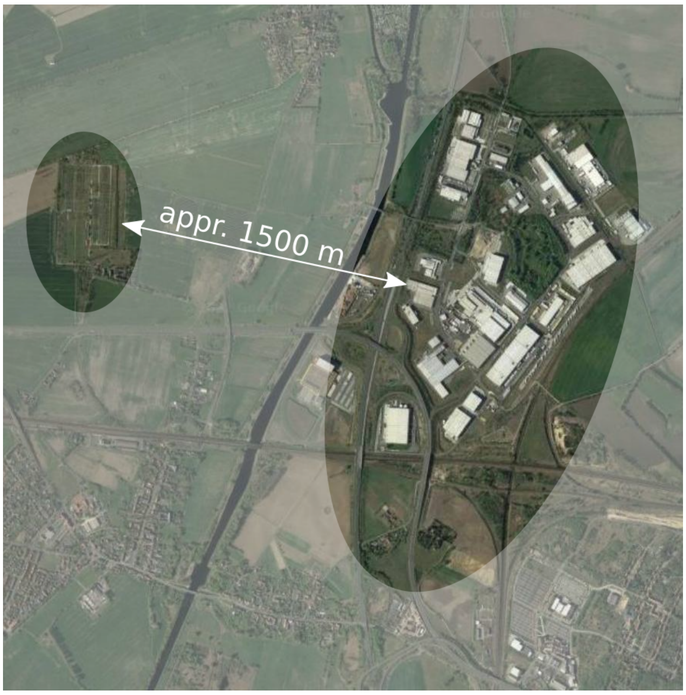


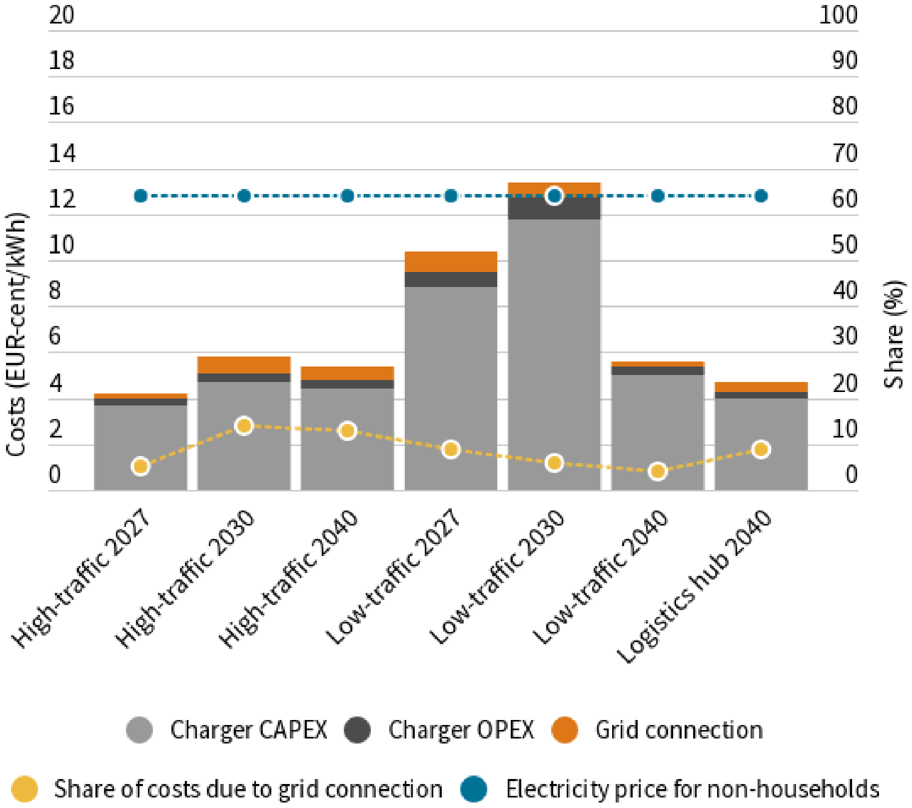
Figure 7. Logistics hub Wustermark, Germany, with a nearby high-voltage transmission substation

Operational processes and the structure of the hub's area may require certain adaptations. Dedicated and accessible space for (semi-)public charging at those hubs will be an essential part of the concept. The required capacity of the network connection for the charging infrastructure at logistic hubs is in a range of 0.5 to 1.0 MW/hectare. This is a factor of 10 - 20 compared to the current grid situation at those locations. High-voltage grid infrastructure in the vicinity of logistics hubs may therefore become an important factor for future site selection and development.

3.4. Resulting grid connection costs

The installation and operational costs for the chargers and for the grid connection were included in the analysis. Costs for electricity generation, taxes, levies, network tariffs or profit margins nor those due to planning, permitting or the acquisition of new building sites were not taken into account.

As shown in Figure 8 and depending on the scenario, the costs required for refinancing the chargers and the grid connection is about 4 - 6 EUR-cent per kWh of electricity charged for the high-traffic station and the logistics hub. Higher utilisation rates at these stations explain the relatively lower cost. In the case of the low-traffic charging station, the cost of the infrastructure is higher (10 - 14 EUR-cent per kWh). This can be explained by the lower utilisation rates at less frequented stations.



Notes: EU electricity price for non-household consumers (first half of 2021) excludes non-recoverable taxes and levies and represents an annual consumption of 500 - 2,000 MWh similar to small- and medium-sized haulage companies.

Sources: Burges and Kippelt (2021) and Eurostat (2021).

Figure 8. Infrastructure-related costs per kWh charged for the different scenarios

In the case of all examined archetypes, the costs of the charging infrastructure are dominated by the costs for the chargers. In most scenarios they represent about 90% of total infrastructure costs. In other words, the costs related to the grid connection are, in most cases, less than 10% of the infrastructure-related costs.

For comparison, the EU average electricity price for non-household consumers similar to haulage companies and excluding recoverable taxes and levies was around 13 EUR-cent/kWh in the first half of 2021.[22] The charger and grid connection costs are therefore the rough equivalent of 50% of the electricity price in the high-traffic and logistics hub scenario. In the low-traffic scenario, the costs are roughly the same as the electricity price. In practice, charging point operators (CPOs) will recover the charger and grid connection costs by adding a premium to the charging price for the customer.

The technical study suggests that the gradual expansion within the medium-voltage grid from initially low connection capacities to power levels close to 30 MW is comparatively straightforward, even in the case of the busiest charging locations. In certain cases, for example where it is already foreseeable that an upgrade will become necessary within just a few years, a forward-looking design of the grid connection can reduce overall investment costs.

3.5. Charging management

Load levelling through active charging management is a crucial factor to reduce the peak power and consequently the necessary grid connection capacity and can be integrated without affecting the service level or customer satisfaction. There are strong synergy effects between MCS and CCS in regards to the grid connection and it is highly recommended to combine these charger types at one charging location. MCS and overnight CCS charging points show very different utilisation times. The highest customer arrivals and the maximum customer volume of MCS charging occurs at around 10 and 11 AM, while for the CCS, most customers arrive at around 8 PM (see Figure 2).

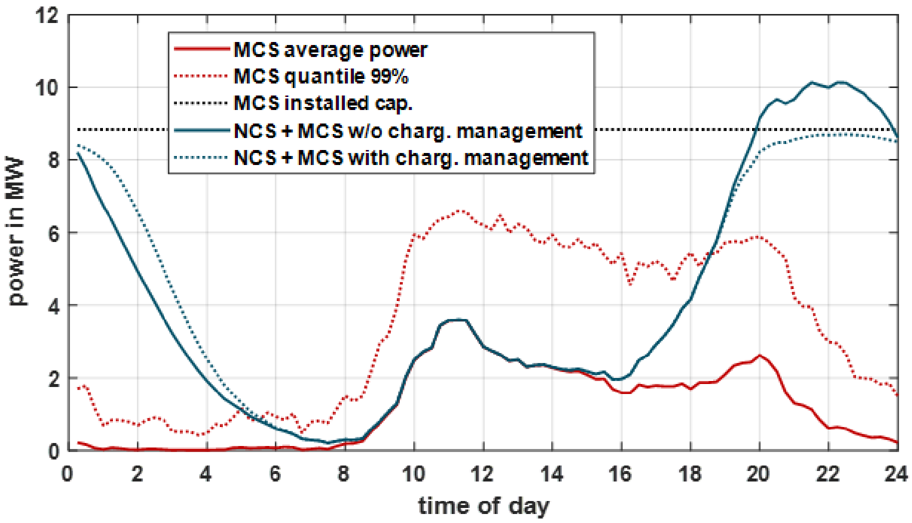


Figure 9. Effect of charging management on the daily power demand profile

Charging management can reduce the peak power requirements as illustrated by Figure 9 and 10 which represent the high-traffic motorway station in 2030 for one direction and an average distance

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[22] Eurostat (2021). Electricity prices for non-household consumers - bi-annual data (from 2007 onwards). Link.

of 100 km between the stations. The red dotted line in Figure 9 illustrates the MCS peak power demand of around 6 MW at noon with a 99% customer satisfaction rate. The blue line illustrates the combined peak power demand of MCS and CCS overnight charging points which reaches its maximum of 10 MW at around 10 PM without any charging management.

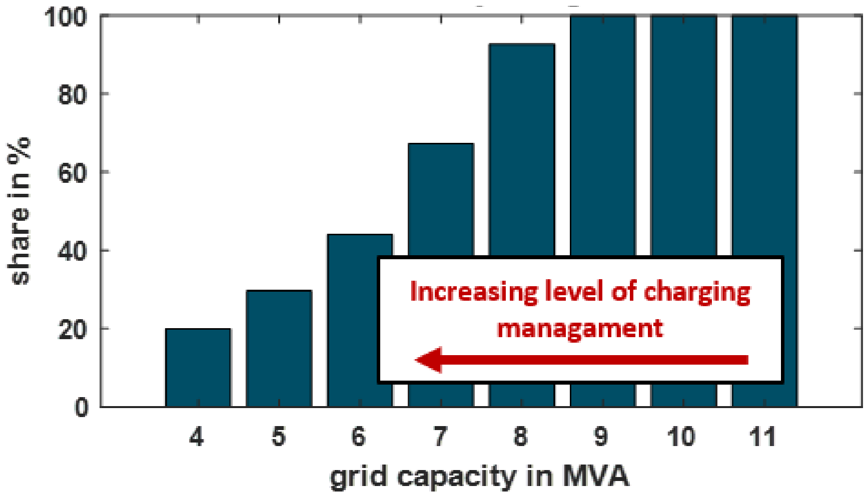

Figure 10. Effect of charging management on the share of fully charged trucks

The charging events at the MCS points should not be affected, while the CCS points offer great potential for charging management due to the longer overnight rest period. When stretching the charging time during the overnight rest, it is possible to reduce the combined peak power to 8.4 MW. In all examined scenarios, charging management is limited in a way which ensures that the trucks always reach a 100% SOC at the end of their overnight rest period.

3.6. Stationary battery storage

Stationary batteries can provide flexibility to a power system which will be increasingly dominated by renewables.[23] Due to the rapidly developing economies of scale in the automotive industry and the future availability of new batteries and used ones from vehicles after their end of life, batteries could provide short-term electricity storage services at competitive costs depending on economic conditions.[24]

Stationary batteries could reduce the peak power demand of truck charging stations and could therefore reduce the grid connection capacity. They may also offer other co-benefits such as the maximised use of on-site renewable electricity generation, ancillary services (e.g. power frequency control) or power backup supply (e.g. balancing frequency fluctuations).

The technical study by RE-xpertise and ef.Ruhr found that the installation of stationary battery storage at truck charging stations can be an economically viable option in some selected cases, especially if it allows for a temporary delay of the grid connection upgrade during the ramp-up phase. In cases where the connection to a higher grid level shall be delayed, batteries could work as a bridging solution.

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[23] International Energy Agency (2021). Energy Storage. Link.
[24] Lazard (2021). Lazard's Levelised Cost of Storage Analysis - Version 7.0. Link.

However, economic benefits are very individual and depend on the economic and technical circumstances as well as the development of traffic flows and peak power demand at a given charging location. In most examined cases, a significant reduction of the peak power demand would require the battery system to operate for up to ten hours at its given power output. This value is unusually high for peak shaving purposes and results in comparatively high levelised storage costs.

The reason can be found in the underlying charging management of overnight charging which renders the load profile almost perfectly ‘flat’ between 7 PM and 1 AM (see Figure 9). A storage system would need to shift all power between night and day and could not recharge in-between. Below a grid connection capacity of 5.5 MW, electricity would even need to be stored and its consumption shifted between weekends and weekdays, resulting in even higher battery capacities which would be required.

In contrast to locations which combine MCS and overnight CCS charging points, those with an exclusive focus on MCS charging can show a better suitability for battery storage. In this case, the battery does not compete with the (cheaper) charging management option and significantly smaller battery capacities are needed to reduce the required grid connection capacity. In addition, shorter usage times favour the combination with other use cases, such as optimising the use of locally generated renewable electricity, reducing procurement costs or providing ancillary and backup services, and can therefore improve the overall economic viability of the charging infrastructure.

4. Policy recommendations at EU level

4.1. Alternative Fuels Infrastructure Regulation

Making the infrastructure targets fit for electric trucks

As the first series production of long-haul BETs is expected for 2024, an initial network of high-power charging stations will need to be installed no later than 2025. Postponing this date would delay the mass adoption of BETs.

The proposed distance-based charging infrastructure targets are underestimating the expected market deployment of BETs. It is therefore necessary to increase the power output of the charging pools located along the TEN-T core and comprehensive network as well as at the urban nodes based on the highest scenario which was assessed as part of the Commission’s impact assessment:

- TEN-T core network: a charging pool with at least 2,000 kW (instead of 1,400 kW) of power output every 60 km by 2025, 5,000 kW (instead of 3,500 kW) by 2030.
- TEN-T comprehensive network: a charging pool with at least 2,000 kW (instead of 1,400 kW) of power output every 100 km by 2030, 5,000 kW (instead of 3,500 kW) by 2035.
- TEN-T urban nodes: at least 1,200 kW power output (instead of 600 kW) for each node in 2025 and 3,500 kW (instead of 1,200 kW) in 2030

A significant share of BETs will also need to charge while they are parked at logistics hubs for (un)loading goods which can typically take up to 3 hours. Targets for at least one 350 kW (semi-)public charging point by 2025 at each of these locations should therefore be included. This charging point should preferably be shared between multiple transport operators and be made accessible in a way so that it can be used publicly.

Shortening permitting procedures through the National Policy Frameworks

As laid out above, the archetypical charging stations are technically and economically feasible and no fundamental challenges in regards to the grid connection are expected. However, the planning, permitting and procurement processes to deploy charging stations, medium- and high-voltage substations and power lines can take several years. The complexity of the approval process and the time it takes to obtain the necessary permits can vary considerably by Member State and region, particularly for grid connections in the medium- and high-voltage range.[25]

Cumbersome and lengthy procedures to install charging stations are often cited as a key barrier by business. The planning, permitting and procurement procedures need to be streamlined, any administrative obstacles removed and development times shortened. This also requires public authorities to increase administrative capacities to speed up the processing of permitting requests.

As part of the AFIR proposal, the Commission has proposed to strengthen the national infrastructure plans, the so-called 'National Policy Frameworks', which require Member States to put forward measures to improve the effectiveness of the deployment of charging infrastructure. This provides a first starting point to identify how Member States intend to reduce obstacles with regard to infrastructure planning, permitting and procurement. However, the vague language of the provisions fails to ensure that substantial progress can be made on these issues quickly enough.

Without prejudice to national permitting and planning processes, the AFIR should require Member States to ensure that obtaining the final permit and building authorisation for a publicly accessible charging station does not take longer than six months from the date of the initial permitting request.

Integrating the MCS standard as soon as it is available

The current CCS standard only allows for charging powers up to 350 kW and this power level will not be sufficient for HDVs.[26] CharIN, the industry's standardisation initiative, is currently developing the MCS standard for commercial vehicles which can deliver power levels up to 3.8 MW.[27] The MCS standard should also define a standardised attachment point for the charging inlet, located on the front left-hand side of the vehicle to enable a uniform design of parking facilities.

The MCS standard is expected to be fully certified by 2023 or 2024.[28] As soon as it is available, the Commission should add the MCS standard to the technical specifications of the AFIR through a delegated act and increase the minimum power output for charging stations along the TEN-T core and comprehensive network as well as at the urban nodes to at least 800 kW. AFIR should also set the requirement to make all CCS and MCS charging points for HDVs capable of smart charging.

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[25] European Commission (2021). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A strategic rollout plan to outline a set of supplementary actions to support the rapid deployment of alternative fuels infrastructure. Link.

[26] CharIN (2021). Position Paper of Charging Interface Initiative e.V. DC CCS Power Classes V7.1. Link.

[27] CharIN (2020). Megawatt Charging System (MCS). Link.

[28] Nationale Plattform Mobilität (2021). Schwere Nutzfahrzeuge – Standards und Normen für alternative Antriebe. Link.

In the interest of time, it will be necessary to begin the infrastructure roll-out on the basis of the CCS standard already in the early 2020s before the first AFIR targets come into effect. The upgradability to MCS should be factored in simultaneously (e.g. in regards to voltage requirements) so that only the plugs and cables need to be replaced when the charging points are upgraded at a later stage.[29]

4.2. Safe and secure truck parking areas

Long-haul trucks do not always return to base and need at least one overnight stay on single distance trips above 500 km. Today, a total of 396,000 HGVs require appropriate parking facilities every day in the EU.[30] Haulage companies and truck drivers are struggling with limited and unsafe parking areas along the TEN-T corridors. This issue deserves more attention, particularly in the context of the future installation of charging infrastructure at these parking areas.

The upcoming EU standard for 'safe and secure parking areas for trucks' can help improve the parking situation and working conditions of drivers as well as reduce cargo theft.[31] At the same time, these truck parking areas also offer an opportunity to combine social and labour policy objectives with the future roll-out of truck charging to the mutual benefit of both.

The Commission has recognised this and included charging targets for safe and secure truck parking areas in the AFIR proposal, albeit with insufficient ambition. These areas should be equipped with at least two charging points with at least 100 kW by 2025 and with at least five charging points by 2030.

The Commission is currently finalising the delegated act to establish the relevant standard.[32] Unfortunately, the draft act includes only weak requirements to provide electric power facilities for refrigerated road transport vehicles whose power level is by far not sufficient for future overnight truck charging points.[33] It also does not include a requirement to assess the existing grid infrastructure in the proximity of a new parking area or to make the certification subject to the location of medium- or high-voltage substations in its vicinity.

This is a missed opportunity and should be fixed at the earliest occasion. To ensure that their commercial infrastructure is future-proof, business representatives of parking places will have a strong interest in ensuring that when they build or renovate a truck parking site along the TEN-T network, the grid connection is being designed while considering future charging demand from HDVs.

4.3. Credit mechanism under the Renewable Energy Directive

The proposed revision of the Renewable Energy Directive (RED) requires Member States to establish a mechanism through which CPOs generate exchangeable credits for the renewable electricity they

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[29] Nationale Plattform Mobilität (2021). Ladeinfrastruktur für batterieelektrische Lkw. Link.

[30] European Commission (2018). Study on Safe and Secure Parking Places for Trucks. Task 3a: Mapping Demand and Supply. Link.

[31] European Commission (2018). Study on Safe and Secure Parking Places for Trucks. Final Report. Link.

[32] European Commission (2020). Experts group on Safe and Secure Parking Areas for Trucks (E03642). Link.

[33] European Commission (2021). Commission Delegated Regulation .../... of XXX supplementing Regulation (EC) No 561/2006 of the European Parliament and of the Council with regard to the establishment of standards detailing the level of service and security of safe and secure parking areas and to the procedures for their certification. Link.

supply to electric vehicles.[34] Fuel suppliers can purchase these credits from COPs to meet their targets to achieve a certain level of renewable energy in transport or reduce the carbon intensity of transport fuels. Such a system was already introduced in the Netherlands and Germany and will soon follow in France (and exists in California in the form of the Low Carbon Fuel Standard (LCFS) credits). The mechanism will promote the roll-out of an EU-wide charging infrastructure network and significantly improve the business case for CPOs and truck charging stations.

However, the Commission proposal only allows for the crediting of renewable electricity which is charged at public charging stations, despite the fact that a significant share of truck charging will also be done at private locations such as depots and freight terminals. Private charging should therefore also be made eligible for credits under the mechanism.[35]

Second, the proposed system should not restrict renewable electricity to the 'the average share of renewable electricity supplied in the territory of the Member State in the two previous years'. Instead, CPOs should be given the option to invest in additional, up to 100% renewable electricity beyond what is available on the grid and receive credits accordingly.

5. Policy recommendations at national level

5.1. Coordination with grid operators, public authorities and industry

Given that all charging stations will need to be connected to at least the medium-voltage grid, all stakeholders urgently need to start planning for the electrification of trucks. The planning process needs to begin well before the infrastructure needs materialise and be coordinated between all involved authorities and stakeholders.

Already today, CPOs can face difficulties in finding suitable locations for deploying charging stations. Due to the long development times, transmission and especially distribution grid operators need to incorporate the roll-out of truck charging infrastructure early in their grid extension planning. For this, they need a high degree of planning certainty, especially concerning the expected fleet development and future power requirements at the charging locations. Public authorities should coordinate the deployment of charging infrastructure to ensure that it is deployed in an efficient and integrated manner.

The dimensioning of the grid connection capacity should ensure the expendability of charging stations which can be expected following the increasing fleet penetration of battery-powered road vehicles. Significant increases of the power load may require upgrades of the underlying grid level. It is important to also leverage synergies with charging stations for LDVs and in regards to electrification developments in other economic sectors such as buildings and industry.

For this to work, regulators, government agencies such as type-approval authorities but also industry stakeholders including vehicle manufacturers need to provide information on the expected charging needs, current and future fleet and sales of both LDVs and HDVs as well as local traffic data to the grid operators. In return, grid operators should also publish detailed data on network usage to

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[34] Searle (2021). Alternative transport fuels elements of the European Union's "Fit for 55" package. Link.
[35] Transport & Environment (2021). The EU's green fuels law: A clean shift for EU transport fuels? Link.

better manage and optimise grid loads. Based and in collaboration with grid operators, public authorities should map appropriate locations for site development with sufficient grid capacity and make this information publicly available.[36]

The German Federal Ministry for Economic Affairs and Climate Action has already formalised such information and data sharing between the relevant stakeholders to enable an effective and forward-looking approach to grid planning.[37]

Other examples are Germany's 'StandortTOOL' which provides data on the LDV fleet, the existing charging infrastructure as well as driving behaviour and locally available grid capacity.[38] The UK's Power Networks' 'DG Mapping Tool' shows the approximate locations of the company's medium- and high-voltage lines.[39]

5.2. Procurement and tendering

The economic viability of truck charging stations relies on a cost-effective and well-planned infrastructure roll-out. Policy-makers should take an early and proactive role to encourage a cost-effective development of truck charging infrastructure. By improving concession, procurement and tendering procedures, public authorities can help steer the roll-out of charging stations depending on the needs.[40] Initial public support may also be needed to address possible market failure in less attractive regions.

Well-designed public tenders are an effective policy tool to ensure an essential basic infrastructure coverage and allocate public support to where it is most needed, for example at locations where charging stations will need to be deployed first to incentivise the initial market uptake of vehicles.[41] Such public tenders can take the form of an auctioning system for charging station locations, thereby catering for the individual economic value of a location similar to what the German authorities have done with their tendering concept for LDVs.[42]

5.3. Smart charging, flexible pricing and network tariff design

Enabling smart charging, flexible price models and time-varying network tariffs can help balance supply of renewables and charging demand from electric vehicles.[43] CPOs need to be able to offer flexible use charges with time-differentiated prices to transport operators to steer charging demand towards the hours of the day where renewable electricity generation is higher, for example during midday hours and overnight.

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[36] Sustainable Transport Forum (2021). Recommendations for public authorities on: procuring, awarding concessions, licences and/or granting support for electric recharging infrastructure for passenger cars and vans. Link.

[37] Bundesministerium für Wirtschaft und Klimaschutz (2020). Umsetzung der Maßnahme „Vorausschauender Ausbau der Netze“ aus dem Masterplan Ladeinfrastruktur der Bundesregierung. Link.

[38] StandortTOOL (no date). StandortTOOL. Link.

[39] UK Power Networks (no date). DG Mapping Tool. Link.

[40] Sustainable Transport Forum (2021). Summary Handbook of the STF Recommendations for public authorities for procuring, awarding concessions, licences and/or granting support for electric recharging infrastructure for passenger cars and vans. Link.

[41] Hildermeier (2020). Building a market for EV charging infrastructure: A clear path for policymakers and planners. Link.

[42] Nationale Leitstelle Ladeinfrastruktur (2021). The Deutschlandnetz: Basic principles of the call for tenders for 1,000 locations with high-power charging points based on the Fast Charging Act. Link.

[43] Transport & Environment (2020). How implementing the Clean Energy Package can foster electromobility. Link.

Flexible price models will also be needed to allow for charging management which will help reduce the overall grid connection capacity (see Section 3.5.). Balancing supply and demand could be further optimised by communication flows between fleet operators and CPOs, for example by communicating a vehicle's location and remaining battery capacity to provide adjusted price quotes.

In some Member States such as Germany, network tariffs are based on the peak power demand which can make it difficult to create viable business cases, notably during the early ramp-up phase with lower utilisation rates or at more remote locations.[44] Network tariffs in the EU which are based on the peak power demand can make up a quarter of the final electricity price depending on the overall consumption.[45] Instead of determining network tariffs based on the peak demand which only occurs once a year, they should be varied based on peak time and depending on the grid situation and renewables supply as it is already the case in some Member States.[46]

5.4. Reservation system

An efficient utilisation of charging points is crucial. To optimise costs and grid requirements, the technical study by RE-xpertise and ef.Ruhr assumed a lean design of charging infrastructure in relation to the vehicle fleet in order to reduce the necessary grid connection capacity. This means that adequate booking systems need to be implemented to ensure an optimised utilisation of the charging points, underpinned by a robust digital system.

With the increasing market uptake of BETs, transport operators will need to rely on a digital reservation system to reserve charging points in advance so that they can seamlessly carry out their haulage operations without disruptions. Waiting times need to be kept to a minimum to maximise the charging time during the daily breaks and rest period. Transport operators should have the possibility to access a software-based pre-booking service. The service could also provide a live status of parking and charging facilities nearby or located along the planned route. Such a reservation system will also offer economic opportunities for CPOs to better anticipate the utilisation of their infrastructure and to manage charging demand accordingly.

6. Conclusions

There is increasing consensus among European truck manufacturers and industry stakeholders that BETs will play a dominant role in the decarbonisation of the road freight sector. Most truck makers including Daimler, MAN, Scania and Volvo are now focusing on bringing battery-powered trucks to the mass market for all vehicle segments, and including long-haul starting from 2024. For this, a network of public high-power and overnight charging points needs to be rolled out across Europe no later than 2025.

The technical study examines the techno-economic feasibility of these charging stations for long-haul trucks and their connection to the electricity grid. It evaluates possible charging and grid connection configurations for three scenarios: a high- and a low-traffic motorway station, as well as a

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[44] Regulatory Assistance Project, Agora Verkehrswende and Agora Energiewende (2021): Ladeblockade Netzentgelte. Wie Netzentgelte den Ausbau der Schnellladeinfrastruktur für Elektromobilität gefährden und was der Bund dagegen tun kann. Link.

[45] Hildermeier et al. (2020). Electrifying EU city logistics. An analysis of energy demand and charging cost. Link.

[46] Agora Energiewende, Consentec GmbH and Regulatory Assistance Project (2021). Zukünftige Anforderungen an eine energiewendegerechte Netzkostenallokation. Link.

logistics hub. The findings show that high-power truck charging is technically and economically feasible and would not pose any fundamental challenges with respect to the grid connection.

However, the planning, permitting and procurement processes to deploy charging stations, medium- and high-voltage substations and power lines can take several years. Cumbersome and lengthy procedures to install charging stations are often cited as a key barrier by business. The planning, permitting and procurement procedures need to be streamlined, any administrative obstacles removed and development times shortened. The planning process needs to be coordinated between all involved authorities and stakeholders, including improved coordination between EU-, national and local authorities.

Public authorities should coordinate the deployment of charging infrastructure to ensure that it is deployed in an efficient and integrated manner. Following best practices in Germany and in collaboration with grid operators, public authorities should map appropriate locations for site development with sufficient grid capacity and make this information publicly available.

This study shows that, just as battery-powered trucks are about to hit the market, their high-power charging infrastructure does not pose technical or economic challenges with respect to the grid connection. But preparing and planning for these charging stations must start now so as to not delay the transition to zero-emission trucking and the climate benefits they bring.