Hochleistungsladen Lkw-Fernverkehr

Megawatt charging in long-haul trucking: First findings on challenges and solutions

Gefördert durch:

Bundesministerium für Digitales und Verkehr

Finanziert von der Europäischen Union NextGenerationEU

aufgrund eines Beschlusses des Deutschen Bundestages

Place: Karlsruhe

Date: March 2024

Final

Imprint

Challenges and Solution in Truck Megawatt Charging

Project management

Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Straße 48, 76139 Karlsruhe
Patrick Plötz, patrick.ploetz@isi.fraunhofer.de

Authors

Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Straße 48, 76139 Karlsruhe
Patrick Plötz, Daniel Speth, Lena Kappler

Participating institutes

Fraunhofer Institute for Systems and Innovation Research IAO
Breslauer Straße 48, 76139 Karlsruhe
Florian Klausmann, Florian.Klausmann@iao.fraunhofer.de

P3 automotive GmbH
Heilbronner Str. 86, 70191 Stuttgart
Bonjat Satvat, bonjad.satvat@p3-group.com

Promotion

The HoLa project is being funded by the Federal Ministry for Digital and Transport with a total of 12 million Euros as part of the electric mobility funding guideline and is being carried out as a technology and testing project as part of the implementation of the overall concept for climate-friendly commercial vehicles. Funding for this measure is also being provided as part of the German Recovery and Resilience Plan (DARP) via the European Recovery and Resilience Facilities (ARF) in the NextGenerationEU programme. The funding guideline is coordinated by NOW GmbH and implemented by Project Management Jülich (PtJ).

Picture credits

Cover page: HoLa Consortium

Citation recommendation

Plötz, P., Speth, D., Kappler, L., Klausmann, F., Satvat, B. (2024): Megawatt charging in long-haul trucking: First find-ings on challenges and solutions. Karlsruhe: Fraunhofer ISI.

Published

March 2024

Notes

Table of contents

Summary

Battery-electric trucks drive locally CO_2-free and all major manufacturers offer corresponding series models. In the "HoLa - High performance charging for long-haul trucking " project, a total of eight high-performance charging points with the so-called Megawatt Charging Systems (MCS) and additional ten Combined Charging standard (CCS) charging points are being set up, operated and used in real logistics operations at five locations. The project serves to test this new system in practice and supports the nationwide expansion by the Federal Ministry for Digital and Transport.

The aim of this report is to present the most important findings and experiences from the first half of the project term and includes results from the period September 2021 until December 2023, i.e. before the first charging points in the project are commissioned. This includes aspects from all three parts of the project Planning and selection of locations, construction and planning of CCS and MCS charging points, monitoring and accompanying analysis. The project and this report are thus intended to make a contribution to the nationwide expansion.

The project experience, analyses and results to date have led to the following recommendations for action.

The future role of MCS and planning of a charging network

1. MCS charging should be expanded along all long-distance axes.
2. Slow charging with significantly less than 350 kW per charging point and load management should primarily be implemented in depots and private parking spaces to enable rapid expansion.
3. An initial public fast-charging network with at least 1,000 MCS charging points should be established by 2030. With rapid market penetration of e-trucks in long-distance transport and longer charge point occupation times of 45 minutes, about 2,000 MCS charging points are more likely to be needed by 2030.
4. Large charging locations (>4 fast charging points) should be located in particular on important long-distance axes. At the same time, a nationwide infrastructure with small charging locations (2-4 fast charging points) must be ensured.
5. The development of an advanced fast-charging infrastructure should already be planned today with regard to the necessary expansion of the electricity grid and the required parking spaces.
6. Infrastructure requirements should be continuously estimated and evaluated on the basis of current data on the (expected) market ramp-up and usage behaviour.

Grid connection, calibration law and planning

7. All relevant stakeholders (landowner, grid operator, concession holder if applicable, municipality if applicable) should be involved at an early stage.
8. The aim should be for grid operators to publish local capacity data at medium-voltage level.
9. The connection conditions and procedures should be simplified and standardized.
10. Suspension of calibration law for MW charging systems until metering systems that comply with calibration law are available in sufficient quantities.
11. A forward-looking provision of more power by the grid operators along the highway or other neuralgic points with expected future charging demand should be made possible to accelerate the expansion of the charging infrastructure within the set regulatory limits.

Standard layout and space availability

12. Highway charging stations should be built to save as much space as possible so that as little parking space as possible is lost.
13. Areas along the highway are very limited; areas next to the highway must also be used.
14. The integration of slow and fast charging of trucks should be considered in the site layout.
15. Shared use of truck charging locations for MCS charging, overnight charging or the charging of cars with trailers can increase the utilization of charging locations and alleviate the pressure on space.

Data availability:

16. A comprehensive survey on the temporally and spatially resolved driving behaviour of trucks would simplify demand estimates for charging infrastructure and should therefore be examined.
17. Data on the electricity grid and available grid power should be standardized and made centrally available to authorized users in order to accelerate the development of electrical infrastructure.

In the further course of the HoLa project, the real use of the charging points in operation will take place, including further accompanying research and analysis.

1 Background and objectives

Project background

Battery-electric trucks drive locally CO_2-free and all major manufacturers offer corresponding series models. However, the transport profiles in the field of long-distance transportation with heavy trucks pose particular challenges in terms of charging systems and energy supply in order to charge battery-powered trucks within the statutory break times of 45 minutes.

In the "HoLa - High-performance charging in long-distance truck transport" project, two high-performance charging points with the so-called Megawatt Charging Systems (MCS) will be set up, operated and used in real logistics operations at four locations. Two Combined Charging System (CCS) charging points for trucks will be planned and installed at each of five locations along the A2 highway between Berlin and the Ruhr area. Three locations will be used on the freeway and two locations in logistics centres (cf. Figure 1). These locations will be used for the early integration of e-trucks into logistics processes and as a test case for the new fast charging of e-trucks and to gather experience in real operation. At the end of the project, ten CCS charging points and eight MCS charging points will be available at five locations to support real-life testing and form the basis for a nationwide expansion of this technology. The HoLa project is being funded by the Federal Ministry for Digital and Transport with a total of 12 million euros as part of the electric mobility funding guideline and is being carried out as a technology and testing project as part of the implementation of the overall concept for climate-friendly commercial vehicles. The funding guideline is coordinated by NOW GmbH and implemented by Project Management Jülich (PtJ).

Figure 1: Charging corridor of the HoLa project

Source: HoLa Consortium

Four truck manufacturers are taking part in the project, supplying a total of twelve vehicles, at least four of which will be MCS-capable, which will be tested by logistics partners in real-life operations and loaded along the route. The development of the infrastructure and the operation of the vehicles will be accompanied by extensive research activities.

Objective

The aim of this report is to present the most important findings and experiences from the first half of the project term and includes results from the period September 2021 - December 2023, i.e. before the first charging stations in the project are commissioned. This includes aspects from all three parts of the project planning and selection of locations, construction and planning of CCS and MCS charging points, monitoring and environmental analysis. The project and this report are thus intended to provide a contribution and template for the nationwide expansion.

Embedding in the infrastructure ramp-up for battery-powered trucks in Europe

In Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure (AFIR), the European Union (EU) has defined minimum requirements for the expansion of public fast-charging networks in the EU Member States.

For the purposes of the Regulation, "a charging location comprises one or more charging stations at a given location, including any adjacent dedicated parking spaces. [The] defined targets for charging locations could be provided by one or more charging stations. A charging station is a physical installation for charging electric vehicles. Each charging station has a theoretical maximum charging power expressed in kW and has at least one charging point at which only one vehicle can be charged at a time. The number of charging points at a charging station determines how many vehicles can be charged at this station at any given time. If more than one vehicle is charged simultaneously at this charging station, the maximum charging power is divided between the individual charging points so that the power at each individual charging point is lower than the charging power of this charging station." (Regulation (EU) 2023/1804).

Table 1 summarizes the requirements for the TEN corridors. Table 2 shows the results of the AFIR requirements for public infrastructure along the TEN-T corridors by country.

Table 1 Summary of AFIR requirements for truck charging infrastructure

"CP" = charging point

	End of 2025	End of 2027	End of 2030
Core network	Charging location every 120 km on at least 15% of the network in each direction: - at least 1.4 MW total - 1 CP with at least 350 kW	Charging location every 120 km on at least 50% of the network in each direction: - at least 2.8 MW total - 2 CP with at least 350 kW	Charging location every 60 km of the network in each direction: - at least 3.6 MW total - 2 CP with at least 350 kW
Overall network	Charging location every 100 km to at least 15% of the network in each direction: - at least 1.4 MW total - 1 CP with at least 350 kW	Charging location every 100 km on at least 50% of the network in each direction: - at least 1.4 MW total - 1 CP with at least 350 kW	Charging location every 100 km of the network in each direction: - at least 1.5 MW total - 1 LP with at least 350 kW

	End of 2025	End of 2027	End of 2030
Safe and secure truck parking areas	-	At least 2 CP with at least 100 kW each	At least 4 CP with at least 100 kW each
Urban nodes	At least 0.9 MW each with at least 150 kW per CP		In each case at least 1.8 MW with at least 150 kW per CP

Source: Regulation (EU) 2023/1804

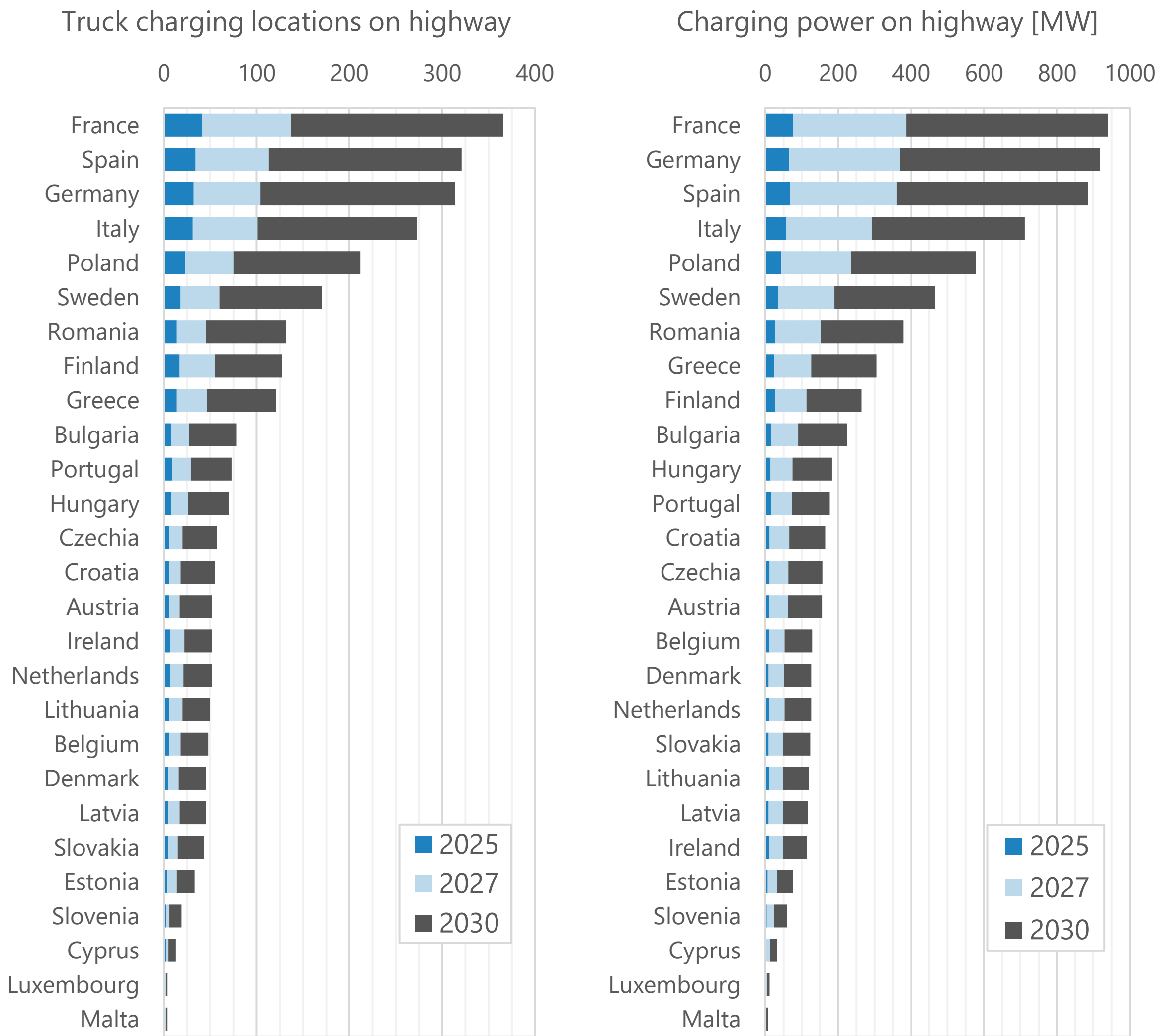
Table 2 AFIR requirements for public truck charging infrastructure by country

	Network km		Truck charging locations			Truck charging power in MW		
	Core	Compr.	2025	2027	2030	2025	2027	2030
Austria	1,097	730	6	17	52	10.9	62	156
Belgium	805	1,038	6	18	48	10.1	53	129
Bulgaria	1,508	1,340	8	27	78	16.4	90	224
Croatia	1,153	780	6	18	55	11.6	66	164
Cyprus	157	336	2	5	13	2.7	13	32
Czech Rep.	1,015	1,134	6	20	57	12.0	64	157
Denmark	813	849	5	16	45	9.5	51	126
Germany	6,369	5,027	32	104	314	65.9	369	918
Estonia	375	975	4	14	33	6.9	32	77
Finland	1,040	4,572	17	55	127	26.7	113	264
France	5,555	8,960	41	137	366	76.9	386	940
Greece	1,760	3,079	14	46	121	25.4	126	305
Hungary	1,102	1,607	8	26	70	14.7	75	183
Ireland	504	1,715	7	22	52	10.9	48	114
Italy	4,319	6,416	31	101	273	57.3	292	712
Latvia	719	1,012	5	17	45	9.5	48	118
Lithuania	609	1,450	6	20	50	10.5	50	119
Luxembourg	70	20	1	2	4	0.8	5	12
Malta	16	111	1	2	4	0.8	4	8
Netherlands	670	1,417	7	21	52	10.9	53	126
Poland	3,700	4,398	23	75	212	44.5	235	578
Portugal	946	2,015	9	29	73	15.3	74	177
Romania	2,575	2,268	14	45	132	27.7	153	379
Slovakia	834	747	5	15	43	9.0	50	123
Slovenia	446	157	2	6	19	4.0	24	60
Spain	5,774	6,365	34	113	321	67.4	360	887
Sweden	3,010	3,435	18	60	170	35.7	190	467
EU-27	**46,939**	**61,958**	**304**	**1,012**	**2,805**	**589**	**3,059**	**7,494**

Source: Own analysis based on Regulation (EU) 2023/1804 and TEN-T network data

According to the AFIR, a total of about 2,800 charging locations with a total charging power of 7.5 GW along the almost 110,000 km of TEN-T corridors are to be installed throughout Europe by 2030. With regard to the number of charging stations, it should be noted that a slightly lower number of charging locations is also possible for the interim targets of 2025 and 2027, as the calculation of the share effectively allows for slightly greater distances or for locations that can be accessed from both sides in accordance with Art. 4(2) of the AFIR, and the total charging power can also be reduced in the event of very low traffic density.

Figure 2: Truck charging locations and power by country according to AFIR



The AFIR and the objectives form an important background for the HoLa project. The interim findings of the project are presented below.

2 Results and options for action Demonstration

2.1 Mains connection fast charging

Truck charging stations require considerable connected loads for operation and will generally be connected to medium voltage in the future. The corresponding applications and connection conditions differ from grid operator to grid operator, making the process time-consuming and complex. The application for grid connection can only be submitted by the owner of the site, who often has no expertise in the energy industry. At the same time, the local grid operator must always be contacted regarding available power when searching for a site, as the coordinates of many substations are publicly available but not their available power. Here, a public database of all or some grid operators regarding the available power at all or near highway locations could speed up the search considerably. The establishment of a corresponding directory for MCS charging of trucks is currently being examined in Sweden, for example. [1]

The higher the desired connected load, the longer the lead times for the grid connection usually are. Depending on local conditions, i.e. available power or space in transformer stations and the desired voltage level, the times can range from several months to several years, or even several years for connections to higher voltage levels.

The continuously increasing demand for charging power for cars and trucks along highways over the next ten years requires a simplification and acceleration of the grid expansion. The installation of additional connection power by the network operators should already be made possible without a specific application for a network connection in order to ensure a forward-looking expansion of the capacity. This can gain valuable time for the necessary speed of the charging network expansion.

Furthermore, for the rapid installation of fast-charging stations, the specifications of the transformers vary depending on the grid operator and, with current delivery times of around one year, the transformers cannot simply be ordered and stored as a lump sum, but must always be ordered on a site-specific basis.

Recommended actions for grid connection and planning:

1. All relevant stakeholders (landowner, grid operator, concession holder if applicable, municipality if applicable) should be involved at an early stage.

2. Grid operators should strive to publish local capacity data at medium-voltage level.

3. The connection conditions and procedures should be simplified and standardized.

4. A forward-looking provision of more power by the network operators along the highway or other neuralgic points with expected future charging demand should be made possible to accelerate the expansion of the charging infrastructure within the set regulatory limits.

2.2 Availability of space

Charging infrastructure, including parking spaces for trucks, requires considerable space, which is very limited, especially at service areas. Here it is important that as little truck parking space as possible is lost due to the necessary expansion of truck charging infrastructure, as there are too few truck parking spaces on and near freeways overall. At the same time, it makes sense to develop additional areas near

[1] See Energimyndighetens (2023): Handling program for charging infrastructure and tank infrastructure for gas. Report ER 2023:23. Section 6.1.3. https://www.energimyndigheten.se/4ab6d0/globalassets/nyheter/2023/ER202323

the highway, e.g. at truck stops and in industrial areas, which expand the capacity of the service stations. These additional areas also have the advantage that the number of possible locations is much greater and competition for a small amount of space is reduced. In addition, many locations next to the highway can be accessed from both sides and there is often a greater selection of services for drivers (showers, restaurants, and shopping facilities) at truck stops, for example. If the stop is located next to the highway in an industrial area, the grid connection could also be easier and cheaper there.

Due to the many reasons for additional charging facilities next to highways, it has been observed for several years that large new locations for fast charging of cars along the highway are often being built next to highway exits at industrial areas or truck stops.

Recommended actions on space availability:

1. Areas along the highway are very limited, areas next to the highway must also be used in any case.

2. Highway charging stations should be built to save as much space as possible so that as little parking space as possible is lost.

3. Shared use of truck charging locations for MCS charging, overnight charging or the charging of cars with trailers can increase the utilization of the charging locations and alleviate the pressure on space.

2.3 Calibration law

Megawatt charging systems and the corresponding standard are currently under development. According to German law, electricity meters must be calibrated if electricity is to be billed exactly according to kWh. However, there are currently no ready-made, calibration-compliant direct current meters in the MW range from any manufacturer and it is unlikely that there will be a sufficient selection of calibration-compliant suppliers in the next few years. The calibration law for MW charging systems should therefore be suspended until there are sufficient metering systems that comply with calibration law.[2] Alternatively, time-based tariffs for billing could be permitted on a transitional basis.

Recommended action on calibration law:

1. Suspension of the calibration law for MW charging systems until metering systems that comply with calibration law are available in sufficient quantities.

2.4 Standard layout

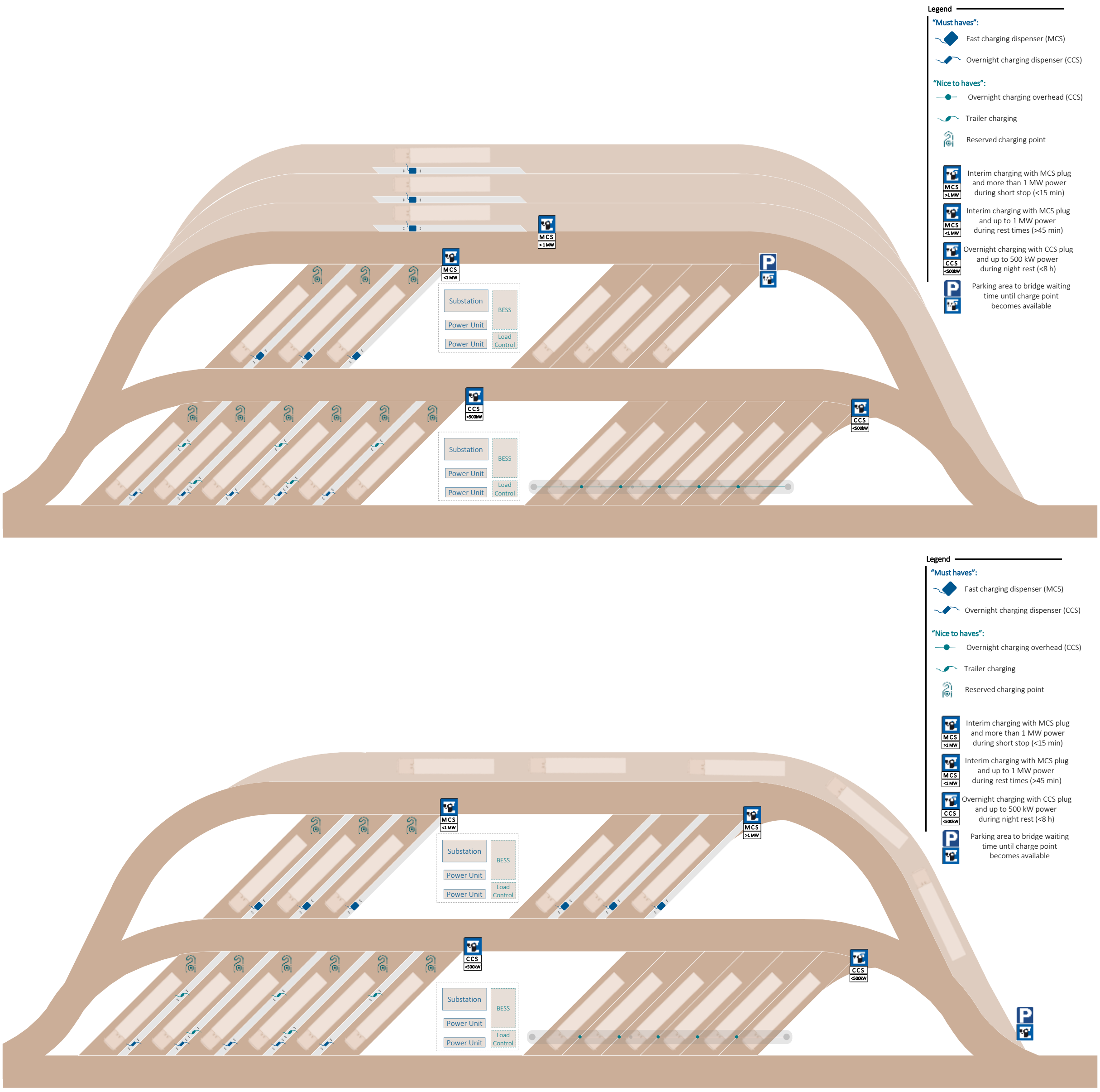
A uniform or similar layout of the charging locations is helpful for a quick ramp-up and simple, uniform use by vehicle drivers. Many questions arise here, such as "What should charging locations look like so that as little parking space as possible is lost?", "How can the charging locations be easily expanded?", "How can use for fast and slow charging be combined?", or "Should charging locations also be made accessible for other vehicles?"

As part of HoLa, drafts for possible standard layouts were created on the basis of stakeholder discussions and our own simulations and analyses. Figure 3 shows two examples of charging station layouts.

[2] See also the recommendation of the ZVEI https://www.zvei.org/fileadmin/user_upload/Themen/Mobilitaet/Eichrecht-Ladeinfrastruktur/Positionspapier_Eichrecht_Ladeinfrastruktur_13062023.pdf

Figure 3: Proposal for a standard layout of highway truck charging stations

Upper example incl. drive-through charging facilities, lower example with separate waiting area.



Source: HoLa Consortium

Both examples show a large charging location with over six charging points. The upper example also includes drive-through charging options and the lower example has a separate, larger waiting area for electric trucks. When entering the charging location (from the right in the illustration), good and clear signage for the charging station can be seen. There are various options for the exact design of the signs, but it should be clear to drivers where CCS or MCS charging points are located.

MCS and CCS charging sockets are shown in the illustration. It should be noted in the layout that the MCS charging socket will always be on the left-hand side of the vehicle in the direction of travel due to an industry agreement, but the CCS socket can be on the left or right. Furthermore, there is also a space-saving option without charging islands with low power, e.g. overnight charging with charging cables from above (bottom right in the example illustrations). Finally, the space required for transformers and possibly a battery buffer or load management system must also be included in the planning.

Various simulation results and extensive discussions with different stakeholders have led to a number of aspects that need to be taken into account when designing a public truck charging location. A distinction must be made between urgent requirements ("must have") and desirable requirements ("nice to have"). Furthermore, some aspects are already very clear and well documented, while others are not yet entirely certain. The following table provides a clear overview of the aspects collected so far in the project for the design of a public truck charging station.

Table 3: Aspects of the design of a public truck charging station

No.	Safe knowledge & must-haves	Uncertain or nice-to-have
1	Space is very limited, and all charging options need to be designed to use as little parking space from trucks as possible.	Overnight CCS charging can be implemented with long cables from above as overhead solution or from regular charging stations; overhead solution potentially requires less space.
2	MCS is located on the left-hand side (in the direction of travel) of the vehicles; CCS can be located on the left or right-hand side	Ratio of CCS position (left vs. right) to be considered when designing CCS charging site layout.
3	Both slow overnight and interim MCS charging will be required. The ratio is not certain but stop duration indicate more overnight charging points than MCS points per location	4:1 is a rough estimate for the ratio between overnight and MCS charging points which should be possibly adjusted when empirical public data become available.
4	Forward entering and exiting charging spaces is most useful, specifically for interim MCS charging.	For CCS, interoperability for passenger cars should be investigated, especially for towing vehicles.
5	Clear road signs and explicit signage of truck overnight and interim MCS charging is helpful; including availability of charging points.	Load management and/or stationary battery storages can reduce the required grid connection and optimize utilization, but need to be designed properly to their cost effectiveness.
6	Locations need to work for truck dimensions with four meters vehicle height, up to 40 t GVW and under consideration of vehicle turning radius.	Additional charging possibility for trailer charging dependent on technology approach which is not standardized yet.
7	Proper cable management for dispenser and charging bridge solution required to ease cable handling and avoid loosely hanging cables.	Sufficient space should be reserved for future upgrades and increase of charging points.
8	Substation, power unit, BESS and load management need to be positioned outside the parking area for safety reasons.	Innovative solutions to reduce required space are generally preferred (e.g., charging bridge).
9	Anti-collision bumpers are required to prevent significant damage to the chargers.	Charging bridge requires extra efforts due to customization (different site conditions).
10	Need for waiting area; especially in early stages w/o mature reservation system and lack of CP.	Reservability of charging points can increase predictability for the logistics providers when the charging demand is high.
11	Installation of power lines along transit route should be avoided / reduced due to blocking issues during repairs.	Power hub concept, converting AC to DC centrally and distributing it to dispensers, may lead to benefits such as modularity, scalability, cost-efficiency, upgradability.

No.	Safe knowledge & must-haves	Uncertain or nice-to-have
12	Charging lots will require more space than common parking lots to offer sufficient room for cable handling.	Utilization of overnight chargers vs. megawatt chargers will be highly dependent on price benefit ratio.

Source: Own representation

This results in the following key recommendations for the layout of truck charging locations.

Recommended action standard layout:

1. When planning charging locations, the integration of slow and fast charging of trucks should be considered together.

2. As little parking space as possible should be lost through clever planning.

3. Good signage and appropriate waiting and manoeuvring areas for trucks must be planned.

3 Results and options for action Network & environment

3.1 Network and planning

The project provides initial estimates for the expected future demand for fast charging infrastructure with a power of up to one megawatt per charging point. Using various modelling approaches, a possible, regionally resolved demand for Germany will be derived based on scenarios. The project thus supports the ongoing activities of the National Centre for Charging Infrastructure and the Federal Ministry of Digital and Transport with regard to the planning and tendering of a charging network for electric trucks in Germany in accordance with the Charging Infrastructure Master Plan II. [3]

Following the basic idea of the AFIR (Alternative Fuel Infrastructure Regulation - Regulation (EU) 2023/1804) of the European Union), it is illustratively assumed that fast-charging infrastructure for battery-powered trucks must be available at least 100 km apart along every German highway. Figure 3 shows a possible network. The locations shown do not represent exact positions, but rather a section of the route. The exact positioning depends on local conditions, such as parking space availability and the available power grid connection. In total, the modelled network consists of 142 charging locations, each serving both directions of travel.

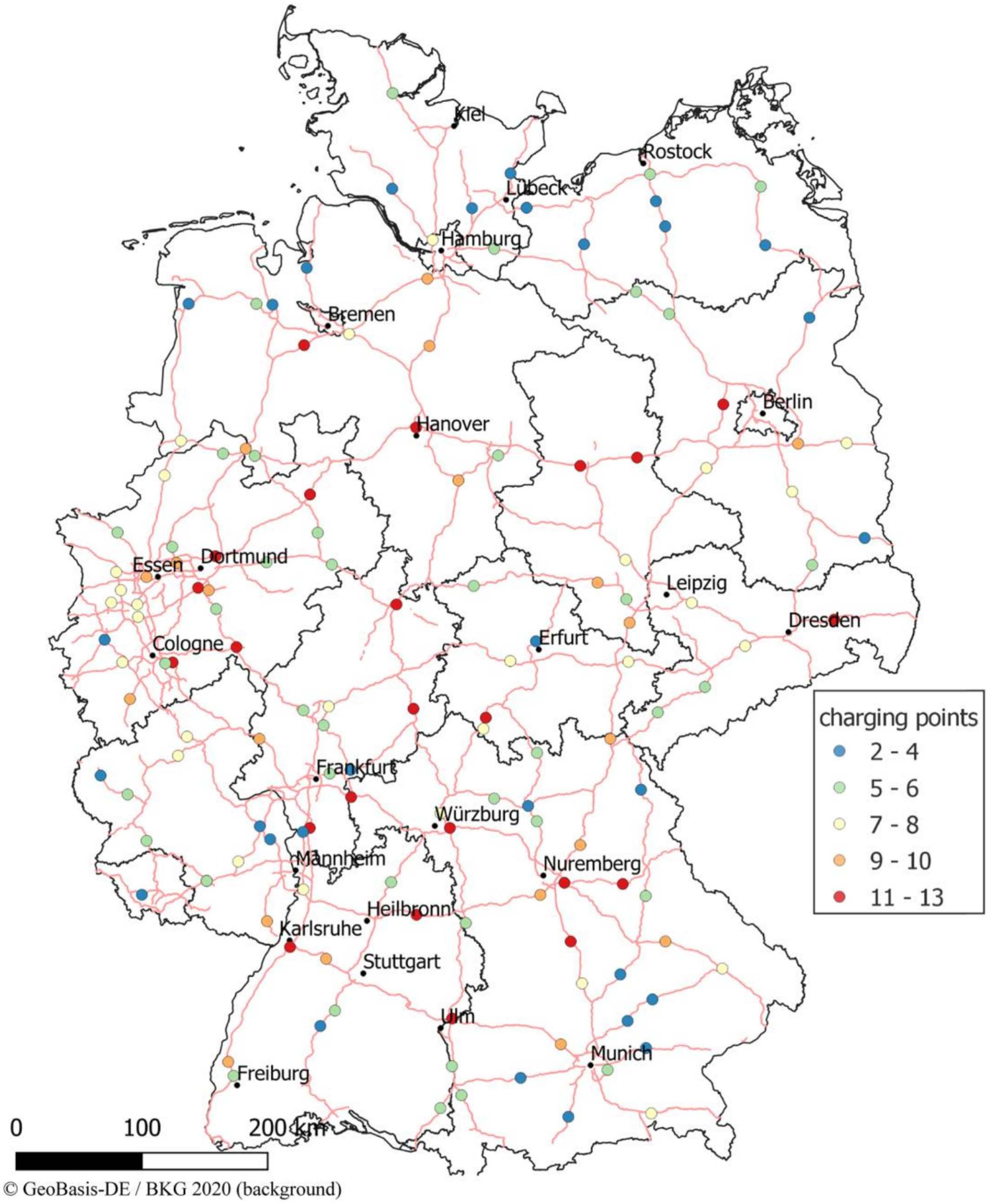
In addition to the number of locations, the dimensioning of the individual locations is crucial. For the scenario presented here, it is assumed that trucks in 2030 will be recharged during the legally prescribed 45-minute break in driving time after 4.5 hours of driving. To simplify matters, it is assumed that 15% of vehicles will be battery electric in 2030 and that half of the charging processes will take place at public charging infrastructure. Taking into account the local traffic volume from traffic count data and the daily course of traffic volume, an average waiting time in the peak hour of a maximum of 5 minutes results in a demand for 1,000 charging points. Large locations have up to 13 charging points, small stations have two charging points. While small stations ensure complete coverage of the road network in particular, large stations are positioned along important long-distance corridors. This includes, for example, the HoLa route along the A2 from Dortmund via Hanover to Berlin. The route is one of the most important connections between major European ports (Amsterdam, Rotterdam, Antwerp) and Eastern Europe.

A number of influencing factors have a significant impact on the calculated requirement for MCS charging points. According to current driving time regulations, drivers are not allowed to move the truck during the long break of 45 minutes. With MCS charging capacities, however, 30 minutes could be sufficient and if the charging point is released for another vehicle after 30 minutes, fewer charging points are required overall. Furthermore, the number of e-trucks with intermediate charging requirements is of course a decisive factor for the need for MCS charging points and also the question of whether and, if so, what waiting times would be acceptable at MCS charging points. It should be noted that more charging points with the same charging demand naturally mean fewer or only infrequent waiting times, but at the same time the average utilization of the charging points would also decrease and charging would therefore become more expensive (higher investments must be allocated to the same amount of energy).

[3] Cf. https://bmdv.bund.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur-2.pdf?__blob=publicationFile

Figure 4: Locations for 142 fast charging stations with a distance of 100 km

Fast charging network (1 MW per charging point) with a battery-electric truck share of 15% and a public charging share of 50%. Total charging points: 1,003.



Source: Speth et al. (2022b)

The scenario presented here provides an initial estimate for determining an order of magnitude. Detailed documentation and further modelling approaches can be found in Speth et al. (2022b), Speth et al. (2022c), Speth et al. (2023b) and Menter et al. (2023).

Recommended actions charging network:

1. An initial public fast-charging network with at least 1,000 MCS charging points should be established by 2030. With rapid market penetration of e-trucks in long-distance transport and longer idle times of 45 minutes, 2,000 MCS charging points are more likely to be needed by 2030.

2. Large charging locations (>4 fast charging points) should be located in particular on important long-distance routes. At the same time, a nationwide infrastructure with small charging locations (2-4 fast charging points) must be ensured.
3. The development of an advanced fast-charging infrastructure should already be planned today with regard to the necessary expansion of the electricity grid and the required parking spaces.
4. Infrastructure requirements should be continuously estimated and evaluated on the basis of current data on the (expected) market ramp-up and user behaviour.

3.2 Data availability

A comprehensive and detailed data basis is required to derive future charging requirements and to identify suitable locations. This concerns (1) technical data on battery-electric trucks, (2) data on the temporally and spatially resolved usage behaviour of trucks, (3) data on regional parameters, for example the availability of parking spaces and the existing electricity grid infrastructure.

Technical data for battery-electric (long-haul) trucks are generally based on literature values from simulations or expert estimates (see for example Basma et al. (2021), Mareev et al. (2018), Noll et al. (2022), Speth et al. (2022a)). The range, fast-charging capability and energy consumption are of particular interest for modelling the infrastructure. In the project, corresponding real values are collected in the implementation phase. In the future, the vehicle models available on the market and manufacturer announcements will allow a more detailed analysis.

The usage behaviour of the vehicles can be used to identify charging locations and charging times. Table 4 shows the most relevant data on the usage behaviour of trucks in Germany. One group of data sets allows statements to be made about local traffic volumes. These can be either GPS data (TSL) - for example from parked trucks - or manual (M-TDC) or automated (A-TCD) traffic count data. This data allows general conclusions to be drawn about local charging requirements, but does not allow any conclusions to be drawn about the driving behaviour of individual vehicles. A second group contains data on the source and destination of freight and traffic flows. However, these datasets either do not contain any real driving profiles (VVP, ETIS), are regionally limited to Germany (KiD, VVP), have a low regional resolution (ERFT) or the underlying data is only publicly available to a limited extent (KiD, VVP, ERFT). A comprehensive, representative data set of temporally and spatially resolved travel profiles does not currently exist. A comprehensive database could further improve estimates of charging infrastructure requirements and avoid mis-investments.

Estimates of regional parameters, such as parking lot capacities and the medium-voltage grid relevant for connecting charging parks, can be taken from OpenStreetMap for an initial approximation. However, there are no relevant key figures for the electricity grid in particular, such as the available connected load.

In addition to vehicle and parking space data, information on available grid connection power by transformer station would be very important. Currently, every charging point operator has to ask the local grid operator via the owner of the space (over 800 in Germany) whether and how much connected load is available. In general, little data is available on the electricity distribution grid (medium voltage is particularly relevant for MCS) and ideally, available connected loads along the freeways would be standardized and made available centrally across the various grid operators in order to speed up the development of electrical infrastructure.

Table 4: Overview of truck traffic data for Germany and Europe

	Plötz et al. (2021)	BAST (2017)	BAST (2022)	WVI et al. (2012)	BVU et al. (2014)	Eurostat (2023)	Szimba et al. (2013)
Metadata							
Abbreviation	TSL	M-TCD	A-TCD	KiD	VVP	ERFT	ETIS
Current year	2021	2015	2021	2010	2030	2021	2010
Availability	restricted	Public	Public	scientific	scientific	scientific	Public
Method	GPS	Manual counting	Automatic counting	Question-naire	Modelling	Question-naire	Modelling
Cover							
Regional	Europe	EN	EN	EN*	EN**	Europe	Europe
Resolution							
Regional[4]	Coordinates	Coordinates	Coordinates	NUTS-3	NUTS-3	NUTS-2	NUTS-3
Temporal	-	Daily aver-age	Hourly	Timestamp	Timestamp	-	-
Individual vehi-cles	-	-	-	√	-	√	-
Source-destina-tion data	-	-	-	√	√	√	√

* The data set contains German vehicles, some of which are also in use in Europe. **Adjacent regions are included in less detail.

Source: HoLa Consortium

As part of the HoLa project, two new data sets have been created so far that can facilitate the selection of charging locations. Firstly, based on the ETIS dataset, an updated source-destination matrix of truck traffic in Europe has been published, which is suitable for identifying road sections with potentially high charging demand (Speth et al. 2022d). Secondly, using publicly available map data, parking lots in Germany were evaluated in terms of their attractiveness for fast truck charging (Auer et al. 2023). An expansion to Europe is planned.

Recommended action data availability:

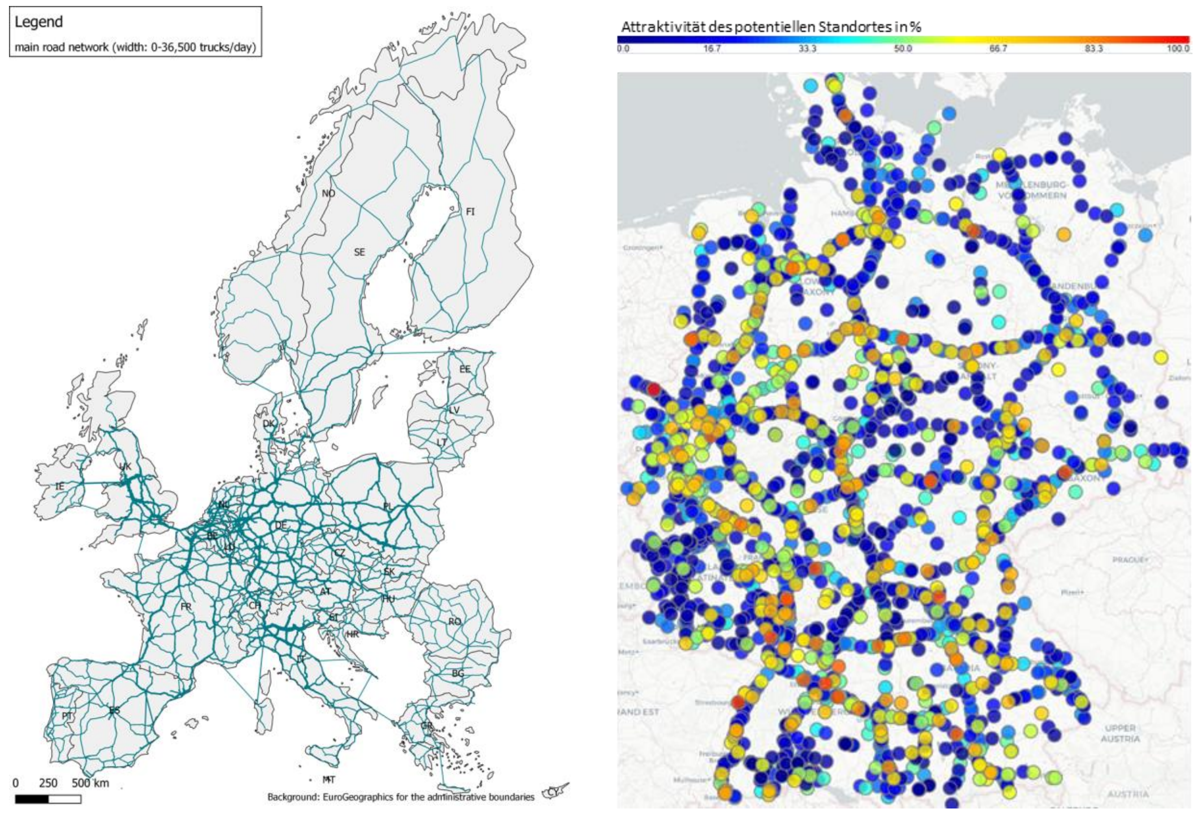
1. A comprehensive survey on the temporally and spatially resolved driving behaviour of trucks would simplify demand estimates for charging infrastructure and should therefore be examined.

2. Data on the electricity grid and available connected load should be standardized and made centrally available to authorized users in order to accelerate the development of electrical infrastructure.

[4] NUTS-3: Nomenclature des unités territoriales statistiques. In Germany, level 3 corresponds to districts and independent cities. Level 2 corresponds to administrative districts.

Figure 5: New data basis for planning charging infrastructure for trucks from HoLa

(a) Modelled European truck freight flows 2019; (b) Attractiveness of potential charging locations



(a) (b)

Source: HoLa consortium, based on Speth et al. (2022d) and Auer et al. (2023)

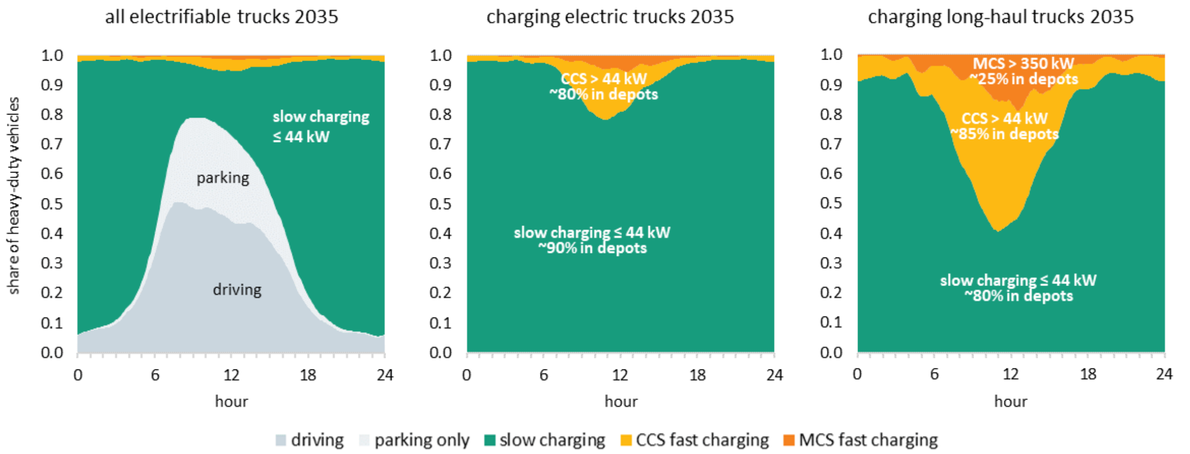
3.3 The role of MCS

In Europe, a truck driver may drive for a maximum of 4.5 hours at a time before taking a break of at least 45 minutes (EU 2006). During this time, the vehicle can cover up to 360 km. It usually requires slightly more than 1 kWh/km (Speth et al. 2022a). The Combined Charging System (CCS) currently used in the passenger car sector typically delivers up to 350 kW and is therefore not sufficient to charge the vehicle within the statutory break time. The Megawatt Charging System (MCS), which is currently still under development, is expected to allow charging capacities of up to 3.75 MW (1,250 V, 3,000 A) (CharIN 2023). However, a peak power of around 1 MW is likely to be sufficient to fully recharge the truck within the statutory break period.

However, only some of the trucks are used for long-distance transportation. The survey "Motor vehicle traffic in Germany" (WVI et al. 2012) provides data from more than 2,800 heavy trucks and articulated lorries (> 12 t GVW) representative of Germany. Of these, 2,400 driving profiles contain a complete description of the journeys over one day, including journey times (start, end) and details of the location (private, public). This data can be used to simulate a fictitious truck fleet. It is assumed that the vehicles only recharge when they would exceed an energy requirement of at least 75% of the maximum battery capacity on the next journey and that the standing time of at least 30 minutes is sufficient for recharging. It is also assumed that the vehicles charge as slowly as possible during the available standing time, but as quickly as necessary in order to fully recharge the battery by the start of the next journey. The simulations show that with a conservatively assumed battery size of a maximum of 700 kWh (gross, 75% usable) in 2030 and 900 kWh (gross, 85% usable) in 2050, significantly more than 90% of the vehicle fleet can be electrified throughout. Only around a quarter of vehicles will be dependent on public charging. Figure 6 shows an example of the charging behaviour of the simulated fleet over the course of a day in 2035.

Figure 6: Driving and charging behaviour of battery-electric trucks in 2035

Left: All battery trucks; centre: All charging trucks; Right: All charging long-distance trucks (>500 km/d).



Source: Speth et al. (2024)

It is clear to see that the majority of charging processes take place on slow charging infrastructure, usually on private property, with a maximum of 44 kW. This output can technically even be achieved with AC charging. Around 80% of charging processes with a charging power of up to 350 kW, the standard CCS power today, also take place at private charging stations. Charging with over 350 kW, i.e. presumably with MCS, is used in particular for long-distance vehicles for intermediate charging and takes place at public charging stations in around 75% of cases. At the same time, however, MCS charging will account for around 20% of the energy requirements of battery electric trucks in 2035. In purely technical terms, it is of course also possible to charge at less than 350 kW with MCS. It is still an open question whether trucks will only have one plug (CCS or MCS) or both in the long term.

In summary, it can therefore be stated that MCS with a charging power of more than 350 kW plays a relevant role for long-distance transport, while depot charging with lower charging capacities will be sufficient for a large part of the future battery-electric truck fleet.

A detailed documentation of the simulation results presented here can be found in Speth et al. (2023a)

Recommended role of MCS:

1. MCS charging should be expanded along the important long-distance axes.
2. In depots and on private parking spaces, primarily slow charging with typically 50 kW but significantly less than 350 kW per charging point and load management should be implemented to enable rapid expansion.

4 Bibliography

Literature

Auer, J.; Link, S.; Plötz, P. (2023): Public charging locations for battery electric trucks: A GIS-based statistical analysis using real-world truck stop data for Germany. https://doi.org/10.24406/publica-1198.

Basma, H.; Rodríguez, F. (2021): Race to Zero: How manufacturers are positioned for zero-emission commercial trucks and buses in Europe. International Council on Clean Transportation.

BAST (2017): Manual road traffic census 2015 - results on federal highways. Status: 26.01.2017. Bergisch Gladbach: Federal Highway Research Institute.

BAST (2022): Automatic permanent counting stations on highways and federal roads. Available online at https://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/zaehl_node.html, last checked on 14.12.2019.

BVU; Intraplan; IVV; planco (2014): Verkehrsverflechtungsprognose 2030 - Abschlussbericht - Los 3. FE-Nr.: 6.0981/2011. Commissioned by: Federal Ministry of Transport and Digital Infrastructure. BVU consulting group; Intraplan Consult GmbH; IVV GmbH & Co. KG; Planco Consulting GmbH.

CharIN (2023): Megawatt Charging System (MCS). Available online at https://www.charin.global/technology/mcs/, last checked on 20.01.2023.

EU (2006): 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 and amending Council Regulations (EEC) No 3821/85 and (EC) No 2135/98 and repealing Council Regulation (EEC) No 3820/85. Brussels: European Union, last checked on 14.02.2023.

Eurostat (2023): European Road Freight Transport Survey. Available online at https://ec.europa.eu/eurostat/web/microdata/european-road-freight-transport-survey, last checked on 24.01.2023.

Mareev, I.; Becker, J.; Sauer, D. (2018): Battery Dimensioning and Life Cycle Costs Analysis for a Heavy-Duty Truck Considering the Requirements of Long-Haul Transportation. In: Energies, 11 (1), pp. 1-23. https://doi.org/10.3390/en11010055.

Menter, J.; Fay, T.-A.; Grahle, A.; Göhlich, D. (2023): Long-Distance Electric Truck Traffic: Analysis, Modeling and Designing a Demand-Oriented Charging Network for Germany. In: World Electric Vehicle Journal, 14 (8), p. 205. https://doi.org/10.3390/wevj14080205.

Noll, B.; Del Val, S.; Schmidt, T. S.; Steffen, B. (2022): Analyzing the competitiveness of low-carbon drive-technologies in road-freight: A total cost of ownership analysis in Europe. In: Applied Energy, 306, pp. 118079. https://doi.org/10.1016/j.apenergy.2021.118079.

Plötz, P.; Speth, D. (2021): Truck Stop Locations in Europe. Final report. Client: European Automobiles Manufacturers Association (ACEA). Karlsruhe: Fraunhofer Institute for Systems and Innovation Research ISI, last checked on 24.01.2023.

Speth, D.; Kappler, L.; Link, S.; Keller, M. (2022a): Attractiveness of alternative fuel trucks with regard to current tax and incentive schemes in Germany: a total cost of ownership analysis. 35th International Electric Vehicle Symposium and Exhibition (EVS35). Oslo, last checked on 02.11.2022.

Speth, D.; Plötz, P. (2024): Depot slow charging is sufficient for most battery electric trucks in Germany. Transportation Research Part D: Transport and Environment **128**, 104078, https://doi.org/10.1016/j.trd.2024.104078.

Speth, D.; Plötz, P.; Funke, S.; Vallarella, E. (2022b): Public fast charging infrastructure for battery electric trucks - a model-based network for Germany. In: Environmental Research: Infrastructure and Sustainability. https://doi.org/10.1088/2634-4505/ac6442.

Speth, D.; Plötz, P.; Wietschel, M. (2023b): Modeling a capacity-constrained public charging infrastructure network for electric trucks in Germany. 36th International Electric Vehicle Symposium and Exhibition (EVS36) Sacramento, California, USA, June 11-14, 2023.

Speth, D.; Sauter, V.; Plötz, P. (2022c): Where to Charge Electric Trucks in Europe-Modelling a Charging Infrastructure Network. In: World Electric Vehicle Journal, 13 (9), p. 162. https://doi.org/10.3390/wevj13090162.

Speth, D.; Sauter, V.; Plötz, P.; Signer, T. (2022d): Synthetic European road freight transport flow data. In: Data in brief, 40. https://doi.org/10.1016/j.dib.2021.107786.

Szimba, E.; Kraft, M.; Ihrig, J.; Schimke, A.; Schnell, O.; Kawabata, Y.; Newton, S.; Breemersch, T.; Versteegh, R.; van Meijeren, J.; Jin-Xue, H.; Stasio, C. de; Fermi, F. (2013): ETISplus Database Content and Methodology: ETISplus Deliverable D6. https://doi.org/10.13140/RG.2.2.16768.25605.

WVI; IVT; DLR; KBA (2012): Motor vehicle traffic in Germany 2010. project no. 70.0829/2008. - Final report -. Braunschweig: WVI Prof. Dr. Wermuth Verkehrsforschung und Infrastrukturplanung GmbH; Institut für angewandte Verkehrs- und Tourismusforschung e.V.; Deutsches Zentrum für Luft- und Raumfahrt - Institut für Verkehrsforschung; Kraftfahrt-Bundesamt .