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ZEFES

ZEFES - Deliverable report

D3.6: Mapping of Charging Stations

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Project summary

Under the European Green Deal, the EU aims to become the first CO_2-neutral continent by 2050, with a milestone of 55% emissions reduction by 2030. For road transport, Regulation (EU) 2019/1242 sets a target of 45% lower CO_2 emissions from heavy-duty vehicles (HDVs) by 2030, progressing from 15% in 2025 to 90% by 2040, based on 2019 levels. Achieving these goals requires widespread adoption of zero-emission vehicles (ZEVs), such as Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs). However, current ZEVs face limitations in range and payload, making them less viable as direct replacements for internal combustion engine (ICE) vehicles. The ZEFES project brings together OEMs, suppliers, logistics providers, and researchers to advance competitive long-haul ZEVs through efficiency improvements, scalable production, and real-world demonstrations. This deliverable investigates the availability of charging infrastructure to support the ZEFES demonstration use cases of HD-BEV. The work assessed the accessibility and comprehensiveness of information from existing charging station mapping to ensure efficient integration of charging events to long haul logistics missions.

Publishable summary

The transition toward zero-emission freight transport in Europe requires the rapid deployment of suitable charging and refuelling infrastructure to support the operation of Heavy-duty (HD) Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) in long-haul applications. Deliverable D3.6, “Mapping of Charging Stations”, developed within WP3 of the Horizon Europe project ZEFES (Zero Emission Flexible Vehicle Platforms with Modular Powertrains Serving the Long-Haul Freight Ecosystem), addresses this need by providing a comprehensive assessment and geographic mapping of existing and planned charging stations relevant to ZEFES demonstration use cases.

This deliverable is structured in 10 chapters. Chapter 1 introduces the ZEFES project context, its objectives, and the relevance of charging infrastructure mapping for enabling long-distance, cross-border heavy-duty electric vehicle operations. This chapter outlines the motivation for developing a harmonized methodology to evaluate the suitability of Europe’s current charging network for ZEFES use cases. The overview of the current trends in European charging infrastructure, including developments in high-power conductive charging, wireless charging, interoperability standards, and compatibility with ZEFES heavy-duty vehicles is described in Chapter 2. This chapter also establishes the technological and regulatory background against which the mapping activities are carried out. Chapter 3 presents the detailed requirements and methodology for TEN-T corridor charging station mapping. It includes data collection, pre-processing, mission-profile-based demand estimation, and spatial analysis processes. Selected ZEFES use cases are assessed as examples, illustrating how the methodology is applied to real routes, charger availability, and infrastructure requirements. Chapter 4 discusses the existing charging station locator maps and tools. Chapter 5 described the charging stations mapping for ZEFES use cases as an example. The possible key challenges during the charging station mapping is discussed in Chapter 6. These include technical constraints (e.g., grid capacity, charging power availability), regulatory and standardization issues, economic barriers, cross-border coordination limits, and data quality/availability problems. The chapter also highlights the gaps that currently hinder seamless deployment of high-power charging infrastructure along major freight corridors. Chapter 7 and 8 is described the possible mitigations for the challenges of charging station deployment in the TEN-T corridor. This chapters also highlighted the ZEFES project contributions to the charging station mapping and results exploitations. Chapters 9 and 10 present the conclusions, recommendations, identified risks, and interconnections with related ZEFES deliverables. These sections summarize the insights gained, propose actions to address deployment challenges, and ensure alignment with upcoming demonstration activities. They also highlight dependencies between infrastructure mapping and other technical, operational, and vehicle-related work packages.

The aim of this deliverable is to establish an evidence-based overview of infrastructure readiness across the Trans-European Transport (TEN-T) corridors, which serve as the backbone for the project’s real-world demonstrations. The report consolidates information from European, national, and private databases, as well as from original partner inputs, to create a harmonised geospatial dataset. This dataset includes technical parameters such as power rating, connector type, accessibility, and grid proximity, enabling the evaluation of site suitability for megawatt-level charging. The mapping methodology ensures compatibility with the ZEFES digital twin framework, facilitating integration into future route planning and fleet management tools. The findings reveal that while High-Power Charging (HPC) infrastructure for light-duty and regional applications has expanded significantly, the

deployment of Megawatt Charging Systems (MCS) for heavy-duty vehicles remains at an early stage. The uneven charging hub distribution may pose challenges for achieving uninterrupted zero-emission freight operations across all demonstration routes. Furthermore, variations in permitting procedures, grid connection capacity, and national data availability present additional barriers to coordinated infrastructure rollout.

The mapped database generated through D3.6 serves as a strategic input to subsequent ZEFES activities, particularly Work Package 4 (Integrated Digital Twin of ZEV in Logistics Operations), Work Package 5 (Modular and Efficient Long Haulage Battery Electric Vehicles (BEVs)), Work Package 7 (Demonstrations & Fleet integration/management in national & cross-border missions), and Work Package 8 (Use-case evaluation, impact assessment and LCA). It provides the empirical foundation for assessing demonstration readiness, optimizing route planning, and guiding future investment decisions. Overall, the deliverable substantiates that over 80% of ZEFES demonstration routes are operationally feasible with the existing or planned infrastructure, though targeted reinforcement remains necessary in specific regions.

By combining geospatial analytics, infrastructure assessment, and policy insight, D3.6 makes a substantial contribution to the ZEFES objective of enabling cost-efficient, interoperable, and sustainable zero-emission logistics across Europe. The outcomes of this work will not only facilitate the execution of ZEFES demonstrations but also inform broader European strategies for the deployment of high-power charging and hydrogen refuelling networks for heavy-duty transport.

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Abbreviations & Definitions

Abbreviation	Explanation
AC	Alternating Current
AFIR	Alternative Fuels Infrastructure Regulation
AFIF	the Alternative Fuels Infrastructure Facility
CCS	Combined Charging System
CEF	Connecting Europe Facility
DC	Direct current
DER	Distributed Energy Resources
DSO	Distribution System Operator
EAFO	European Alternative Fuels Observatory
EV	Electric Vehicles
EVSE	Electric Vehicle Supply Equipment
FMS	Fleet Management System
GCW	Gross Combination Weight
HD-BEV	Heavy-Duty Battery Electric Vehicle
HD-FCEV	Heavy-Duty Fuel Cell Electric Vehicle
HDV	Heavy-Duty Vehicle
HD-ZEV	Heavy-Duty Zero Emission Vehicle
ICE	Internal Combustion Engine
ISO	International Standards Organization
LV	Low Voltage
MCS	Megawatt Charging System
MV	Medium Voltage

MV/HV	Medium and high voltage
OEM	Original Equipment Manufacturer
SAE	Society of Automotive Engineers
TEN-T	Trans-European Transport Network
TSO	Transmission System Operator
UC	Use Case
V2G	Vehicle-to-grid

1 Introduction

1.1 Context and progress

This report presents an overview of the available electric charging infrastructure in Europe for heavy duty battery electric vehicle (HD BEV) trucks. The deliverable aims to identify the required infrastructure to conduct the ZEFES use cases, map existing charging stations, explore ongoing projects related to the electric charging infrastructure upgrades as well as the potential funding schemes. Previous works have defined electric charging station requirements which consist of specifications of HD BEV use cases and its metrics for demonstration. The safety requirements of the HDVs, which also feature combinations with e-trailers, have also been considered as part of the homologation process. This information is essential to demonstrate the electric charging station infrastructure mapping in countries along the ZEFES corridors. The report is arranged as follows: Section 2 discusses about the high-power charging station infrastructure, standards, communication protocols and interoperability. This section also describes the supply chain requirements for charging station mapping. Section 3 describes the charging station mapping requirements based on the mission profile of the long-haul electric trucks in the TEN-T corridor routes. Section 4 represents the charging station mapping for the dedicated use cases defined in ZEFES' WP1. The map is used to identify the electric charging infrastructure available along each use case route. The findings will serve as a reference to establish a road map towards zero-emissions HDVs, highlighting the critical infrastructure needs to be built in regions along TEN-T corridors. Section 5 presents the challenges of charging station infrastructure deployment, including the mapping of available electric recharging infrastructure. It also presents organisations on national, regional, or international level that support the roll-out of electric transportation. Section 6 discusses possible solutions to mitigate the challenges related to deployment, technical, and operational perspectives. This section also mentions some funding opportunities to develop charging infrastructure for TEN-T corridors across the European Union.

2 High-Power Charging Infrastructure Trend

EVs are designed with various charging technologies, capacities, and charging and discharging strategies to fulfil their unique requirements. Therefore, standardized charging levels and models are established to promote EV adoption in the industry. The electric powertrain of modern plug-in EVs is similar and is designed with a high-power battery pack (to maintain voltage and current), a battery management system, various converters to supply appropriate voltage levels, controllers, and drive inverters. EV chargers can be classified as onboard and offboard chargers, as well as unidirectional and bidirectional chargers. Charging methods include conductive charging, battery swapping, wireless charging or inductive charging, as illustrated in Figure 1[1]. Most commercial EVs use conductive charging, where the battery connects through a power electronics interface to the power grid via a cable and connector. Conductive chargers are categorized into three levels (Level 1-3, per SAE J1772) and four modes (Mode 1-4, per IEC 61851-1 standards). Wireless charging uses time-varying magnetic fields to transmit power from the grid to the EV battery and can be divided into dynamic and static wireless charging. The following subsections will describe the three charging levels, four charging modes, different connectors, and ports.

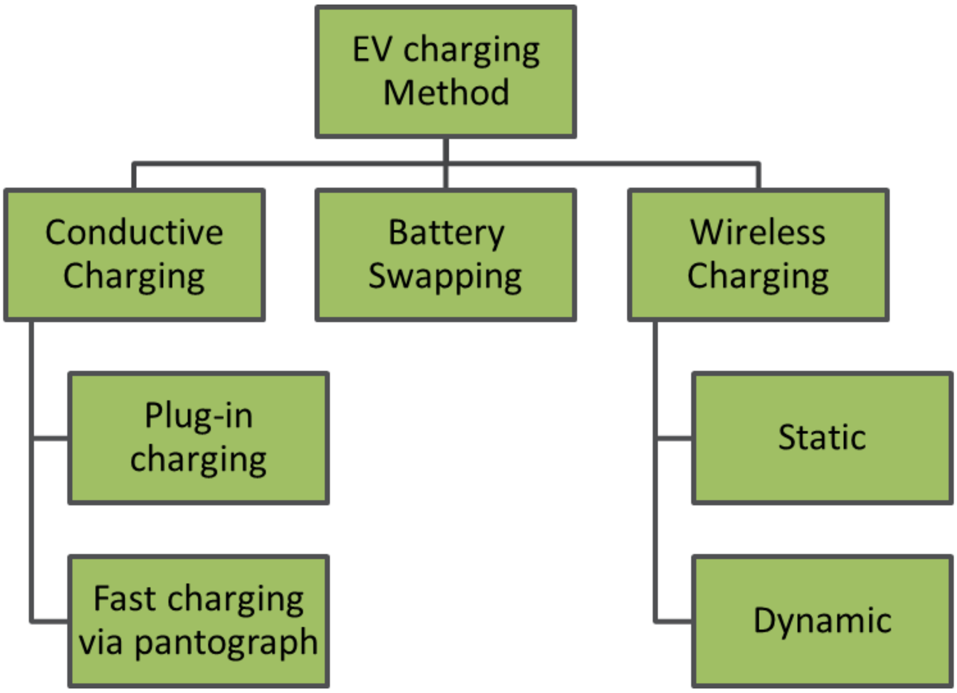


Figure 1 Different Charging Methods for EVs [1]

2.1.1 Overview of Conductive Charging Systems with Power Levels and Ports

The terms 'fast charging' and 'high power charging' are not explicit when brought to the HD-BEV context with traction battery capacities and voltages which are different from a light duty (LD) EV context. In the end, the limiting parameter for a battery system in charging is the C-rate (charging current in relation to its capacity), and for the charging interface the current capability. The most relevant measures for the charging, are the time used for the charging event, and the energy that can be stored during that time. For the ZEFES project, the HDV charging classification and terminology related to charging power and capacity values are presented in Table I. The battery C-rate describes in this case the speed of charging, and it is related to the battery capacity C, expressed in A·s or more commonly in *Ah*. The unit of C-rate is usually 1/h, and it denotes the rate at which a battery is charged. C-rate can also be defined with the ratio of charging power to battery capacity, and it is then known as CP-rate (IEC, 2004), [2]. Similar terminology as with LDVs is used [3], but the power levels for HDVs are higher for each class than with LDVs because their batteries are typically of higher capacity. Other possible terms to be used are low power, rapid, super, and high-power charging, but in this classification only adjectives slow, normal, fast, and ultrafast are used, to avoid misinterpretations.

Table I Different Levels of Conductive Charging [5]

HDV Charging Speed	Charging Voltage (V)	Charging Current (A)	Charging Power (kW)	Battery Capacity (kWh)	C-Rate Range (-)
Slow	400/800	60-400	50-150	400-900	0.05 – 0.37 C
Normal	400/800	200-800	150-400	400-900	0.16 - 1 C
Fast	Up to 1500	300-1000	200-1000	400-900	0.22 - 2.5 C
Ultrafast	Up to 1500	800-3000	1000-2000	400-900	1.1 - 11.3 C

Level 3 (DC fast) chargers deliver 20–350 kW of DC power (300–800 V) directly to the battery through off-board systems connected to a three-phase grid. These chargers can recharge most commercial HDEVs in approximately 0.5–10 hours. Common connector types include CHAdeMO, CCS Combo, and Tesla Superchargers. The different charging connectors for level 1, level 2, and DC fast charging in different regions are shown in Table II.

Table II Level 1 and Level 2 AC Charging Connectors in Different Regions [1]

Specification	Japan	USA	Europe	China	All markets
AC Charger Port Type					
	Type 1 (SAE J1772)		Type 2 (Mennekes)	Type 2 (GB/T)	Tesla

Table III DC Fast Charger Connectors in Different Regions [1]

Specification	Japan	USA	Europe	China	All markets	
DC Charger Port Type						
	CHAdeMO	CCS 1	CCS 2	GB/T	Tesla Supercharger	CHAdeMO

2.1.2 Megawatt Charging Stations (Extreme Fast Charging)

Extreme Fast charging stations are high-power charging systems specifically engineered to satisfy the needs of medium and heavy-duty electric vehicles (EVs), including trucks and buses, by providing megawatt-level power in a brief timeframe. A leading example of this infrastructure is the Megawatt Charging System (MCS), which can deliver up to 3.75 MW facilitating rapid charging during short rest or loading periods. MCS is a standard developed for heavy vehicles with large batteries and high uptime requirement. This standard should be used at all power levels, not only for high power charging. In the following sections, we will explore the primary configurations and architectures of MCS employed in megawatt charging stations [4]. However, it is essential to recognize that these are not the only potential configurations, as ongoing technological advancements are continually introducing innovative designs and approaches for high-power charging applications.

2.1.2.1 Individual Dispensers on an AC Hub:

These systems range from a single low-voltage (480 V) utility connection capable of delivering up to 1 MW of power to one charger, suitable for charging a single vehicle at a time as shown in Figure 2. Another setup combines multiple 1 MW power cabinets in parallel to reach higher overall output and support simultaneous charging of several vehicles, though scalability is limited by the low-voltage connection. A portable option is the containerized plug-and-play solution that consolidates all necessary components into a single container for easier installation and flexible deployment.

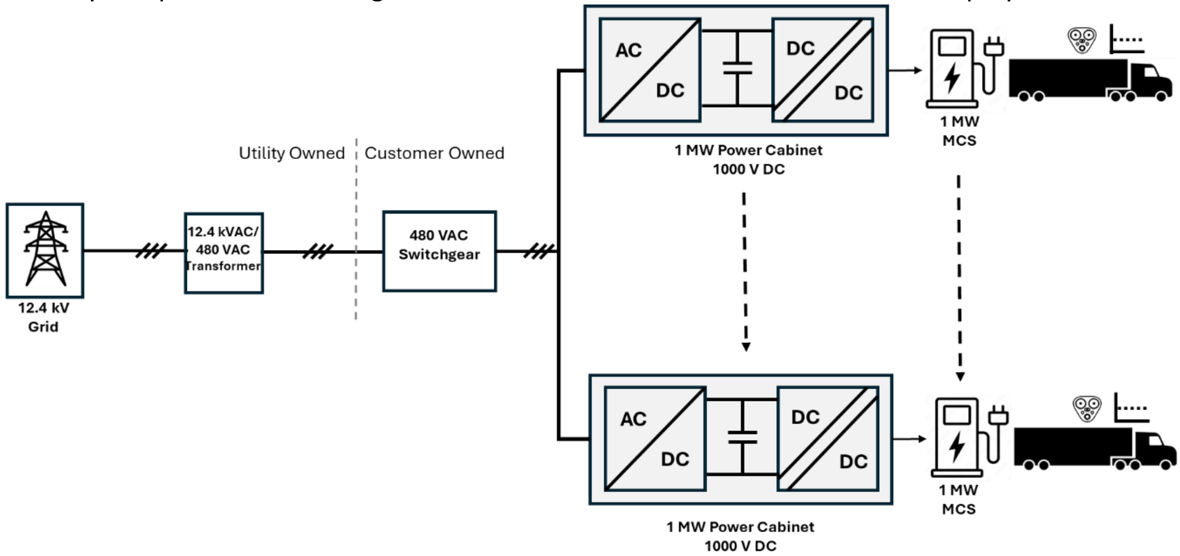


Figure 2 Megawatt-Level Power Cabinets with individual dispenser

2.1.2.2 Multi-Megawatt Dispensers:

The 3 MW Charger Power Configuration features several low-voltage (480 V) connections supplied from the medium-voltage utility grid, where each charger operates through its dedicated transformer as shown in Figure 3. Within the system, the incoming power is converted to provide direct energy delivery to the vehicle, enabling each unit to supply up to 3.75 MW. This configuration is intended for high demand charging sites and supports the growing needs of heavy-duty electric vehicles.

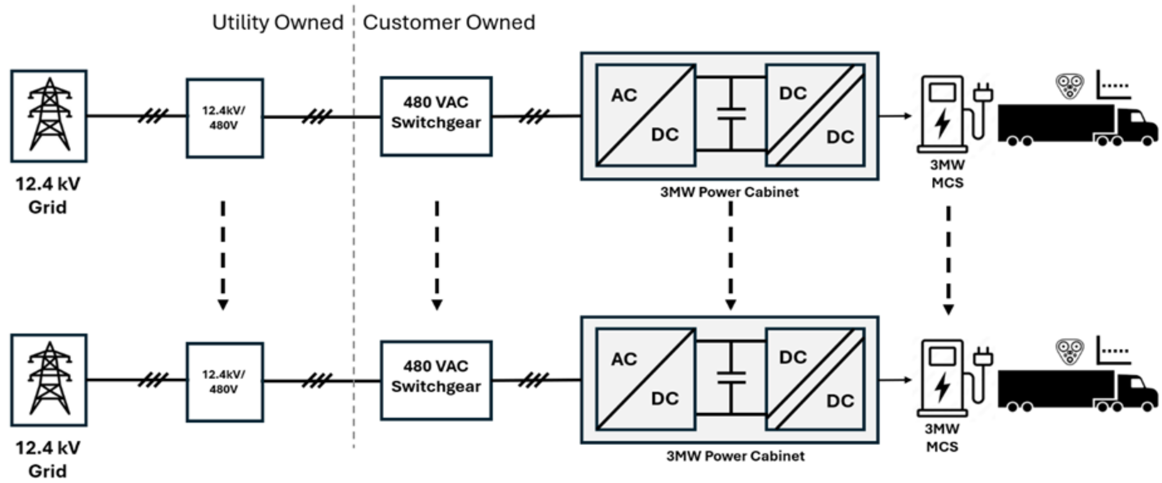


Figure 3 Three MW Charger Power Configuration

2.1.2.3 Central DC Supplied Dispensers on a DC Hub:

Central DC-supplied charging architectures are designed to efficiently distribute high-power DC from a centralized source to multiple dispensers, enabling flexible and scalable megawatt charging as shown in Figure 4. Various configurations exist, such as systems with centralized rectifiers converting low-voltage AC to DC for internal bus distribution, and medium-voltage converters or SST that enhance power throughput and efficiency through direct medium-voltage grid connections.

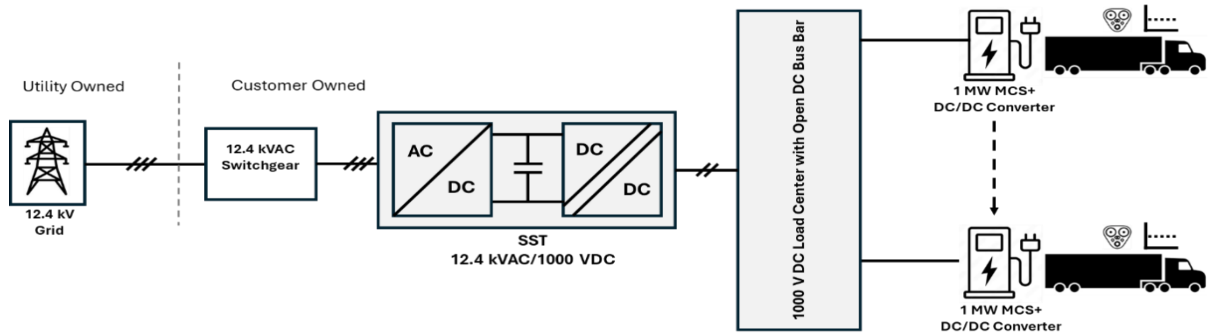


Figure 4 Medium Voltage Converter with Centralized DC Bus

2.1.3 Fast charger via pantograph

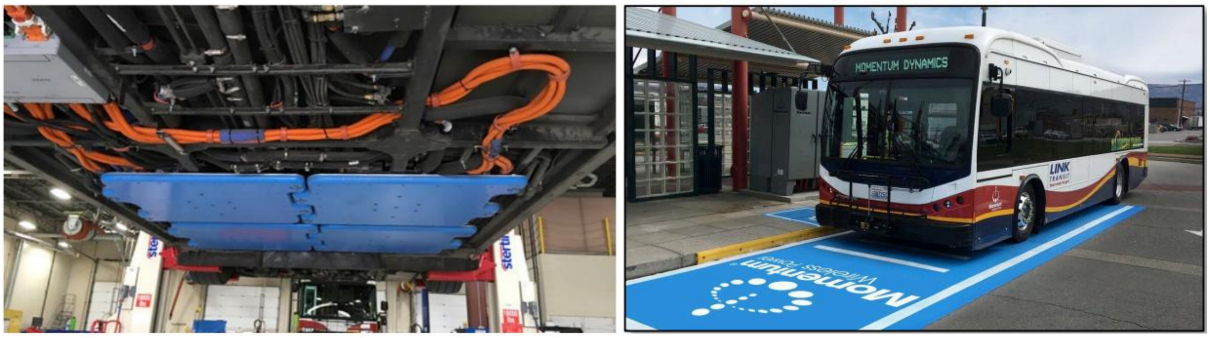
DC fast-charging systems via pantograph can be considered an optimized state for electric trolleybuses, where the energy distribution system disrupts urban planning. The EU Horizon 2020 project "ASSURED" has demonstrated different use cases with fast charging using pantograph [5] as shown in Figure 5(a) and Figure 5(b). The system is suitable for city buses, medium- and heavy-duty EVs. Trolleybuses have been powered from long electric distribution lines, but during the DC fast-charging process, when vehicles arrive at the station, a short-term and high-power energy flow is initiated from the station to the vehicle. With this energy, the batteries are charged until the next station. During the DC fast-charging process via the pantograph, manufacturers use Wi-Fi protocols for communication between the electric vehicle and the charger.

(a) (b)

Figure 5 The use case demo with fast charging using pantograph technology in Gothenburg, Sweden. (a) Infrastructure mounted ACD by ABB, (b) Roof mounted ACD

2.2 Wireless Charging Stations

Wireless power transfer systems (WPT) for commercial vehicles have not demonstrated full MW power level charging. Of note are two companies that are building 500 kW systems and have plans to build/demonstrate vehicle configurations with WPT multiple transmitter-receiver pairs. These include WAVE IPT, working on a Department of Energy (DOE), USA-funded project with a Class 8 vehicle manufacturer and other partners, and Momentum Dynamics, focused on delivery vehicles and transit buses. Figure 6 shows excerpts from the Momentum Dynamics presentation [6] on facility layout and examples of the receivers mounted to the bottom of a commercial vehicle. In this case, there are four interlocked receiver coils. The static wireless charging technology is demonstrated as shown in Figure 6 for a passenger bus.



(a) (b)

Figure 6: Static Wireless Charging for a Public Bus (a) 2X2 receiver coil (b) Static wireless charging park for 12 m bus

ElectReon (TASE: ELWS), developing and implementing Wireless Electric Road Systems that wirelessly charge commercial and passenger electric vehicles while driving, as shown Figure 7(a), has completed the deployment of 1.65 km of a dynamic wireless charging system on a public road in Gotland, Sweden, which is the largest deployment of its kind in the world [7]. Figure 7(b) shows the charging power transmitter coil before covering with asphalt.

(a) (b)

Figure 7 Dynamic Wireless Charging for an Electric Truck (a) dynamic wireless charging lane in Gotland, Sweden for long haul truck (b) transmitter coil in the dynamic charging lane before asphalt.

The fully electric long-haul truck was charged by the road while driving at various speeds of up to 60 km/h on a 200-meter electric road segment, with an average transfer rate of 70 kW from the road to the receivers and into the truck's battery. Moreover, France has launched the world's first wireless electric road system on a 1.5-kilometer section of the A10 motorway near Paris, allowing electric cars, buses, and trucks to charge while driving. The system, a collaboration between Electreon and VINCI Autoroutes, uses copper coils under the road to wirelessly transfer energy and is a key part of the government's goal to deploy 9,000 km of such roads by 2035 [8].

2.3 Interoperability and Standardization

Standards play a key role in the development and deployment of EV technology in society, which serves as a crucial foundation for broad market penetration and customer satisfaction. The high level of EV charging integration has created new challenges and requirements in the automotive industry and electricity networks. Standards and grid codes are designed to ensure reliable and safe EV integration with the power grid and other energy resources. Charging standards are applied to EVs to provide accurate functionality, protection, interoperability, and integration with various parameters and conditions. EV charging standards are employed around the world to interact with the charging infrastructure. The Society of Automotive Engineers (SAE) and the Institute of Electrical and Electronics Engineers (IEEE) are two main contributors to charging and grid integration standardizations. The SAE and International Electrotechnical Commission (IEC) standards are widely used for EV conductive charging systems. **Fout! Verwijzingsbron niet gevonden.** below lists the preferred international standards for EV charging systems, including conductive charging, safety, and grid integration regulations.

Charging standardizations can be classified in terms of charging components, grid integration, and safety. The specifications for EV conductive charging components, including connectors, plugs, outlet sockets, and inlets, are defined by SAE J1772 and IEC 62196 standards. A series of standards within IEC 62196 and IEC 61851 outline the specifications for EV connectors in AC and DC charging systems. Inductive charging standards include SAE J1772 and IEC 61980, while battery swapping charging systems use IEC 62840 standards. AC charging systems utilize SAE J1772 standards with 100V domestic power in the US and Japan and 220V power in Europe. GB/T 20234 standards are applied to AC charging systems in China. Connectors and ports in DC charging systems are designed according to IEC 61851 standards, CHAdeMO (described in GB/T 20234), and CCS Combo standards.

Table IV also displays internationally recognized standards related to specific EV characteristics. The charging and discharging processes of EVs via the grid adhere to grid integration standards and codes. In V2G operation mode, EVs are regarded as distributed energy resources aligned with power grid integration standards. These include regulations on power, safety, and power quality, along with essential grid codes that promote reliable EV integration. Organizations like the Institute of Electrical and Electronics Engineers (IEEE) and Underwriters Laboratories (UL) set the standards for grid interconnection and safety. IEEE 1547 specifies the requirements for connecting distributed resources to the power grid, covering performance, maintenance, testing, and safety aspects for all DERs in distribution systems. UL 1741 details the specifications for power converters, controllers, and safety of DERs. Communication standards such as IEEE 2030.5 and ISO 15118 facilitate interoperable EV control through information exchange, testing protocols, response guidelines, and security measures [9].

EVSEs communicate with electric vehicles (EVs) to ensure safe and appropriate power transfer, beyond just energy delivery between the EV battery and the energy source. Consequently, some standards focus on signalling and communication across multiple devices. The main goal of these communication standards is to regulate the current supplied and control the current flow for different devices. Additionally, the battery's state of charge (SoC) influences and permits the use of EVSEs. The communication protocols for DC off-board fast chargers are based on SAE J2847/2 standards [9], while PLC communication requirements are outlined in SAE J2931/4. The International Organization for Standardization (ISO) has also developed numerous safety standards and technical regulations for lithium-ion battery packs (ISO 64691-3) and high-voltage EV systems (ISO/DIS 21498) [10].

Table IV Major Standards of EV Charging Systems

Standard	Description
SAE J1772	Conductive charger coupling of AEVs and HEVs
SAE J2234	Guidelines for EV safety
SAE J2894/2	Power quality requirements
SAE J2953	Standard for interoperability of EV and charger
SAE J2954	Wireless power transfer for light-duty plug-in/EVs and alignment methodology
SAE J2847/1	Communication between EV and the grid
SAE J3068	EV power transfer system using a three-phase AC capable coupling
SAE J2931/7	Security for PEV communication
IEC 60038	Standards for the voltage of charging applications
IEC 62196	Standards for EV conductive charging components (outlets, plugs, connectors, and inlets)
IEC 60664-1	Installation coordination for charging equipment in the LV supply
IEC 62752	Standards for cable control and protection devices
IEC 61851	Covering safety-related specifications on the charging station

IEC 61980	EV wireless power transfer
ISO 15118	Standards for V2G communication protocols and interfaces
ISO 17409	Specifications for the connection of an EV with an external energy source
ISO 19363	Electrically propelled road vehicles- magnetic field wireless power transfer safety and interoperability requirements

2.4 Compatibility with the ZEFES HDVs

2.4.1 Charging connectors

The MCS standard is being led by CharIN and has many industry partners in its working group. The ZEFES project use case vehicles are prepared to adopt this MCS technology during HDV charging sessions. When using the simulator as EVSE, the maximum electrical characteristics of the gun are as shown in Figure 8 below.

Figure 8 MCS Male gun

Table V MCS Male Gun electrical specifications

Electrical Properties	
Rated Voltage for power contacts	DC 1000 V (acc. UL) DC 1500 V (acc. IEC)
Rated Current for power contacts	up to 1500 A (with proper cooling)
Maximum charging power	2.25 MW
Overvoltage category	CATIII
Number of power contacts	3 (DC+/DC-/PE)
Rated Voltage for signal contacts	AC 30 V / DC 48 V
Rated current for signal contacts	2 A
Number of signal contacts	4 (CP, PP, PHY1, PHY2)

For the simulator acting as EV, the maximum electrical characteristics of the inlet are:

Figure 9 MCS female inlet

Table VI Inlet electrical specifications

Electrical Properties	
Rated voltage for power contacts	DC 1250 V (acc. UL) DC 1500 V (acc. IEC)
Rated current for power contacts	up to 2000 A
Maximum charging power	3 MW
Overvoltage category	CATIII
Number of power contacts	3 (DC+/DC-/PE)
Rated Voltage for signal contacts	AC 30 V / DC 48 V
Rated current for signal contacts	2 A
Number of signal contacts	4 (CP, PP, PHY1, PHY2)

2.4.2 Communication Protocols

To analyse the protocols, it is important to understand the application of each one with regards to EV charging. The first concept that needs to be remarked is “communication”. Two general types can be differentiated, “high-level communication” and “low-level communication” or basic/safety signalling. “High-level communication” is used for exchange of charging parameters such as voltage, currents, remaining time for full/bulk SoC etc. It is mostly implemented via Power Line Communication (PLC) but for automated connection devices WLAN is also utilized. High level communication is specified in ISO 15118-2, -20 where an explanation of how to implement the following features is detailed.

i. Identification
ii. Payment
iii. Load levelling
iv. Value Added Services

“Low-level communication” is used to control the state of the charge, giving means to the EV and EV supply equipment to notify each other whether there are no issues, and the power flow is allowed, or it exists a failure or potential error that needs the charging to be stopped immediately. It is specified in IEC 61851-1, -23 and the items explained are the following:

i. Vehicle States
ii. Control pilot handling for safety
iii. Control pilot handling energy transfer initialization

The relationship between high-level and low-level communication is treated across several subparts of the ISO 15118 standard series:

- ISO 15118-2 Network and application protocol requirements

- ISO 15118-20 Network and application protocol requirements
- ISO 15118-3 Physical data link requirements
- ISO 15118-8 Physical layer and data
- Additionally, IEC 61851 Electric vehicle conductive charging system

2.5 Use Case Vehicles for Charging Stations Utilization

Table VII List of the ZEFES project Use Case vehicles

Use Case Route	Truck Fuel	Shipper	Body Length (m)	Gross Weight (ton)	CCS Compatible	MCS Compatible	eTrailer
UC 722	BEV	Volvo	17.4	44	Yes	Yes	Yes
UC 723-1	BEV	P&G	17.4	44	Yes	Yes	Yes
UC 723-2	BEV	Primafrio	17.4	44	Yes	Yes	No
UC 724	BEV	DPD	25.25	48	Yes	No	Yes
UC 731	BEV	Scania	16.5	44	Yes	Yes	No
UC 733	BEV	Primafrio	16.5	44	Yes	Yes	No
UC 734-1	BEV	GSS	16.5	44	Yes	Yes	Yes
UC 734-2	BEV	GSS	32	64	Yes	Yes	No
UC 741	BEV	Michelin	17.6	44	Yes	Yes	No
UC 742	BEV	Renault	17.6	44	Yes	Yes	No
UC 743-1	BEV	Renault	17.6	44	Yes	Yes	No
UC 743-2	BEV	Renault	17.6	44	Yes	Yes	No

2.6 Supply Chain Requirements for Charging Stations

There is a need to take zero emission long-haul goods transport in Europe to the next level by executing real-world demonstrations of BEVs and FCEVs in Europe to operate in complex transport supply chains. The comprehensive analysis of different real-life truck and intermodal operations as integrated parts of supply chains are discussed in ZEFES D1.4. In this section, the supply chain requirements for the electrification of Battery Electric Trucks are discussed. The Figure 10 illustrates charging needs across the logistics supply chain, distinguishing between depot-based operations, destination charging, and long-haul corridor charging. Short-distance regional operations (<150 km) can be fulfilled primarily by depot overnight charging (up to 150 kW) or charging at destination logistics hubs (up to 350 kW). Meanwhile, long-haul routes (>300 km) require public high-power daytime charging ranging from 500 kW to 1 MW, complemented by secured overnight charging at parking facilities.

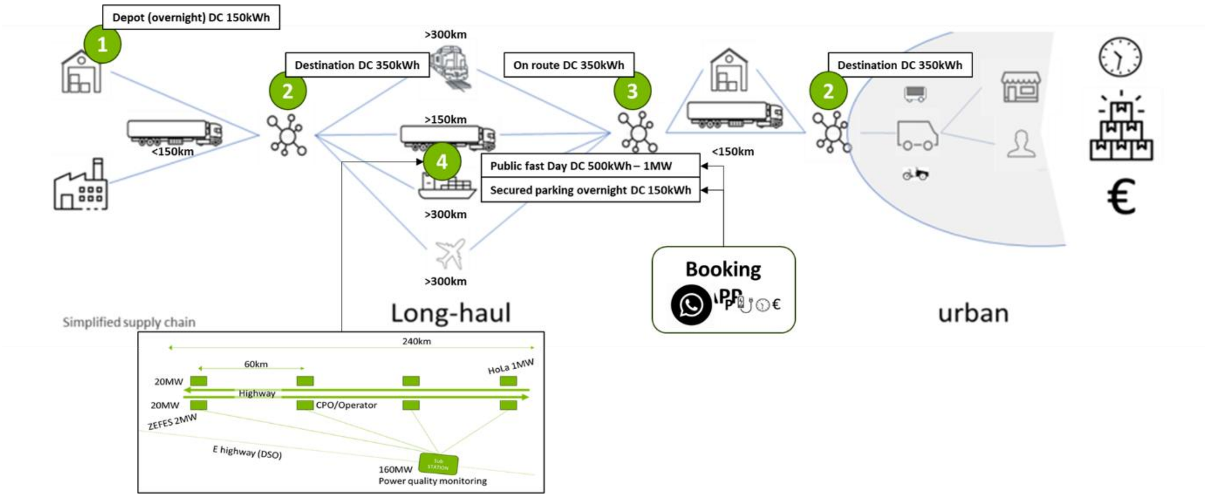


Figure 10 Strategic approach of supply chain requirements for charging stations

Figure 10 also highlights interoperability between logistics nodes such as factories, ports, warehouses, and multimodal terminals, where energy demand varies with trip length and operating schedules. A booking system ensures availability, pricing transparency, and optimized charging coordination for fleets. The lower schematic shows expected power distribution along highways, including substations, multiple high-power charging sites (20 MW class), and monitoring infrastructure, illustrating the need for coordinated grid planning to support megawatt-scale truck charging.

2.7 Identified infrastructure for the ZEFES use cases

Table VIII List of charging stations accessible for HD-BEV for each UCs

Use Case	Route	No. of Charging Stations			MCS required
		Ready	Opening	Planned	
UC 722	Gothenburg, SE to Ghent, BE	12	3	3	Yes
UC 723-1	Amiens, FR to Zeebrugge, BE	4	2	-	Yes
UC 723-2	Dudelange, LU to Halmstad, SE	15	3	2	Yes
UC 724	Munich, DE to Eindhoven, NL	11	-	-	No
UC 731	Sodertalje, SE to Zwolle, NL	13	-	-	Yes
UC 733	Murcia, ES to Boulou, FR	-	2	3	Yes
UC 734-1	Le Boulou, FR to Martorell, ES	3	-	-	Yes
UC 734-2	Dudelange, LU to Heilbronn, DE	-	-	1	No
UC 741	Blanzy, FR to Blavozy, FR	2	-	-	No
UC 742	Lyon, FR to Turin, IT	3	-	1	No
UC 743-1	Veenendaal, NL to Berkel en Rodenrijs, NL	3	-	1	Yes
UC 743-2	Veenendaal, NL to Vilvoorde, BE	3	-	1	No

3 Charging Station Mapping Requirements

3.1 Data Collection and Pre-processing

The systematic collection of spatial and technical data relevant to charging and refuelling infrastructure is the significant pre-requisite for proceeding to the charging station mapping across the specific TEN-T corridor. This includes the geolocations and attributes of existing CCS, and MCS obtained from European and national databases, industry operators, and open data repositories regarding charging infrastructure (Google Maps). The complementary data layers were gathered to provide contextual insights, including road networks, traffic flows, logistics hubs, industrial clusters, and electricity grid or hydrogen supply infrastructures. Additionally, socio-economic indicators such as freight activity and urbanization levels were considered to understand the demand context. The possible data types with collection sources are listed in Table IX.

Table IX List of data required for the mapping exercise

Data Type	Purpose	Data collection source examples
Existing charging infrastructure	To know what is already deployed	National/regional databases (EU AFIR registry), alternative fuels observatories (e.g. EAFO), open data portals, industry CPO disclosures
Road network & TEN-T corridors	To overlay and see connectivity, distances	European road GIS (OpenStreetMap, EuroGeographics, etc.)
Traffic status	To estimate where heavy trucks travel and where demand occurs	Transport authorities, freight flow datasets, surveys, logistics companies
Use case mission profiles	To know where and when ZEVs will travel, charging needs, ranges, dwell times	Data is collected from WP1, WP2.
Topography, land use, environment	To filter unsuitable sites (e.g. steep slopes, protected areas)	GIS layers: elevation, slope, land cover, protected areas
Electricity grid data	Grid strength, substation location	Partner DSOs, and grid operators
Socio-economic / demand context	To capture demand drivers near nodes (depots, hubs, cities)	Population, industrial zones, logistics parks, ports
Regulatory / planning constraints	Zoning, permitting constraints, safety setback buffers	Local planning maps, environmental constraints

All datasets were harmonized using common spatial projections, cleaned to remove duplicates or obsolete entries, and integrated into a geospatial analysis environment.

3.2 Mission Profile based Demand Estimation

The demand for charging was estimated using a mission-based modelling method. In the mission-based approach, the vehicle mission profiles developed in earlier work packages served as the basis for calculating energy demand along representative duty cycles. Energy requirements in terms of electricity consumption (kWh) which was determined for specific routes, corridors, and operational cycles of HD ZEVs. The charging station was mapped where vehicles are likely to stop or need charging/refuelling (depots, rest stops, distribution hubs).

3.3 Spatial Mapping and Analysis

The integration of demand estimates with infrastructure availability through mission profile-based analysis. Existing CCS, and MCS, were mapped against the TEN-T core and comprehensive corridors to assess their spatial distribution and accessibility. Isochrone analyses were conducted to determine the catchment areas of each station within defined driving ranges, thereby quantifying the share of corridor segments that are adequately served. The gap assessment was then performed to identify regions and corridor stretches that lack sufficient coverage or exceed acceptable detour thresholds for heavy-duty vehicles. Furthermore, technical adequacy was assessed by examining station attributes such as maximum charging power, number of connectors, and proximity to the electricity.

3.4 Validation and Stakeholder Engagement

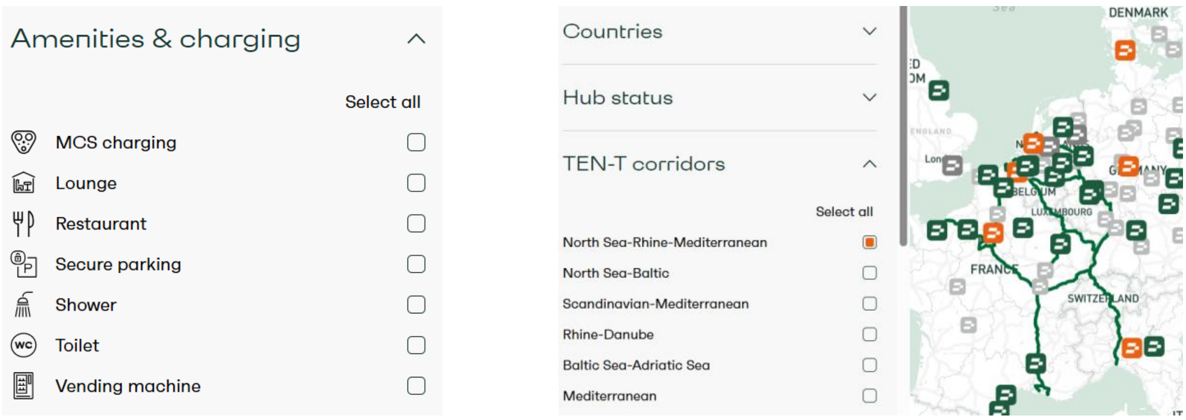
The proposed mapping and optimization results were validated through iterative stakeholder consultations. Feedback was solicited from project partners, charge point operators (CPOs), grid operators, and local authorities. This engagement ensured that technical feasibility, regulatory conditions, and land use constraints were adequately reflected in the mapping exercise. Additionally, sensitivity analyses were performed to test the robustness of the results under variations in key parameters such as vehicle adoption rates, energy consumption per kilometre, and permissible detour distances. This iterative validation process allowed the final roadmap to be both evidence-based and practically implementable, while remaining adaptable to future technological and market developments.

4 Charging Station Mapping

The information on HD-BEV charging locations is available in several sources, including charger locator application, CPO's own website, driving maps, and European Alternative Fuels Observatory (EAFO). However, most of these platforms are initially designed for passenger car and light duty vehicles purposes. To ensure efficient BE HDV logistics mission, there are several factors that determine the compatibility of a charging hub especially its accessibility for larger dimension vehicles. In November 2025, there have been few mappings designed to accommodate HDV charging needs. Some platforms show complementary services such as amenities for drivers and acceptable payment method. This has been part of the effort to integrate charging events to the existing logistics mission efficiently, including synchronization with driver mandatory breaks.

4.1. CPO's own map

The mapping created by CPOs is exclusive to their site network. The first example shows the Milence network map, presenting information of station operation ability and charging power. The map is equipped with filter of available amenities for truck drivers as seen on Figure 11(a). While the map can be overlaid with TEN-T corridor routes, showing its proximity from the main route.



(a) Driver amenities (b) Filter to overlay TEN-T corridor route

Figure 11 Example of CPO's own mapping [15]

What is particularly valuable is the availability of a video showcasing each station's layout and facilities, as illustrated in Figure 12. Although originally produced for promotional purposes, the footage provides useful insights into the accessibility of the charging bay, especially those not exclusively designed for trucks or constructed on brownfield sites, such as already existing gas stations.

During this work of charging infrastructure mapping, station accessibility was verified using multiple approaches, including secondary sources such as site photographs. Building on this, incorporating video demonstration of truck flows, from entry and charging to exit are useful to better assess manoeuvrability of a charging hub during route planning.

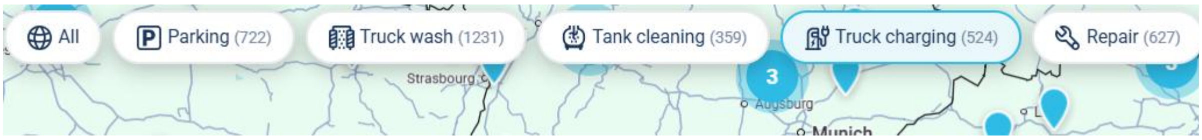
Figure 12 Video demonstration of truck accessing the charging bay [15]

4.2. Third party charger locator

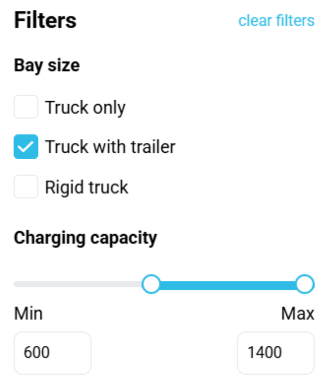
Travis Road Service has launched a comprehensive map offering a range of services tailored to truck hauling operations, including secure parking facilities, charging hubs, truck wash stations, repair workshops, and tank cleaning services. The platform features filter options for station bay size and charging outlet type, as illustrated in Figure 13(b). These filters help ensure accessibility for heavy-duty vehicles (HDVs) by accommodating their manoeuvrability requirements, while also preventing trucks from blocking access to chargers intended for passenger or light-duty vehicles. Additional information is provided for each charging hub, including:

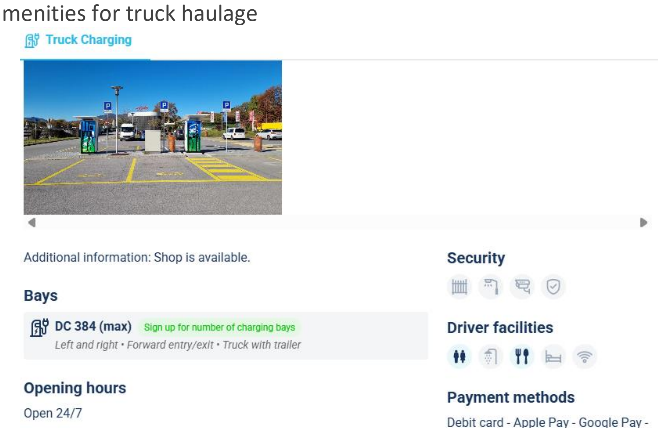
i. Operating hours
ii. Power outlet specifications
iii. Security measures
iv. Driver amenities
v. Accepted payment methods

Images of the charging bays are also available, though not consistently across all listings. A reservation system is available, but only reserved for TRAVIS account holders, where there are two categories: Drivers and Transport and fleet managers.



a) Range of services and amenities for truck haulage





b) Station locator filter c) Detail information of station operations

Figure 13 Example of third-party charger locator [16]

4.3. Truck OEM maps

Truck manufacturers have also begun developing databases and mapping tools for truck charging infrastructure. A notable example is Renault's open-access map, which provides a simplified yet practical overview of charging stations. The map includes operational truck charging facilities and planned expansions of truck-dedicated hubs. In addition to dedicated truck facilities, the map highlights stations that are potentially viable for truck access, though further verification may be required. These categories are visually distinguished using colour coding, as shown in Figure 14.

Figure 14 Example of OEM's truck charging map [17]

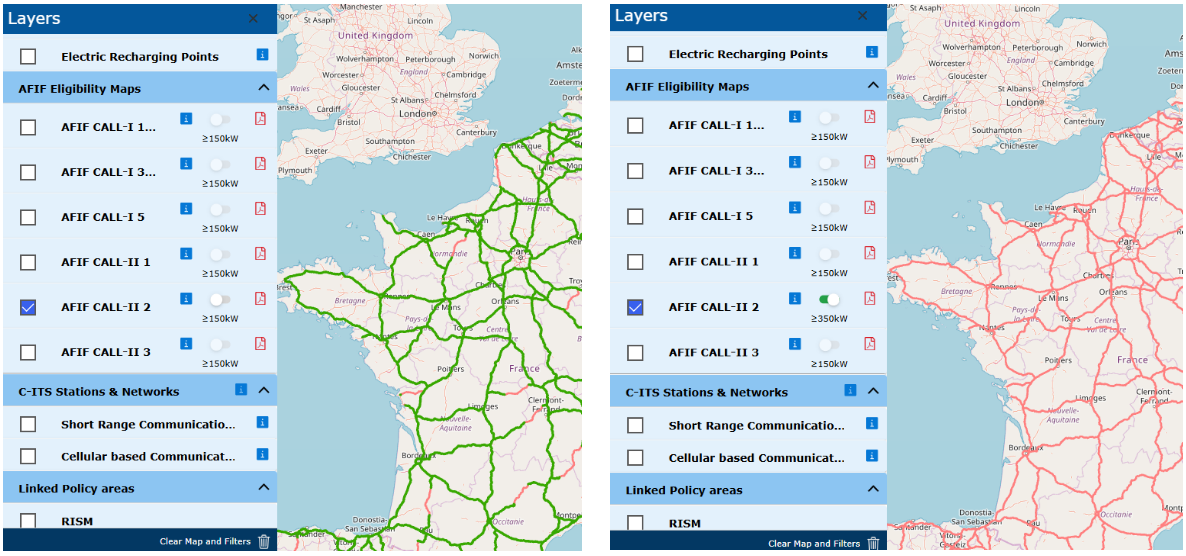
Facilities marked as 'viable for trucks' may be subject to specific accessibility constraints. As illustrated in Figure 15, detailed descriptions are provided to help transport planners and truck drivers assess whether a station is suitable, based on vehicle type and dimensions. In some cases, pre-authorization may be required before accessing the station. This information can enhance the utilization of existing charging infrastructure without compromising the reliability of the logistics mission with HD-BEV. Moreover, the network of viable options can serve as a strategic backup for truck charging, particularly when dedicated truck-only hubs are unavailable or when delivering goods to destinations with lower charger density.

Vehicle accessibility Accessible by rigids only Description Emergency access (left side) - Rambouillet to Ablis direction	Vehicle accessibility no drive through Description it can be driven in forwards, but must be reversed out again
Vehicle accessibility Ok with semi-trailer	Vehicle accessibility max 3 m height Description Call ENGIE Vianeo before going there because we need to ask for autorisation for trucks

Figure 15 Example of vehicle accessibility limitation remarks on mixed-fleet hubs [17]

4.4. European Alternative Fuels Observatory – [TENtec map]

The European Alternative Fuels Observatory has launched a map containing a database of various alternative fuels infrastructure, including electric charging stations. The infrastructure locations are overlaid on the TEN-T corridor map, providing visibility into past and future projects along each strategic corridor. As shown in Figure 16, the map features the Alternative Fuels Infrastructure Facility (AFIF) layer, which is based on a gap analysis of recharging stations on the TEN-T network and includes previously selected AFIF projects. Gaps in TEN-T coverage are identified where the distance between recharging stations exceeds 60 km. These sections are highlighted in red on the map, and investments in recharging points along them are therefore potentially eligible for AFIF support. The criteria can be adjusted according to minimum power outputs of 150 kW and 350 kW, ensuring alignment with evolving infrastructure needs. For example, Figure 16 (a) shows that only a few routes still fail to meet the minimum 60 km spacing for ≥150 kW chargers, while Figure 16 (b) illustrates that most corridors remain under-equipped with ≥350 kW chargers.



(a) Gap Analysis of High-Power Charging Infrastructure (≥150 kW)

(b) Gap Analysis of High-Power Charging Infrastructure (≥350 kW)

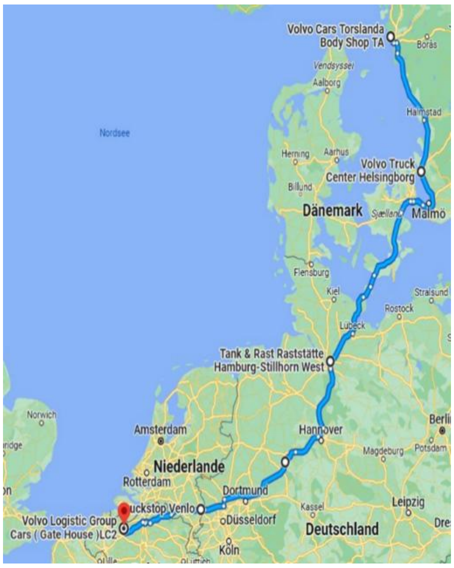
Figure 16 European Alternative Fuels Observatory map

5 Charging stations Mapping for the ZEFES Use Cases

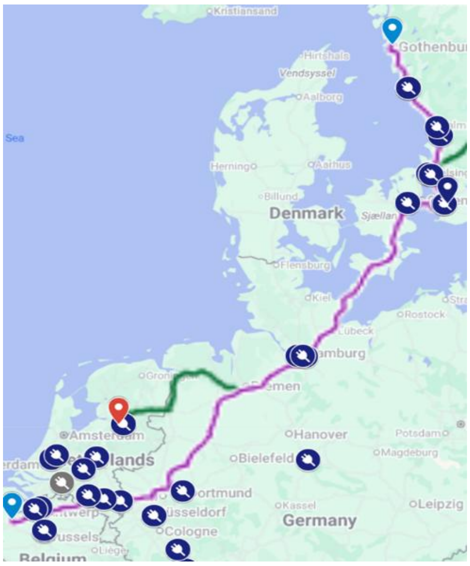
Unlike maps developed by other stakeholders which has been explained on the earlier section, this platform is not a charger locator. The information presented is static and does not reflect facility operational status. Instead, the platform serves to synergies charging infrastructure development, enhancing cross-collaboration and enabling continued use of infrastructure after demonstration phases. For example, in the ZEFES charging infrastructure mapping, some hubs were built on preceding research projects such as HoLa.

5.1 UC 722: Gothenburg, SE to Ghent, BE

The transport route extends from Gothenburg (Sweden) to Ghent (Belgium), operated by Volvo for the shipment of automotive parts with long truck-trailer combinations (EMS2/R+ST, 17.4 m, 44 tonnes). The case highlights the critical dependence on planned Megawatt Charging System (MCS) installations in Gothenburg, Helsingborg, and Germany (HoLa project sites), with complementary Combined Charging System (CCS) stations in Venlo, Eindhoven, and Ghent. This use case exemplifies the infrastructure gaps along high-volume freight corridors where both CCS and MCS availability are essential.



(a)



(b)

Figure 17 UC 722 Gothenburg, Sweden to Ghent, Belgium (a) map view for UC722, (b) charging station mapping

The charging station mapping including the 18 locations of UC 722 (purple) from Gothenburg, Sweden to Ghent, Belgium is listed in Table X.

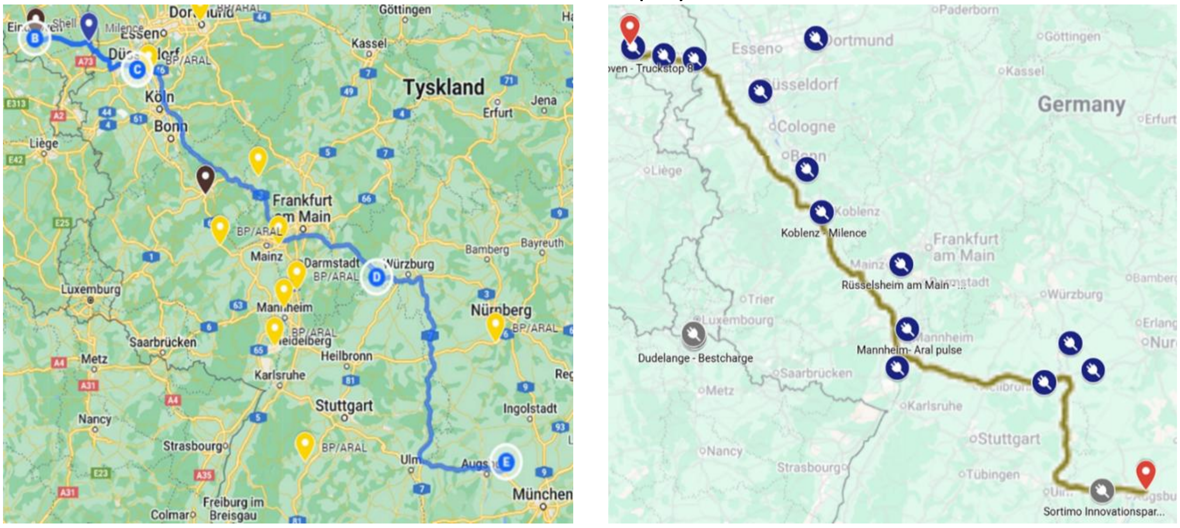
Table X Charging Infrastructure Mapping on UC 722 Route

Use Case Vehicle Type					
Charging Station Name	**No. of Ports**	**Power Level (kW)**	**Status**	**Charger Port type**	**Address**
Volvo Truck	1	-	Ready (ZEFES)	CCS	Gropegårdsgatan, 417 15 Göteborg (through ZEFES)
Volvo Truck Center	1	-	Ready (ZEFES)	CCS	Trintegatan, 253 68 Helsingborg (through ZEFES)
Volvo	1	-	Ready (ZEFES)	CCS	Smalleheerweg, 9041 Gent (through ZEFES)
Raststätte Lipperland	1	-	Ready	MCS	Am Speckenbach 30, 32107 Bad Salzuflen (HoLa project)

GITO	2	350	Ready	CCS	Oljehamnsleden, 252 25 Helsingborg, Sweden
Circle-K	10	400	Ready	CCS	Rusthållsgatan 51, 253 61 Helsingborg, Sweden
GITO	4	350	Ready	CCS	Trintegatan 2, 253 68 Helsingborg, Sweden
Circle-K	4 &4	360 & 300	Ready	CCS	Snapparp östra 1, 312 91 Laholm, Sweden
OKQ8 Halmstad	2	360	Ready	CCS	Laholmsvägen 206, 302 60 Halmstad
Verberg Einride	4&6	400 & 300	Ready	CCS	Pollengatan 4, 432 48 Varberg, Sweden
Milence	8	400	Ready	CCS	Pollengatan 10, 432 48 Varberg, Sweden
EON Drive	5	400	Ready	CCS	Høje Taastrup, Estland Alle 3, 2630 Taastrup
Eon Drive	8	400	Ready	CCS	Hamburg Port, Altenwerder Hauptdeich, 21129 Hamburg, Germany
Aral Pulse	12	300	Ready	CCS	Amandus-Stubbe-Straße6, 22113 Hamburg
Shell	4	360	Ready	CCS	Georgswerder Bogen 12, 21109 Hamburg
Milence (Venlo)	8	400	Ready	CCS	James Cookweg 31
Aral Pulse	1		End of 2025	MCS	An d. Autobahn 1, 29690 Buchholz (Aller), Germany
Aral Pulse	1		End of 2025	MCS	Am Leineufer 52, 30419 Hannover, Germany

5.2 UC 724: Munich, DE to Eindhoven, NL

To Use Case 7.2.4 considers parcel delivery operations by DPD, transporting goods from Munich (Germany) to Eindhoven (the Netherlands) with EMS1 configurations (25.25 m, 48 tonnes). The corridor relies on CCS charging hubs at Venlo, Eindhoven, Zusmarshausen, Koblenz, and Rebro, with multiple sites planned for commissioning by 2025. This scenario underscores the role of CCS-based infrastructure as a transitional backbone while MCS deployment remains limited.



(a) (b)

Figure 18 UC 724 Munich, Germany to Eindhoven, the Netherlands (a) map view for UC724, (b) charging station mapping on UC 724

The charging station mapping including the 20 locations of UC 724 from Munich, Germany to Eindhoven, Netherland is listed in Table XI.

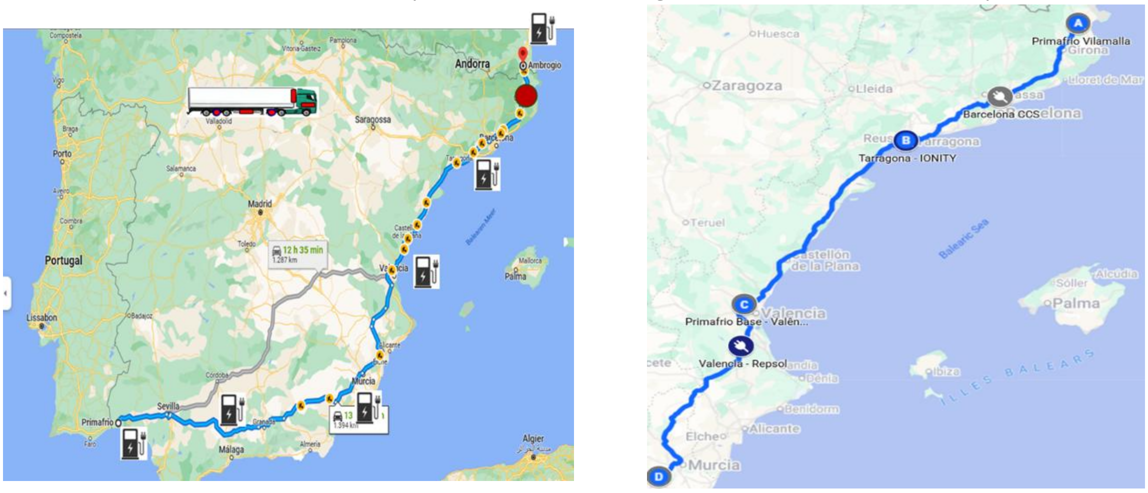
Table XI Charging Infrastructure Mapping on UC 724 Route

Use Case Vehicle Type					
Charging Station Name	**No. of Ports**	**Power Level (kW)**	**Status**	**Charger Port type**	**Address**
SIZ Charging Hub	20	300	Ready	CCS	Am Innovationspark 2, 86441 Zusmarshausen, Germany
Milence	8	400	Ready	CCS	Von-Humboldt-Straße 5/2, 74592 Kirchberg an der Jagst, Germany

Aral Pulse	2	300	Ready	CCS	Am Eichelberg 1, 91567 Herrieden, Germany
Aral Pulse	2	300	Ready	CCS	Baukreativstraße 7, 91628 Steinsfeld, Germany
Aral Pulse	2	300	Ready	CCS	Mainzer Str. 95, 65428 Rüsselsheim am Main, Germany
Milence	8	400	Ready	CCS	Im Sinderfeld 1, 56072 Koblenz, Germany
Aral Pulse	8	300	Ready	CCS	Gewerbegebiet, Gewerbepark Dachsberg 8, 53604 Bad Honnef, Germany
Aral Pulse	10	300	Ready	CCS	Münchener Str. 300, 40589 Düsseldorf, Germany
Milence	8	400	Ready	CCS	James Cookweg 31, 5928 LJ Venlo, the Netherlands
Greenpoint	4	400	Ready	CCS	Florapark 1, 5721 SZ Asten, the Netherlands
Shell	8	300	Ready	CCS	Het Schakelplein 30, 5651 CA Eindhoven, the Netherlands

5.3 UC 733: Murcia ES to Le Boulou, FR

Use case 7.3.3 features Primafrío's cross-border transport between Spain and France using temperature-cooled e-trailer, requiring a hybrid network of CCS, MCS, as well as e-trailer charging at 400 V. This use case focuses on temperature-controlled goods that need to be transported.



(a) (b)

Figure 19 UC 733 Huelva, Spain to Le Boulou, France (a) map view for UC733, (b) charging station mapping on UC 733

The charging station mapping including the 20 locations of UC 733 from Huelva, Spain to Le Boulou, France is listed in Table XII.

Table XII Charging Infrastructure Mapping on UC 733Route

Use Case Vehicle Type					
Charging Station Name	**No. of Ports**	**Power Level (kW)**	**Status**	**Charger Port type**	**Address**
Repsol	2	120	Ready	CCS	CR. A-7, PK 379, 5 M.D, 46292 Dir, Valencia, Spain
Primafrio Murcia	1		Planning	CCS	Carr. de Cadiz, Salida 596, 30840 Alhama de Murcia, Murcia, Spain
Primafrio Valencia	1		Planning	CCS	Calle Ue Sector I-1, 9J, 46184, Valencia, Spain
Primafrio Vilamalla	1		Planning	MCS	Avinguda d'Europa, 16-22, 17469 Vilamalla, Girona, Spain
IONITY Tarragona	1	350	Ready	CCS	Carrer del Llibreters, 8, 43204 Reus, Tarragona, Spain

6 Challenges on Charging Station Deployment

6.1 Site availability and special requirements

Despite several planned charging sites across Europe, the spatial and operational accessibility for heavy-duty trucks remains a critical limitation. Many existing CCS locations are technically functional but physically unsuitable for long truck-trailer combinations due to limited manoeuvring space, inadequate parking geometry, and insufficient entry or exit clearances. This restricts their usability for cross-border freight routes involving extended vehicle lengths (up to 32 m) and high gross weights (up to 64 tons). In contrast, MCS infrastructure is still in the early deployment stage, with projects such as HoLa (Germany), ABB–MAN (Munich), and planned sites in Hamburg, Dudelange, and Mechelen yet to become operational. The limited operational readiness of MCS locations poses logistical challenges for planned long-haul routes, requiring fallback reliance on lower-power CCS sites. Moreover, the geographic distribution of high-power sites does not yet align with real freight corridors or ferry terminals, creating coverage gaps between strategic nodes such as Gothenburg, Ghent, Hamburg, and Zeebrugge. These gaps complicate route planning and require additional mapping of grid capacity, land-use compatibility, and cross-border energy regulations. Consequently, effective CCS/MCS infrastructure mapping must address both technical grid feasibility and spatial accessibility for truck operations, ensuring continuity, reliability, and interoperability along trans-European transport corridors.

6.2 Standardization and technological readiness

This challenge is primarily rooted in the uneven technological maturity and lack of harmonized standards across Europe. While CCS technology is commercially available, its current power levels (≤400 kW) are insufficient for heavy-duty truck applications, and interface compatibility across manufacturers remains inconsistent. Conversely, the MCS standard is still under development, with only prototype demonstrations, such as those by ABB–MAN and the HoLa project, indicating early-stage readiness. The absence of finalized MCS connector standards, communication protocols, and grid integration guidelines hamper large-scale deployment and interoperability. Furthermore, variations in national permitting procedures, connector configurations, and software control architectures complicate cross-border operations. Collectively, these issues delay coordinated infrastructure roll-out, impede interoperability between CCS and MCS systems, and increase investment uncertainty for operators planning high-power corridor charging networks.

6.3 Economic viability

When an EV is charged, especially at a high-power DC fast charging station, the charging point operator typically incurs two key cost components (1) Energy price (€/kWh) is mainly charged by the energy supplier based on the energy consumption by the consumer, (2) Grid tariff is charged by the DSO to cover the cost of maintaining, operating, and expanding the grid infrastructure. In countries like the Netherlands, where grid congestion is already a pressing issue, particularly in urban areas, DSOs have implemented increasingly granular and punitive grid tariffs for users with high peak loads [11]. This reflects a broader trend in grid tariff design, which aims to internalize the cost of grid strain and incentivize users to adopt more grid-friendly load profiles. Table XIIIillustrates this phenomenon with a breakdown of grid tariff categories from a Dutch DSO. The table shows a stepwise increase in monthly grid charges as the contracted peak capacity rises. These charges are not just marginal adjustments—they can dominate the overall operational expenses of a charging station, often eclipsing the energy costs themselves.

Table XIII An example of grid fee in the Netherlands. LV: < 1 kV; MV: > 1 kV; < 20 kV [12]

Connection Capacity	One-off Connection fee (€)	Annual fee to maintain the connection (€)
>175 kVA to 630 kVA via LV measurement	34,002	
>630 kVA to 1000 kVA via LV measurement	36,000	1,455
>1000 kVA to 1750 kVA via MV measurement	58,000	
>1750 kVA to 5000 kVA	330,000	3,642

Transport Capacity	Transportation Service			
	Fixed Rate	Variable Rate		
	Transport fee per month (€)	Contract fee per month per kW (€)	Double tariff per kWh (€)	Reactive Energy Fee per kVARh (€)
151 to 1500 kW	36.75	2.0250	0.0198	0.017
>1500 kW	230	1.8958	0.0198	0.017

A quantitative assessment was conducted to evaluate the contribution of grid-related expenses to the total levelized cost of a high-power charging infrastructure. The findings, illustrated in Figure 20, reveal that for a large-scale 3.5 MW charging station, grid transportation service fees account for approximately 18% of the annual levelized cost. These fees correspond to recurring operational expenses associated with the use of the distribution network, including peak-based charges levied by the DSO. In addition to the transportation tariff, grid connection costs which include the capital investment required to establish a dedicated grid connection capable of supporting such high loads represent a further 7% of the levelized cost, assuming a service life of 11.2 years.

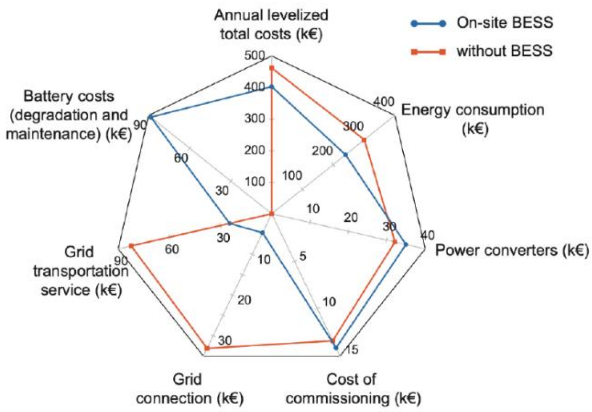


Figure 20 Annual levelized cost of a 3.5 MW charging station with and without BESS.

The following assumptions are made for the study: the peak load is 3.5 MW. In the case without BESS, the grid connection is 3.5 MVA. In the case with BESS, the grid connection is 1 MVA, and a 2.5 MW/2.5MWh battery energy storage is connected. LFP battery is used. The electricity price is flexible. The lifetime of the battery is 11.2 years under the given load profile.

6.4 Cross-border coordination

The fragmented regulatory frameworks, inconsistent infrastructure readiness, and heterogeneous technical standards across European countries are the reason behind for cross-border coordination issue. The multi-national use cases as examples, cross-border freight routes such as those connecting Sweden, Denmark, Germany, the Netherlands, Belgium, and France encounter discontinuities in charging availability, power levels, and accessibility. Differences in validation procedures, grid connection requirements, and energy pricing mechanisms hinder synchronized deployment of CCS and MCS infrastructure along trans-European transport corridors. Furthermore, variations in data-sharing practices, digital communication protocols, and interoperability certification impede seamless route planning and real-time charging management for logistics operators. The lack of coordinated investment strategies between national stakeholders and utility operators delays the establishment of continuous high-power charging corridors. Consequently, achieving operational continuity for long-haul zero-emission freight transport requires harmonized planning frameworks, cross-border infrastructure agreements, and unified European interoperability standards for CCS and MCS systems.

6.5 Grid and energy infrastructure constraints

Most charging systems rely on the electric power grid, the backbone of modern energy distribution, which now faces growing capacity constraints. Much of this infrastructure was built decades ago for lower, less variable demand. Although utilities have maintained and upgraded systems, overall capacity has not kept pace with rising electrification.

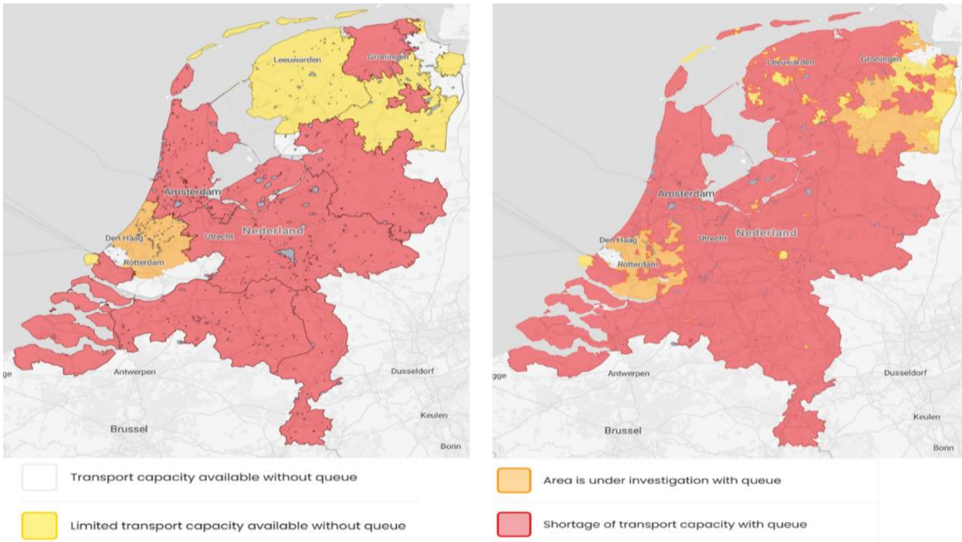


Figure 21 The example grid congestion in the Netherlands such as consumption congestion (left) and generation congestion (right) [13]

The concurrent integration of renewable energy which introducing intermittent supply and the rapid growth of electric vehicles also create high, concentrated charging loads. These integration issues have intensified stress on the grid. Consequently, it exposes structural weaknesses in grid resilience and highlights the urgent need for modernization to ensure reliability, flexibility, and stability in the evolving energy landscape. The challenge is most evident in densely populated and industrialized regions where electricity grids operate close to their technical limits. The Netherlands exemplifies this situation: despite being a leader in renewable energy and e-mobility, the country faces significant grid congestion. As shown in Figure 21, both consumers and energy suppliers encounter severe transport capacity constraints. In the red-marked regions, new customers requiring connections above 3×80 A experience delays of up to six to seven years. This prolonged waiting period highlights critical grid bottlenecks and underscores the urgent need for innovative measures such as local energy storage, demand-side management, and advanced grid planning.

According to use cases, the rapid expansion of both CCS and MCS networks is severely limited by the uneven availability of medium and high-voltage grid connections across Europe. The potential charging sites, including those planned in Hamburg, Dudelange, and Mechelen, lack immediate access to sufficient electrical capacity, necessitating costly and time-intensive grid reinforcement or substation upgrades. The integration of MCS imposes unprecedented demands on local distribution networks, often requiring new transformers, switchgear, and grid protection systems capable of managing transient power peaks and high continuous loads. There are limited feeder capacity and long utility lead times can cause the further delay for infrastructure commissioning in several cross-border corridors, particularly those spanning Sweden, Denmark, Germany, and Belgium. Moreover, the lack of standardized procedures for grid impact assessment and interconnection agreements across countries introduces administrative uncertainty, complicating project scheduling and cost estimation.

7 Possible Solutions to Mitigate the Challenges of Deployment

7.1 From R&D to Deployment: Technical pathways

7.1.1 Grid infrastructure advancement

Based on the selected use cases, strategically enhancing grid capacity, flexibility, and digital integration is essential to accelerate the deployment of high-power charging networks along trans-European freight corridors. TSOs should focus on medium- and high-voltage (MV/HV) grid extensions near major logistics hubs to enable direct connections for megawatt-scale chargers. Additionally, DSOs must ensure local grid reinforcement, deploy smart substations, and implement automated load management for stable operation. The integration of BESS, on-site renewables, and vehicle-to-grid (V2G) functionalities can buffer demand peaks and strengthen resilience. Coordinated TSO–DSO planning, supported by digitalized monitoring and cross-border harmonization of interconnection standards, will streamline permitting and enhance overall system efficiency. Simultaneously, the advancements in digital grid management including predictive analytics, real-time monitoring, and vehicle-to-grid (V2G) capabilities can optimize load balancing and improve operational efficiency.

7.1.2 Energy Storage Integration

The grid supply power to the charging site may be lower than the charging demand, at least at certain times of day. Shortfalls could be overcome using energy storage. Energy storage could allow less usage of the utility grid during peak electricity times. DER, including solar PV and backup generators, might also be beneficial in supporting site power needs. For these reasons, energy storage and DER integration are expected for megawatt charging sites. Today it is common practice to integrate these on the AC side of the EVSE as shown in Figure *24*. In the future, a more cost- and space-effective approach could be to integrate on the DC side as shown in Figure *22*, especially since BESS and Solar PV are DC supplies ash shown in Figure *23*. The possible MCS infrastructure with BESS can be improved by implementing the following approaches:

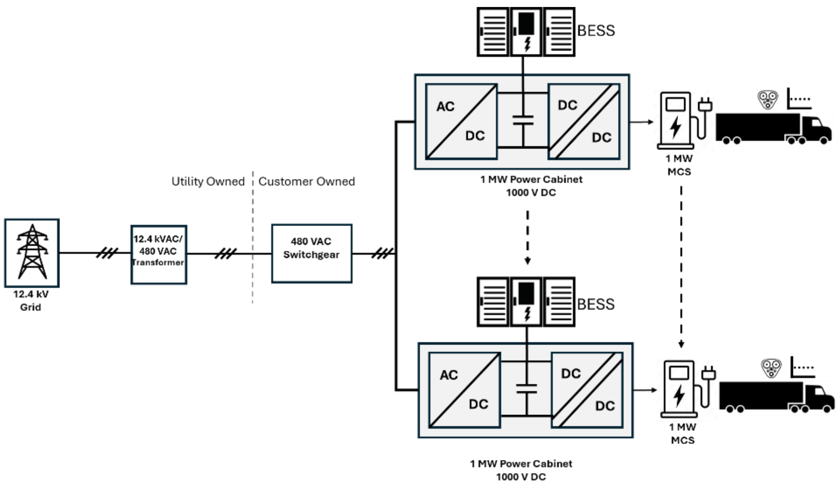


Figure 22 The distributed DC-BESS based Multi-MCS dispenser concept to ensure highest uptime of MW EVSE

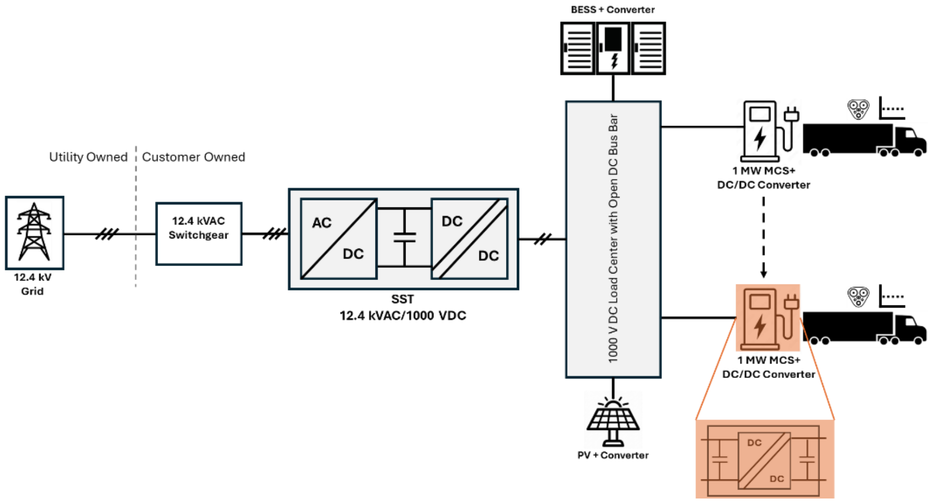


Figure 23 The renewable integration with DC-BESS based Multi-MCS dispenser concept to ensure reduced energy cost

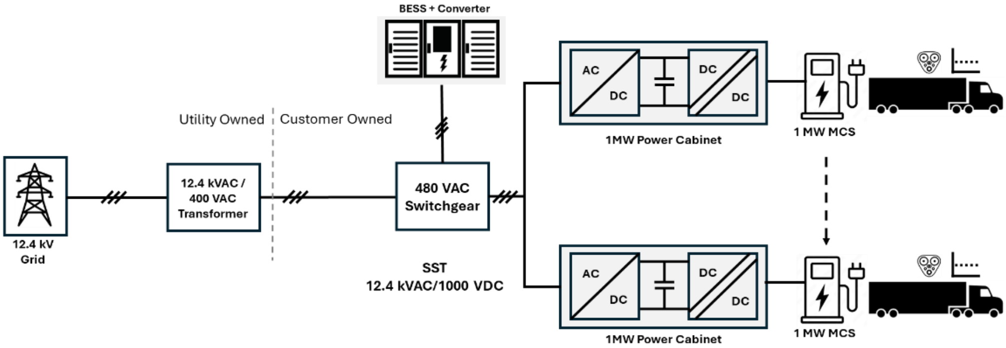


Figure 24 The AC-BESS based Multi-MCS dispenser concept to ensure reduced infrastructure cost

7.1.3 Smart charging and load management

Smart charging and load management present effective solutions to mitigate the deployment challenges of Charging Infrastructure (CCS and MCS) identified in the use cases. The dynamic adjustment of charging power based on grid capacity, vehicle demand, and energy pricing, smart charging systems can reduce peak load stress and defer costly grid reinforcement. Smart load management enables the coordinated operation of multiple chargers, ensuring optimal utilization of available electrical capacity, particularly in high-demand nodes such as Hamburg, Dudelange, and Venlo. The BESS incorporation further enhances flexibility by buffering energy during off-peak periods and supplying it during demand surges. Moreover, implementing V2G functionality supports grid stability and renewable energy integration. Thus, these digital and control-based strategies improve infrastructure efficiency, minimize operational bottlenecks, and enhance the economic and technical feasibility of large-scale CCS and MCS deployment across cross-border freight corridors.

7.2 Operational improvement

7.2.1 Charging demand uncertainty management

This management can be beneficial to all stakeholders such as grid operators, charging station operators, and fleet service providers. The robust forecast of charging power demand for day-ahead, hour-ahead, and 15-minute ahead to allow utilities to appropriately schedule power within their system. Charging station operators will want to maximize utilization of their EVSE to improve profitability. A clear forecast of expected charging through the coming days could allow station operators to incentivize their fleet customers to schedule charging at low utilization times. Charging station operators can also manage peak demands on their stations by scheduling truck charging and/or reducing charge power available to meet an agreed truck charging time. Maximum power management can enable the charging site to manage its charging services to be within the power capacity of its utility service and the EVSE rating. Fleets will require certainty that charging points are available for their trucks to use. Hence, a reservation system would be greatly beneficial. Additionally, fleets may want to adjust their operations to use charging stations at low utilization times of day when the cost of charging may be lower.

7.2.2 Advanced software tools incorporation

Software solutions could be developed to provide managed charging demand. These solutions could focus on three key aspects such as EVSE reservation system, integration of reservation system in FMS, and future load forecasting. Online reservation systems allow truck drivers to reserve charging slots in advance. This system could allow private depots to make their chargers available for other fleets to use, when not used by depot trucks. Reservation systems could be extended to register when trucks arrive and depart as well as effectively manage payments. The reservation systems would need to manage late or early arrivals. If the action is left with the truck driver making the booking, then the driver will need to book a longer window for charging than that required to charge the vehicle. This will lead to under-utilized EVSE, although the charging station operator might recover costs through a reservation charge. A sophisticated fleet will track its vehicles and expected arrival times at depots. Fleets can send messages to their drivers to slow their journeys to meet optimum arrival times and improve fuel efficiency. In addition, fleets can track delays in journeys and manage their depot docks accordingly. This approach of fleet-managed arrivals could be extended to the reservation system. The fleet management software could exchange data with the reservation system to provide improved management of dynamic reservation slots. In principle, reserved charging slots can provide a strong basis for forecasting charging demand. This could be supplemented by gathering data on seasonal variations in expected load demand, which can be extracted from historical EVSE usage data. Charging demand forecasting based on reservation systems is outside the current eTRUC program focus, although the demonstration sites will be able to provide initial data on variations in load demand from trucks visiting the locations.

7.2.3 Required High EVSE Uptime

High uptime is critical for megawatt-scale charging since the chargers become essential to trucking operations. In our surveys, the industry stated that uptime would need to be >97%. Additionally, high uptime should improve the return on investment for charging station operators easing financing for initial systems and upgrades. Two R&D approaches could improve uptimes: 1) remote monitoring of systems and prognostics, and 2) development of redundancy and self-healing designs. Remote monitoring systems can collect real-time data on key operating systems and enable immediate recognition of fault conditions. If a fault is detected, the remote operator can try to remotely reset the system and/or dispatch maintenance staff to service the faulty equipment. This can reduce the duration of any downtime and improve operational reliability. Prognostic systems seek to predict when maintenance conditions will occur in the future. The analysis is based on operational data including parameters such as voltage, current, ambient temperatures, and device operating temperatures. An effective means of improving uptime is for the EVSE to be resilient to internal faults. This would require a design having redundancy built in. If an equipment fault occurs, the EVSE could self-heal by shutting down (if necessary), switching out the faulty component, restarting (potentially in a limited power mode), and sending a service request to the remote monitoring station.

7.3 Funding Opportunities Utilization for Charging Infrastructure Development

The effective utilization of funding opportunities is a decisive factor in accelerating charging infrastructure development along the TEN-T corridors, particularly for large-scale CCS and MCS deployment as evidenced by the documented use cases. Many of these cross-border projects such as those spanning Sweden, Denmark, Germany, the Netherlands, Belgium, and France highlight the need for substantial public and private co-investment to overcome high capital costs, grid connection expenses, and initial low utilization rates.

7.3.1 CEF Transport Alternative Fuels Infrastructure Facility (AFIF) Funding Opportunities

The Connecting Europe Facility (CEF) and the Alternative Fuels Infrastructure Facility (AFIF) provide key European Union funding mechanisms that can be leveraged to support corridor-based charging hubs. These programs prioritize projects that enhance interoperability, cross-border continuity, and multimodal logistics integration criteria directly aligned with the use cases discussed, such as the HoLa Project (Germany) and ABB–MAN MCS pilot sites.

7.3.2 Horizon Europe and Innovation Action Funding Opportunities

The Horizon Europe and Innovation Fund programs can finance research and pre-commercial deployment of advanced technologies, including megawatt charging systems, smart grid integration, and digital energy management platforms. National co-financing and public-private partnerships (PPPs) can further complement EU-level support, ensuring financial viability and long-term operation.

7.3.3 Clean Transport Corridor Initiative

The Clean Transport Corridor Initiative, endorsed by nine EU Member States along the two transport corridors, will be highlighted at a signing ceremony of a Ministerial Declaration on truck recharging infrastructure in Brussels [14]. This initiative convened under the chairmanship of the EU Commissioner for Sustainable Transport and Tourism. The declaration sets out commitments to enhance cooperation and tackle key challenges, including lengthy planning and permitting processes, limited site availability, fragmented funding, insufficient grid capacity, and delays in electricity grid access. It represents both a joint political commitment and a strategic guide for current and future policies on truck recharging infrastructure.

8 Contribution

8.1 Contribution to ZEFES

Deliverable D3.6 “Mapping of Charging Stations” directly supports the ZEFES overall objectives as defined in the Description of the Action (DoA – Part B, pp. 5/6). Its core contribution lies in identifying and mapping the existing and planned charging and refuelling infrastructure along the ZEFES demonstration corridors for both BEVs and FCEVs. By accumulating geographic, technical, and operational data across EU, D3.6 provides:

- A reference infrastructure database for all ZEFES demonstration use cases (UC722–UC743).
- The foundation for energy system integration and logistics planning in WP4 (Demonstration Execution).
- Key insights into regional infrastructure readiness, grid connection feasibility, and deployment bottlenecks, guiding both OEM and logistics partners.

Hence, D3.6 directly contributes to the following ZEFES objectives (O):

O1: Demonstrate an interoperable Megawatt Charging System (MCS) and the location deployment strategy for hydrogen refuelling stations (HRS) to accommodate and make ZE HD transport possible along a number of corridors.

O2: demonstrate missions on cross-border, TEN-T corridors, fulfilling the requirements for range and payload, and comparing the BEVs and FCEVs deployment for different mission profiles.

In summary, D3.6 acts as a cross-cutting enabler for ZEFES technical, operational, and strategic targets by ensuring that infrastructure deployment aligns with the real-world demonstration needs.

8.2 Contribution to exploitable results

Deliverable D3.6 contributes to multiple exploitable results within ZEFES, particularly in the domains of process innovation, infrastructure planning, and policy development.

Exploitable Scope	Contribution of D3.6	Target User
Methodology	Structured methodology for identifying, classifying, and assessing charging sites for long-haul ZEVs.	OEMs, Fleet Operators, Infrastructure Planners
Database	GIS-based database of existing and planned HPC, MCS, and HRS sites across demonstration corridors.	WP4, WP5, WP6 partners; public agencies
Technical Result	Correlation between corridor logistics demand and infrastructure availability forming a basis for academic and industrial publications.	Research partners (VUB, TNO, Fraunhofer)
Strategic Recommendation	Evidence-based insights for TEN-T corridor planning, national infrastructure targets, and interoperability standards.	Policy makers, CINEA, EU Member States
Demonstration Readiness	Verified mapping ensures the demonstrators can plan charging stops within safe operational margins.	OEMs & Demonstration Leads (Volvo, Renault, Scania, Ford, Hyundai)

9 Conclusion and Recommendation

9.1 Conclusions

The mapping of charging stations has revealed significant progress in the deployment of High Power Charging infrastructure (HPC) with CCS for light and medium-duty vehicles, while MCS for heavy-duty long-haul applications remain in early deployment stages. The study identified several established charger locator platforms developed by various stakeholders. A few are specifically designed to support truck charging, while others include filters or indicators for truck suitability.

Main challenges and barriers identified:

- *Infrastructure readiness gaps:* Limited MCS-capable sites; uneven HRS coverage across corridors, especially in Eastern and Southern Europe.
- *Grid connection constraints:* Long permitting times and lack of high-capacity feeders for megawatt-level charging hubs.
- *Data availability issues:* Missing technical details from certain national databases or private operators.
- *Visibility over HD*-BEV compatible charging hubs: Site accessibility remains a challenge particularly for HD-BEVs with larger dimensions and higher tonnage. In some cases, manual confirmation with Charge Point Operators (CPOs) was necessary to verify station compatibility during the project.

Potential solutions and mitigations:

- *Temporary measures:* BESS and renewable integration DC charging units to ensure uninterrupted ZEFES demonstrations.
- *Collaborative grid planning:* Early coordination with DSOs and TSOs to secure power connections.
- *Standardization efforts:* Integration with ongoing CharIN MCS recommendations and AFIR-aligned site design guidelines. This includes requirements for HD-BEV site accessibility to provide certainty for truck operators planning their charging stop.

Most use cases (UC722–UC743) now have operationally viable routes with at least partial infrastructure coverage. For BEV routes, temporary charging solutions are planned where public HPC is insufficient. Overall, demonstration execution readiness exceeds 80% relative to initial DoA targets.

9.2 Recommendations

To ensure smooth demonstration execution and future scalability:

- *Infrastructure acceleration:* Engage with national authorities and private investors to fast-track MCS deployment along TEN-T corridors.
- *Data standardization:* Harmonize data exchange formats for charging site availability, capacity, and grid readiness.
- *Interoperability testing:* Conduct early interoperability trials between OEM charging systems and selected MCSs providers.
- *Dynamic planning tools:* Integrate the D3.6 database into the ZEFES Digital Twin Platform to support real-time logistics and energy optimization.
- *Post-demonstration exploitation:* Use the mapped data to define replicable corridor deployment models for European rollout beyond ZEFES.

10 Risks and interconnections

10.1 Risks/problems encountered

WP Ref	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
WP3	Delay in infrastructure data collection or incomplete datasets for some regions	2	1	Engage with national contact points, use open-data APIs, and validate through logistic partners
WP3/WP4	Infrastructure readiness not matching demo start timelines	1	1	Employ temporary chargers; reschedule demo phases where needed
WP3	Potential dependency on D3.5 (Infrastructure Requirements Definition) outcomes	2	1	Close coordination with D3.5 team; iterative update of maps
WP3/WP4	Regulatory or permitting delays for new installations	2	2	Early engagement with permitting authorities and site hosts

1) Probability risk will occur: 1 = high, 2 = medium, 3 = Low

10.2 Interconnections with other deliverables

Deliverable Ref	WPs	Dependency Description	Type of dependency
D7.1	WP7	Provides a detailed plan and availability of relevant documents to support all demonstrations related to charging sessions.	Document Support
D7.2	WP7	Provides the lists of charging sites, charging station type, corresponding use case vehicles, etc which will help perform demonstration	Information
D8.3	WP8	Provides necessary data regarding the high power charging stations along the use case routes to accelerate the use case evaluation precisely	Use case data
D8.4	WP8	Provides the charging station information regarding power level, technologies, and specific site which will help to assess the environmental impact due to charging the vehicles.	Information

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Project partners:

#	Partner short name	Partner Full Name
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2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
4	KAE	KASSBOHRER FAHRZEUGWERKE GMBH
5	REN	RENAULT TRUCKS SAS
6	SCA	SCANIA CV AB
7	VET	VAN ECK TRAILERS BV
8	VOL	VOLVO TECHNOLOGY AB
8.1	CPA	CPAC SYSTEMS AB
9	ABB	ABB E-MOBILITY BV
9.1	ABP	ABB E-MOBILITY SPOLKA Z OGRANICZONAODPOWIEDZIALNOSCIA
9.2	ABG	ABB E-MOBILITY GMBH
10	AVL	AVL LIST GMBH
11	CM	SOCIEDAD ESPANOLA DE CARBUROS METALICOS SA
11.1	APG	AIR PRODUCTS GMBH
12	HEPL	HITACHI ENERGY POLAND SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
13	MIC	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
14	POW	OPmobility
15	RIC-CZ	RICARDO PRAGUE S.R.O.
15.1	RIC-DE	RICARDO GMBH
16	UNR	UNIRESEARCH BV
17	ZF	ZF CV SYSTEMS HANNOVER GMBH
18	ALI	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE
19	DPD	DPD (NEDERLAND) B.V.
20	COL	ETABLISSEMENTEN FRANZ COLRUYT NV
21	GRU	GRUBER LOGISTICS S.P.A.
22	GBW	GEBRUEDER WEISS GESELLSCHAFT M.B.H.
23	PG	PROCTER & GAMBLE SERVICES COMPANY NV
23.1	PGP	PROCTER AND GAMBLE POLSKA SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
23.2	PGA	PROCTER & GAMBLE AMIENS
23.3	PGG	PROCTER & GAMBLE SERVICE GMBH
24	PRI	PRIMAFRIO CORPORACION, S.A.
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30	UIC	UNION INTERNATIONALE DES CHEMINS DE FER
31	CFL	CFL MULTIMODAL S.A.
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