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D3.4 Charging opportunity on a ferry/rail-wagon

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Project summary

Within the ZEFES project that explores zero-emission solutions for long-haul freight transport across Europe, deliverable D3.4 investigates the feasibility of charging electric heavy-duty vehicles during ferry and rail transport. It evaluates current technologies, operational constraints, and regulatory frameworks.

The study highlights the challenges of onboard charging due to limited energy storage and safety concerns. Terminal-based charging is identified as a more practical alternative to onboard charging solutions. For rail, modular systems like the SWS-PowerBox offer promising solutions for e-reefer charging.

Publishable summary

As part of the Horizon Europe ZEFES project, Deliverable D3.4 explores the feasibility of implementing charging infrastructure for electric heavy-duty vehicles (e-trucks and e-trailers) during ferry and rail transport with the objective to provide greater flexibility to the drivers. The report evaluates the current state of charging technologies, operational constraints, and regulatory frameworks.

For ferries, the study finds that while the implementation of charging stations on ferries is technically feasible, their limited onboard battery capacity, as well as safety and sustainability concerns make truck charging onboard largely impractical. Terminal-based charging is identified as a more feasible alternative, especially as ports increasingly invest in high-capacity grid connections and charging infrastructure.

For rail, two charging concepts are examined: the SWS-PowerBox—a self-contained, wagon-mounted energy system—and head-end power (HEP) solutions. Given the flexibility and lower regulatory burden, the SWS-PowerBox is identified as the most feasible charging concept for e-reefers today.

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Abbreviations

Abbreviation	Explanation
AC	Alternate current
BEV	Battery electric vehicle
CAPEX	Capital expenditure
CCS	Combined charging system
DC	Direct current
EV	Electric vehicle

FCEV	Fuel-cell electric vehicle
GHG	Greenhouse gas
HDV	Heavy-duty vehicle
HEP	Head-end power
HRS	Hydrogen refuelling station
LNG	Liquefied natural gas
MCS	Megawatt charging system
OEM	Original equipment manufacturer
OPEX	Operational expenditure
Reefer	Loading unit to transport temperature-controlled cargo
RoRo	Roll-on/roll-off
TSI	Technical Specifications for Interoperability
V_{AC}	Voltage in alternate current
V_{DC}	Voltage in direct current

1 Introduction

This report is part of Work Package (WP) 3 *Advanced Fast Charging Concepts and Hydrogen Refuelling Stations (HRS) for BEV and FCEV*, aiming primarily at implementing and demonstrating advanced fast charging concepts.

This report, Deliverable D3.4, investigates the technical, operational, and regulatory feasibility of implementing charging infrastructure on ferries and rail wagons. It examines relevant ZEFES use cases, evaluates current technologies, and identifies barriers and enablers for deployment.

1.1 Motivation

Heavy-duty vehicles (HDVs) including trucks, buses and coaches, are responsible for more than a quarter of greenhouse gas (GHG) emissions from road transport in the EU, and for over 6% of total EU GHG emissions. In the context of the European Green Deal, the EU has adopted emission standards for HDVs, which will become increasingly strict over time, starting with 45% CO_2 emission reduction by 2030 to 100% by 2050 [2]. In addition to regulatory pressure and governmental incentives around transport electrification, falling battery prices have been a driving factor for the electrification of heavy-duty trucks. According to the IEA Global EV Outlook, by 2030, one out of 4 medium- and heavy truck registrations in Europe is going to be electric [1].

A successful rollout of electrified long-haul freight transport heavily relies on the availability of a dense network of charging stations along the route across Europe. Providing sufficient opportunity charging infrastructure, long vehicle downtimes can be minimized, and operational efficiency be improved. By avoiding deep discharges, the average battery lifetime can also be improved.

Today’s long-haul transport routes can involve other modes of transport, including rail and ferry transport. This might open interesting opportunities to use the time that e-trucks or e-trailers are transported for charging.

1.2 Scope

This deliverable focuses on evaluating the technical, operational, and regulatory feasibility of implementing opportunity charging solutions for electric heavy-duty vehicles (e-trucks and e-trailers) during ferry and rail transport. Specifically, it aims to:

- Map the current state-of-the-art in charging infrastructure on ferries and rail wagons, including onboard and terminal-based systems.
- Analyze use cases from the ZEFES project to assess the practical viability and technical constraints of integrating charging systems into this multimodal logistics chains.
- Examine regulatory frameworks and approval processes.

While this report explores the technical and regulatory aspects of charging electric trucks and trailers during ferry and rail transport, it does not include a detailed analysis of the economic costs or financial feasibility of implementing such solutions.

1.3 Stakeholder contributions

Valuable input for this study was collected during interviews with the following stakeholders:

Acronym	Full Name	Industry
SLI	Scandlines	Ferry operator
DFDS	Det Forenede Dampskibs-Selskab A/S	Shipping & locigistics company
FL	Finnlines	Ferry operator
ALICE	Alliance for Logistics Innovation through Collaboration in Europe	Logistics technology platform
CFL	CFL Terminals	Multimodal terminal operator
UIC	Union Internationale des Chemins de Fer	Rail union
SWS	SWS Power Solutions	Charging solution provider (rail)

2 Charging Opportunities on Ferries

Electric truck charging on ferries is emerging as a potential solution to support zero-emission logistics across maritime routes, especially as they become more common in long-haul transport. This chapter begins in Section 2.1 by reviewing the current state of EV charging on ferries and at terminals, noting that existing services are limited to passenger vehicles and not yet designed for e-trucks. Building on this, Section 2.2 provides a technical overview of vessel electrical systems, with real-world examples of electric vessels. Section 2.3 then addresses the regulatory challenges, highlighting the absence of clear international standards for onboard EV charging and the reliance on classification societies to assess safety through risk-based approvals. This leads into Section 2.4, which evaluates the feasibility of implementing e-truck charging on ferries, identifying key challenges such as limited onboard energy storage, short trip durations, fleet variability, and safety concerns. It also introduces terminal-based charging as a more practical near-term alternative. Finally, Section 2.5 discusses ZEFES use cases, concluding that while onboard charging is technically feasible, infrastructure and operational constraints currently make terminal-based solutions more viable.

2.1 Status

This section provides an overview of the current state of EV charging opportunities on ferries and at port facilities, beginning with examples of existing services as well as a short overview of the vessel's electrical architecture. Focus here are electric ferries as they have the highest potential to provide sustainable e-truck charging among today's vessel technologies.
Subsequently, different feasibility criteria for onboard charging are discussed before applying them to the ZEFES use cases.

2.1.1 Available charging services on ferries

As electric vehicles (EVs) become increasingly common, ferry operators are beginning to adapt by offering charging services both onboard and at port facilities. However, the rollout of such infrastructure is uneven, shaped by technical, economic, and regulatory challenges. According to [1], the main barriers to wider adoption so far include:

- High installation (CAPEX) and operational costs (OPEX)
- Safety concerns, particularly related to fire risks
- Low occupancy rates of charging stations
- Regulatory complexity and lack of standardized business models

It is important to highlight that all EV charging services currently available onboard are designed for passenger cars, not for trucks. Some examples are provided below.

- **TT-Line** [4]
  - Route: Travemünde (Germany) – Trelleborg (Sweden)
  - Ship Name: Peter Pan, Nils Holgersson
  - Power Source: Liquefied natural gas (LNG)
  - Charging Setup: 32 charging points, both 40 kW DC (CCS Combo connector) and 11 kW AC (Type 2 connector); the use of own charging cables is not permitted.

- **Fjordline** [5][6]
  - Route: Hirtshals (Denmark) – Kristiansand (Norway)
  - Ship Name: Fjord FSTR
  - Power Source: Diesel engine, 36.4 MW
  - Charging Setup: 16 Type 2 charging points, up to 22 kW; passengers must bring their own cable

- **Molslinjen** [7][8][9]
  - Route: Aarhus (Denmark) – Odden (Denmark)
  - Ship Name: HSC Express 2
  - Power Source: Diesel engine, 36 MW
  - Charging Setup: Two onboard charging points with sockets and cables for both Type 1 and Type 2 plugs

- **Öresundslinjen** [10][20]
  - Route: Helsingborg (Sweden) – Helsingør (Denmark)
  - Ship Names: Tycho Brahe
  - Power Source: Fully electric propulsion, 4 MWh battery capacity
  - Charging Setup: Eight onboard DC charging points, up to 160 kW each; over 600 kW combined charging power
  - Details: Approved by Danish and Swedish authorities and Lloyd's Register.

- **Stena Line** [11][12]
  - Route: Kiel – Gothenburg
  - Ship Name: Stena Scandinavica
  - Power Source: Diesel-powered
  - Charging Setup: Three charging stations onboard, supporting up to 6 EVs
  - Details: Charging is conducted during overnight crossings, which have a duration of 14 hours

2.1.2 Terminal-based charging services for e-trucks

Many ferry operators have opted to provide EV charging in terminals at port facilities rather than onboard, often in partnership with third-party providers. Focusing on e-truck charging infrastructure, examples include:

- **Port of Antwerp, Belgium:** Milence, the joint venture between Daimler Truck, the TRATON Group and Volvo Group, has deployed 20 400 kW CCS chargers, as well as two 1.4 MW MCS [49].

- **Gothenburg, Sweden:** DFDS, an international shipping and logistics company, is currently establishing Sweden's largest e-truck charging depot, featuring 38 charging points [50].

- **Port of Rotterdam, Netherlands:** At the Waalhaven Truck Park, 2 360 kW, and 6 180 kW charging points are available [51].

- **Port of Hamburg, Germany:** E.ON is operating four 400 kW charging stations [52].

2.2 Technology overview

In this section, a description of common electrical architectures on vessels and strategies for implementing charging equipment is provided. Focus here are electric ferries as they are currently the most viable candidates for implementing onboard charging from a sustainability perspective.

2.2.1 Onboard architecture of vessels

The maritime industry is increasingly shifting toward electrification to meet stringent environmental regulations and reduce greenhouse gas emissions. Electrification of ships is a key part of this shift, with increasing adoption of advanced power electronics, batteries, and fuel cells. Two main electrical architectures are used in vessels: AC and DC. Each has its own strengths and limitations, and the choice between them depends on the vessel's size, operational profile, and energy sources [1][14][15].

Traditionally, shipboard electrical systems have relied predominantly on AC-based distribution due to its simplicity, established infrastructure, and inherent advantages in protection. AC systems are particularly suitable for large vessels, such as cruise ships and offshore platforms. They benefit from natural current zero-crossing, which simplifies fault detection and circuit interruption. However, they also require complex control strategies to manage synchronization, frequency, and reactive power. Moreover, the integration of modern energy sources such as batteries and fuel cells often necessitates multiple conversion stages, leading to reduced overall efficiency. AC systems also tend to be bulkier, requiring larger conductors and transformers due to skin effect and reactive components, which can be a disadvantage in space-constrained marine environments.

In contrast, DC-based systems are increasingly being adopted in modern vessels, particularly in ferries and hybrid ships. These systems offer higher efficiency by enabling direct integration of DC-based energy sources and reducing the number of power conversion stages, making them ideal for hybrid and fully electric ships. DC systems also allow for simpler control, as they eliminate the need for frequency and phase management. One of the most significant advantages of DC distribution is the ability to operate generators at variable speeds, optimizing fuel consumption and reducing emissions. Additionally, DC systems support more compact and lightweight designs, which is particularly beneficial for shipbuilders aiming to maximize usable space and reduce weight.

Several real-world electric vessels showcase the growing capabilities and diversity of battery-powered maritime transport. The MV Wolfe Islander IV, operating between Kingston, Ontario and Wolfe Island, serves a route of 20 minutes and approximately 5.5 kilometres across Lake Ontario [16]. It is equipped with a 4.6 MWh Leclanché battery system at 930 V and serves as a fully electric ferry with zero emissions [1][17]. It is supported by a 3 MWh onshore battery energy storage system to enable fast charging without overloading the local grid. The MS Yara Birkeland, a 3.2 MW autonomous cargo ship in Norway, is powered by a 7 MWh battery and designed for short-sea shipping with zero emissions [1][18]. Another ambitious project is Incat Hull 096, constructed in Tasmania, which features a massive 40 MWh battery system, design for a route of about 72 km [19]. Meanwhile, the Öresundslinjen ferries MF Tycho Brahe, operating between Helsingør, Denmark, and Helsingborg, Sweden, are fully electric with 4 MWh battery systems [20]. This ferry is charged at both ends of its 20-minute route using a robotic arm that delivers 10.5 MW of power (10.5 kV, 600 A) for 6 minutes in Denmark and 9 minutes in Sweden. The onboard batteries operate at 800 V and are charged via a 10.5 kV input transformer that steps down to 750 V before conversion to DC. To preserve battery life, the state of charge is maintained between 40% and 66% [21], with each trip consuming approximately 1,175 kWh. These vessels demonstrate how electric propulsion, supported by smart charging infrastructure and energy management, is already delivering reliable, efficient, and sustainable maritime transport across a range of vessel types and routes. However, most electric ferries currently in service are limited to short-distance routes. This reflects the present limitations of battery technology, where energy density, charging time, and infrastructure still constrain electric propulsion to short-haul operations.

2.2.2 Integration of charging equipment

For DC-based vessels, integration may be relatively straightforward, potentially requiring only a single stage using isolated DC/DC converters [22] directly connected to the main DC bus. Commercialized DC charging solutions have compatible input voltages as mentioned above, e.g., below 1 kV [23]. In contrast, AC-based vessels likely need two stages, incorporating both an AC/DC conversion stage and a subsequent DC/DC stage, which could result in lower overall efficiency.

2.3 Approval process & regulatory challenges

Despite an increasing number of operating vessels equipped with EV charging stations, there is still a lack of clear guidelines in place that address minimum technical and safety requirements. Below, a short overview of the certification process for novel vessel concepts is provided before discussing recent research initiatives aimed at bridging regulatory gaps.

2.3.1 Regulatory bodies

Several regulatory bodies oversee the safety, compliance, and environmental standards for ferries. Key organizations include:

- The International Maritime Organization (IMO) is a specialized agency of the United Nations and sets global standards for safety, security, and environmental performance of international shipping. Its SOLAS (Safety of Life at Sea) convention sets out the minimum standards for the construction, equipment, and operation of ships. IMO's MARPOL (International Convention for the Prevention of Pollution from ships) convention covers measures to minimize pollution of oceans and seas.

- The flag state authorities under which the ship is registered are responsible for ensuring that the vessel complies with the regulations set by the IMO and any additional national maritime regulations. Flag states can authorize classification societies to act on their behalf to carry out statutory surveys and certification work of their ships.

- Classification societies like Lloyd's Register, DNV, or Bureau Veritas provide technical standards for the design, construction and operation of ships. They ensure that ships, old and new, meet their obligations set by the IMO and national regulations and standards.

Any ship that is entering a port or waterways is required to obtain a classification certificate issued by a classification society. Together with the ship's owner and/or ship's builder, the classification society reviews ship designs to ensure all relevant standards are met. In the case of novel concepts that are not fully covered by existing classification rules, classification societies rely on a risk-based approach to classification. During such an "Approval in principle" (AiP) process, different risk assessment techniques are used to ensure that the novel design or technology provides an acceptable level of safety equivalent to current industry practices.
While an AiP does not directly lead to the final classification approval, it helps identifying issues at an early stage and can clarify the key points of the design that need to be cleared. Depending on the complexity of the new designs and by closely collaborating with classification societies throughout the development, construction and testing phase, the whole classification approval process may be completed within several months or up to two years.

2.3.2 Regulations & guidelines for EV equipment onboard

Safety requirements for transporting and charging electric vehicles are still not clearly defined in the SOLAS convention. According to the IMO Sub-Committee on Ship Systems and Equipment (SSE11), a roadmap and goal-based approach for developing fire safety systems and arrangements to reduce the fire risk of ships carrying new energy vehicles, including battery electric vehicles (BEVs) is currently developed [43].

Until there exist clear guidelines from IMO, it is mainly on the classification societies to assess the safety and reliability of charging equipment on board. The examples given in Section 2.1.1 are a clear indication that approvals can be obtained despite a current lack of international regulations.

In recent years, the safety of electric charging equipment on vessels was also investigated in different research projects. In the ALBERO project [44], research organizations, classification societies, as well as ferry and port operators developed a requirement catalog for the layout of charging stations onboard of ro-ro-ferries [45]. In this work, the need for special considerations due to the unique environmental conditions on board is emphasized, such as vibration resistance, explosion protection, and integration with the ship’s power management system. Also highlighted is the importance of safety measures, including electrical protection, fire prevention, and monitoring systems to ensure safe operation. An interesting conclusion of this project is the recommendation to limit the state-of-charge (SoC) of electric vehicles onboard to 50%. The authors argue that higher SoC levels influence the growth and peak heat release rate in the case of a battery fire, leading to a faster and heat release in higher heat peaks. While this remains a recommendation that is currently not enforced on vessels carrying EVs, implementing the SoC limit could heavily impact the feasibility of on-board charging.

The aim of the EU-funded LASH Fire project [46], on the other hand, was to develop and demonstrate measures to reduce the risk of fires on board ro-ro ships, including in the context of electrical vehicle charging. Recommendations included the implementation of proper electrical insulation, ground and, and protection against short circuits and over currents, as well as the establishment of safety protocols and guidelines for handling charging equipment (e.g. storage of charging cables). Furthermore, real-time monitoring of charging status, power usage and temperature, and automated control systems for load management were suggested.

2.3.3 Regulations & guidelines for EV charging equipment ashore

Apart from cases where the charging equipment is exposed to harsh weather conditions, conventional standards apply. For details on applicable guidelines for the installation and operation of EV charging equipment, especially for MCS installations, see for example *D3.1 Performance of the IMCS concept (VC11) - Charging functionality and control strategies performances [55].*

2.4 Feasibility criteria

2.4.1 Charging on ferries

At the time of this report, charging equipment on ferries was limited to passenger vehicles. While from a technical perspective we have seen that it is possible to integrate equipment for charging electric trucks, there are a variety of factors that limit its overall feasibility. Below we are discussing the most relevant aspects, focusing primarily on operational and legal feasibility criteria.

2.4.1.1 Sustainability

Onboard EV charging systems on ferries typically draw power from the vessel's primary propulsion source. For long-distance routes, diesel engines remain dominant due to their high energy density and reliability. However, using diesel-generated electricity to charge electric vehicles negates the environmental advantages of zero-emission transport, effectively shifting emissions rather than reducing them.

Alternative fuels like LNG promise a reduction of CO_2 emissions, however, their adoption is still limited, and the emissions of unburnt methane (so-called methane slip) has been recognized as an issue that can partially undermine the environmental benefits of LNG [58]. For hybrid propulsion systems—combining diesel engines with electric motors it is critical to evaluate whether energy allocated to EV charging compromises the ferry's own potential for cleaner operation, particularly when electric power could otherwise reduce propulsion-related emissions.

From a sustainability standpoint, only fully electric ferries bear the potential of providing energy with a very low carbon footprint and are therefore the most attractive choice for implementing e-truck charging solutions today.

Since 2018, the EU monitoring, reporting and verification (MRV) regulation requires operators of large ships (more than 5000 gross tonnage) to report carbon emissions, fuel consumption and other related parameters on voyages to, from and between EU Member State ports [47]. Non-compliance can lead to fines, port access restrictions, or operational limits. As such, evaluating charging solutions through a sustainability lens is not only environmentally responsible but also economically relevant.

2.4.1.2 Trip duration

As discussed in Chapter 2.2.1, electric ferries are currently limited to short-distance routes with trip durations often below one hour. Consequently, the time that is available for the charging operation is very limited. Charging the e-trucks described in Chapter 1.1 takes around 45 minutes using megawatt charging, while it can take up to 4 hours when charging at an CCS2 point. For many scenarios, arriving at the final ferry destination with a full charge is therefore unlikely, even when the ferry is equipped with a megawatt charging station.

Instead of aiming at charging e-trucks, an alternative approach could be to focus primarily on charging e-reefers (refrigerated trailers) and e-trailers during transport. Already today, trucks with diesel-powered reefers are obliged to plug the reefers during transport in order to reduce noise and emissions. The challenge here, however, is the limited charging speed that trailer-compatible charging equipment provides[1].

2.4.1.3 Fleet composition

Most ferry routes are serviced by a fleet of vessels that may vary in model and propulsion technology. Especially for shorter routes with frequent departures, fleet operators offer open bookings to provide drivers with greater flexibility, eliminating the need for fixed time reservations. To ensure that e-truck drivers have reliable access to onboard charging points regardless of their arrival time at the terminal, it is crucial that all, or at least the majority, of ferries on a given route are equipped with charging stations. This means that ferry operators must adopt a comprehensive approach, planning to retrofit their entire fleet operating on that route with the necessary charging infrastructure, rather than focusing on individual vessels.

2.4.1.4 Availability of energy storage

One of the biggest concerns raised when discussing charging opportunities on ferries with various ferry operators was the lack of battery capacity for ramping up charging installations on board their electric ferries. With typical onboard energy storage in the order of a few MWh (see Section 2.2.1 for detailed examples), the energy demand of charging multiple e-trucks – each equipped with 600-750 kWh batteries - would require a significant scaling of the ferry’s energy storage.

The optimal battery size for a vessel is determined by physical constraints such as weight distribution and volume but also depends on other key factors such as the route length, schedule and available charging infrastructure at docking points [48]. In addition to higher investments, a larger battery usually results in higher energy consumption due to increased weight and a decrease of available space on the vessel. Hence, scaling the energy storage quickly reaches an upper limit, leaving limited or no margin for additional applications.

2.4.1.5 Safety concerns

As discussed in Chapter 2.3, there are currently still a regulatory gap from the IMO regarding safety requirements and various ferry operators have banned EVs due to safety concerns associated with EV batteries. On the other hand, as discussed in Chapter 2.1.1, there are multiple examples of ferry operators that do not only transport EVs but are already offering EV charging on their routes with necessary approvals in place. During the interviews, ferry operators mentioned a variety of initiatives to address fire safety concerns, ranging from introducing registration systems for EVs, regular risk assessments to updated safety procedures, additional crew trainings and

[1] The speed of the charging depends also on the capacity of the battery.

collaborations with start-ups such as EVtinguish [53] who are developing products to control and extinguish EV fires in narrow spaces.

2.4.1.6 Additional technical requirements

Charging stations on vessel are exposed to other environmental conditions as those ashore and should therefore be designed with additional requirements in mind [45]. With the exposure to spray water and a salty atmosphere, the electrical protection class needs to be adapted. Electrical equipment must be approved for use in ex-protection areas, with specific requirements for different deck levels. Charging stations should undergo additional vibration testing (not mandatory for charging stations ashore) as well as function tests in inclined positions. Additionally, stations must ensure electromagnetic compatibility, handle voltage and frequency deviations, and integrate into the ship's power management system for safe operation.

2.4.2 Charging at the ferry terminal

Given the various challenges of implementing e-truck charging on ferries, it is worth exploring alternatives ashore. While the number of ferry terminals with dedicated e-truck charging facilities is increasing, they remain an exception. From a technical implementation, the charging infrastructure at terminals is similar to other installations, but there are additional considerations to address:

2.4.2.1 Power availability

The availability of an adequate power infrastructure is one of the most critical requirements when assessing locations for e-truck charging systems. In recent years, many terminals have invested in their power infrastructure to meet growing power demands for charging electric vessels. This enhancement may present significant opportunities to implement additional charging infrastructure for e-trucks. In cases where ferries are charged during the short period of boarding and embarking at the terminal, the intervals between ferry charging operations may be utilized to supply power to e-truck charging installations.

The required power to charge EVs will depend on the number of MCS chargers at the location and their use profiles, so specific studies should be performed to assess power requirements from the grid and to dimension the charging installation accordingly.

2.4.2.2 Integration with terminal operations

To ensure smooth terminal operation, care should be taken to integrate new charging infrastructure without interfering with existing workflows. The layout should facilitate smooth traffic flow and minimize additional delays in boarding and disembarking processes. Implementing a scheduling system to coordinate charging times with ferry operations can help to further reduce waiting times for e-trucks.

2.4.2.3 Port ecosystem

While onboard charging operations are fully the responsibility of the ferry operators themselves, the port ecosystem is normally considerably more complex. Port authorities and operators, governmental agencies, shipping lines, rail and road operators, as well as logistic service and third-party charging providers might all be relevant to stakeholders when developing a holistic charging strategy at the port.

2.4.2.4 Technical Requirements

Depending on their location at the terminals, charging stations might be exposed to similar environmental conditions as on the vessels and hence require additional protection.

2.5 Discussion of ZEFES Use Cases

Among all ZEFES use cases, there are three routes that include a ferry trip either between Rødby (Denmark) and Puttgarden (Germany), or between Travemünde (Germany) and Trelleborg or Malmö (Sweden).

Table 1: Overview of use cases that include transport on a ferry.

TASK	USE CASE	ROUTE	OEM	BEV	TRUCK INFORMATION	TRUCK CHARGER	TRAILER + CHARGING	TRANSPORTED GOODS
7.2.2	2	**Gothenburg - Gent** Rødby-Puttgarden	VOLVO	BEV-1	Battery capacity: 728kWh	CCS2 (ISO 15118 - 2 2016) MCS (ISO 15118-20)	1 semi-trailer (no charging required)	Automotive parts
7.2.3-2	4	**Le Bolou - Halmstad** Le Bolou - Dudelange Travemünde – Trelleborg/Malmö)		BEV-2			E-reefer, SCB (S.KOE Cool) Battery: 32kWh (530-660 VDC), 4.5h operating time Charger: CEE 22kW (400V, 32A, 50Hz), 2h charging time	Temperature-controlled goods
7.3.1	6	**Sodertalje - Zwolle** Rødby-Puttgarden	SCANIA	BEV-4	Battery capacity: 624 kWh Max. cont. power: 400 kW Tare weight: 11.000 kg	CCS2 (ISO 15118 - 2 2016) 375 kW MCS (ISO 15118-20) 750 kW	1 semi-trailer as range extender (e-trailer), Kaessbohrer/ZF Battery capacity: 200 kWh CCS2 140 kW	Automotive components

2.5.1 Rødby – Puttgarden

2.5.1.1 Use Case Description

As summarized in Table 1Table 1: Overview of use cases that include transport on a ferry., there are two use cases that include the transportation of automotive components by ferry between Rødby and Puttgarden: In Use Case 2 (Task 7.2.2), automotive parts are transported on a Volvo BEV truck between Volvo factories in Gothenburg (SE) and Gent (BE). In Use Case 6 (Task 7.3.1), Scania transports automotive components between their factories in Södertälje (Sweden) and Zwolle (Netherlands) [29].The battery of the e-trucks has a capacity of 624 kWh. In Use Case 6, also the e-trailer is equipped with a battery, adding another 200 kWh capacity to the vehicle.

The ferry route is operated by Scandlines, the 20 km long trip takes around 45-60 minutes. Throughout the day, ferries depart every 30 minutes, hence waiting times at the ports are typically short.

Scandlines is currently operating one conventional fuel-powered ferry and four hybrid ferries (combining diesel with electric battery power) on this route. By 2025, two ferries will be replaced by fully electric ferries. The ferries are charged both in the ports of Puttgarden and Rødby with a charging time of 12 minutes (on average), providing energy for at least 80 percent of the energy needed for crossing [40]. According to Scandlines, all available battery capacity (max. 10 MWh) is used for the propulsion of the ferry itself.

Neither the ferries nor the ferry terminals are currently equipped with EV charging stations. With the transition to hybrid and electric ferries, Scandlines has been upgrading its terminals in Rødby and Puttgarden with onshore power systems and direct grid connections [41][42].

2.5.1.2 Discussion

While electric ferries are, in principle, particularly well-suited for implementing truck and trailer charging on board, its practical implementation remains challenging. According to Scandlines, the available battery capacity of 10 MWh is used for the propulsion of the ferry itself and there is currently no retrofit of the ferries' battery systems planned. Given this constraint, ferry charging on this route is currently not feasible.

Although currently not in place, the development of charging infrastructure at the two terminals may be an interesting alternative to explore. Already in 2019, Scandlines invested in a 50 kV / 25 MW power cable to Rødbyhavn and, more recently, in a 30 kV / 15 MW power cable for the port of Puttgarden to meet the power demands of their plug-in ferries. This reduces the charging time in each port to 12 or even 8 minutes. The average time between two departures is 30 minutes, potentially leaving some window for alternative charging applications at the port and with appropriate MCS infrastructure and booking system in place, drivers could partially charge the trucks' batteries before boarding the next ferry.

Another relevant aspect to consider for this use case is the construction of the Fehmarnbelt Fixed Link, scheduled to commence operations in 2029. This immersed tube tunnel will connect Puttgarden on the German island of Fehmarn with Rødby on the Danish island of Lolland by a double-track railway line and a four-lane motorway [54] and replace most of today's ferry traffic. The reduction of journey time and local infrastructure upgrades are expected to boost long-distance traffic flows and hence the demand for e-truck charging infrastructure along the motorway rather than at the ferry port.

2.5.2 Travemünde – Trelleborg/Malmö

2.5.2.1 Use Case Description

In Use Case 4, temperature-controlled goods are transported between Le Bolou (France) and Halmstad (Sweden). The route includes a ferry trip from Travemünde (Germany) to either Trelleborg or Malmö (Sweden). Depending on the arrival time in Travemünde, the truck drivers either board a ferry to Trelleborg (8 hours, operated by TT-Line), or a ferry to the nearby Malmö (operated by Finnlines, 9 hours 15 minutes). The e-truck used for this use case is provided by Volvo and has a battery with a capacity of 728 kWh. The trailer is an e-reefer provided by Schmitz Cargobull with an additional 32 kWh capacity.

TT-Line operates 9 ferries on this route, of which two are powered by liquefied natural gas (LNG), a more environmentally friendly alternative to diesel fuel. They are also equipped with 32 EV charging points (40 kW DC or 11 kW AC, CCS2 connectors).

Finnlines' fleet includes hybrid ro-ro ferries equipped with battery systems for zero-emission operation in the ports, however, the 3 ferries that run on the route Travemünde-Malmö are still diesel-propelled. None of their ferries is equipped with EV charging points.

All three terminals in this use case are not owned by the ferry operators but by third parties, i.e. the Lübecker Hafengesellschaft (Travemünde), Municipality of Trelleborg (Trelleborg), and Copenhagen Malmö Port (Malmö).

2.5.2.2 Discussion

Compared to the previous use case, this route is significantly longer, making full electrification of the vessels technically and economically unfeasible in the near term. Assuming the fleet in operation today, the charging stations on the ferries would be powered by diesel generators. Finnlines confirmed that for the foreseeable future, they are not considering offering onboard charging services on their vessels as it would contradict their sustainability strategy. Even if additional battery systems were to be installed, supporting vessel propulsion would be prioritized over additional charging application.

Although TT-Line is already offering EV charging points on this route, a scaling of this service would face similar challenges, i.e. a significant increase of LNG consumption.

Another challenge for this use case is again the requirement from the truck driver, to take the next ferry that is departing from Travemünde, independent of who is operating it or what vessel model it is. This would require a strong commitment from both ferry operators servicing this route to invest in and develop charging opportunities on their ferries. Given these challenges, it is unlikely that truck charging facilities on this route will be realized.

Today, the ferry ports in this use case are not offering public truck charging facilities. According to the Port of Trelleborg's website, there is already charging infrastructure for the port's own vehicles and an expansion of existing installations is planned [56]. The ports in Trelleborg and Travemünde are currently upgrading their facilities to provide onshore power (2.5-3.6 MW) to vessels [34]. Again, potential scenarios on how to efficiently share the available power between onshore and truck charging may be explored.

3 Charging Opportunities on Rail

Today, temperature-controlled containers are powered by diesel engines providing power to the compressor. Motivated by the need to reduce CO_2 emissions in the transport sector, as well as the appearance of novel e-trailer concepts with integrated batteries, there is an increasing interest for electric charging opportunities during rail transport. To better understand the technical requirements towards such a solution, this chapter starts with a short introduction to railway electrification. Section 3.1 and 3.2 provides the current status and the technical foundation, explaining the railway electrification and onboard power systems. Building on this, Section 3.3 introduces two charging concepts: the SWS-PowerBox, a self-contained, wagon-mounted energy system that stores power from axle motion, and head-end power (HEP), which draws electricity from the locomotive. Section 3.4 then outlines the European approval process, involving multiple regulatory bodies and routes, each with varying levels of complexity and legal certainty. Finally, Section 3.5 focuses on the use cases in the ZEFES project, where the SWS-PowerBox is currently being tested through a collaboration between SWS, CFL, and UIC.

3.1 Status

Reefer trailers used in rail transport today are typically equipped with diesel-powered cooling units that operate independently of the train's power supply. This ensures reliable temperature control throughout the journey, regardless of the trailer's position or movement. However, diesel systems are associated with high fuel consumption, CO_2 emissions, and noise.

Driven by climate goals and the emergence of battery-electric reefer trailers, there is growing interest in alternative charging solutions for rail transport. These include systems that enable electric charging during transit, offering the potential to reduce emissions and improve energy efficiency. The following sections explore recent product developments and research initiatives in this area.

3.2 Technical background

To better understand the technical context and constraints relevant to charging solutions for temperature-controlled containers on rail, this section provides background on railway electrification and onboard power supply systems.

3.2.1 Railway networks

Railway electrification plays a vital role in the modernization and sustainability of rail transport. The electrification system of railways can be categorized into DC and AC systems, each with distinct characteristics and regional preferences shaped by historical and technical factors.

DC systems are commonly used in urban transit networks and some mainline railways [24],[25]. For tramways and light rail systems, voltages typically range between 600 V and 750 V DC. These systems are well-suited for short-distance travel with frequent stops, as seen in many metropolitan areas worldwide. For mainline railways, higher-voltage DC systems are employed to support longer distances and heavier loads. The 1,500 V DC system is widely used in countries such as Japan, parts of the

Netherlands, and France. Meanwhile, the 3,000 V DC system is prevalent in Italy, Spain, Belgium, and Poland.

In contrast, AC systems are generally preferred for long-distance and high-speed rail operations due to their superior power transmission capabilities [24][25]. One of the earliest AC systems, operating at 15 kV and 16.7 Hz, is still in use in several European countries, including Germany, Austria, Switzerland, Sweden, and Norway. This system was originally adopted to accommodate the limitations of early electrical equipment and has remained in place due to the extensive infrastructure built around it. The most widely adopted system today, however, is the 25 kV AC at 50 Hz (or 60 Hz), which is the global standard for modern high-speed and mainline railways. Countries such as China, the United Kingdom, and France have embraced this system for its efficiency, compatibility with national power grids, and suitability for high-speed travel.

3.2.2 Onboard power supply system

Modern railway systems rely heavily on sophisticated onboard power supply systems to ensure safe, efficient, and comfortable operation. These systems are responsible for delivering electrical energy not only to the traction motors that drive the train but also to a wide array of auxiliary systems such as lighting, HVAC (heating, ventilation, and air conditioning), communication, and control equipment.

The onboard power supply process begins with energy collection from external infrastructure—typically via overhead catenary lines using pantographs or through third rail systems. This high-voltage input is then processed by traction transformers and converters, which adapt it into suitable forms for propulsion. On the other hand, the auxiliary power supply system—often referred to as head-end power—supports all non-traction electrical loads, ensuring continuous operation of critical onboard services.

A key function of the auxiliary converter is to transform high-voltage input into regulated AC and DC outputs tailored to the needs of various onboard systems [26][27]. Depending on the application and the railway network, DC input variants typically operate within a range of 600 V_{DC} to 3000 V_{DC}, while AC input models are designed to handle voltages such as 1000 V_{AC} at 16.7 Hz, a standard in certain European rail systems. On the output side, these converters supply three-phase AC power, e.g., 230 V at 50 Hz, for auxiliary loads. Additionally, they provide regulated DC outputs, such as 24 V_{DC}, 72 V_{DC}, or 110 V_{DC}, which are essential for control systems and battery charging. The power capacity of auxiliary converters spans a broad spectrum, tailored to the specific demands of different train types and onboard systems. Depending on the configuration and application, these converters are capable of delivering total output power ranging from just a few kilowatts to as much as 1 MW.

3.3 Charging design concepts

In this section, two promising design concepts – the SWS-PowerBox and head-end power charging – will be discussed in more detail.

While not primarily targeted at trailer charging, another research activity worth mentioning is the RailCharge project [28]. In this feasibility study, the Technical University Graz and partners investigated automated charging of battery electric vehicles (BEVs) on specially equipped rail wagons. The system draws power from the railway's overhead catenary via head-end power lines and onboard converters, delivering electricity to BEVs during transit.

3.3.1 SWS-PowerBox

The SWS-PowerBox [30] is a self-contained, rail-mounted energy system developed by SWS PS Power Solutions GmbH to enable climate-neutral cold chain logistics on freight trains. It is currently the solution under consideration for the ZEFES project use case, with field testing scheduled for the second half of 2025. The system addresses the challenge of powering refrigerated containers on rail wagons without relying on diesel generators or head-end power from locomotives.

At its core, the SWS-PowerBox functions as a mobile power bank that autonomously generates, stores, and supplies electricity to cooling units. It does this by harvesting kinetic energy from the wagon's motion using a hydraulic axle generator. This energy is stored in modular battery strings, each with a capacity of 10 kWh, scalable up to 80 kWh depending on operational requirements. The stored energy is then delivered through a three-phase 400V AC output system, capable of supplying up to 30 kW via four CEE 32A 4-pole sockets. These outputs can support up to four refrigerated containers per wagon. Recuperation begins at speeds as low as 30 km/h, with energy recovery rates ranging from 4.5 to 18 kW depending on speed and wheel diameter.

Figure 1 SWS-PowerBox [30].

Mechanically, the SWS-PowerBox is housed in a robust steel frame with a compact footprint of approximately 2.7 meters in length, 0.58 meters in width, and 1.5 meters in height. It is mounted centrally on the wagon's bogie using adapter plates and a hydraulic pump assembly, compatible with 80', 90', and pocket wagons. The system supports all common refrigerated container types, including reefer containers, swap bodies, and tank containers. Installation is designed to be quick and non-invasive, with a plug-and-play approach that allows for full deployment in under a day. The system is equipped with a real-time monitoring platform that transmits operational data every minute, enabling remote diagnostics, predictive maintenance, and over-the-air updates.

The system has already been field-tested and is in regular use in more than 13 European countries.

3.3.2 Head-end power solution

A different approach for trailer charging was previously explored by WASCOSA [31], a freight system provider based in Switzerland. In the project titled *Elektrifizierte Güterwagen* (electrified freight wagons), WASCOSA targeted a sustainable, zero-emission rail transport for temperature-sensitive goods by powering refrigerated containers using electricity from the trains' head-end power (HEP) system, eliminating the need for diesel generators.

The project began in 2015, driven by the growing demand for temperature-controlled logistics due to globalization and containerization. WASCOSA identified the main challenge as obtaining approval for these wagons in key European countries like the Netherlands, Belgium, France, and Italy—countries critical due to their ports and logistics flows.

The technical solution, branded as the WASCOSA e-car [32], involved drawing power from the overhead line, converting it through the UIC ZSS (train power supply system), and delivering 400V industrial AC power to the containers. This system leveraged components already proven in passenger rail, ensuring compatibility and high energy efficiency.

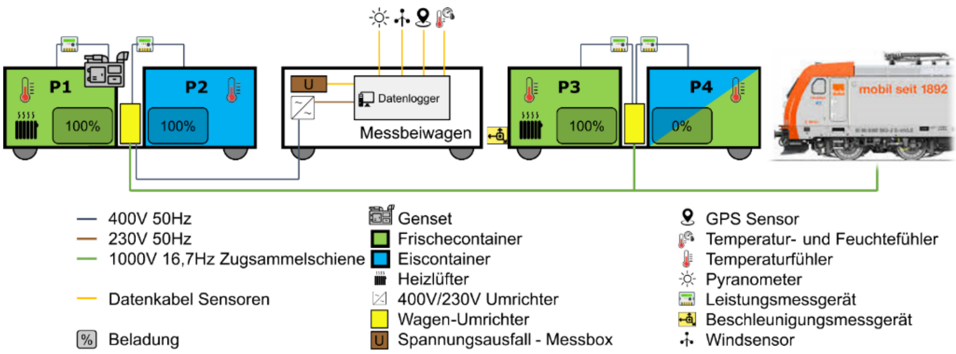

Figure 2 Train Configurations [32]

Environmental benefits were significant. A case study on the route from Rotterdam to Koper showed that using the electrified freight wagons reduced CO_2 emissions by a factor of three compared to diesel-based road transport. Noise emissions were also drastically lower—diesel-powered reefer containers were nearly twice as loud as their electric counterparts.

A related study focused on monitoring strategies for refrigerated transport in rail logistics. It compared diesel gensets and the WASCOSA e-car system in terms of energy consumption and reliability. The e-car system showed lower average power consumption than diesel gensets, especially at lower temperatures. However, its power supply reliability was slightly lower (93.6–93.8%) compared to gensets (99.2%). Most power interruptions were brief (1–2 minutes).

Figure 3 Measurement campaign: "Analysis of the energy requirements of refrigerated containers on the rails" (Analyse des Energiebedarfs von Kühlcontainern auf der Schiene) [32]

The project also advanced technical standards [33]: it contributed to the development and promotion of EN 50238-1 and the draft standard prEN 50728, both of which are central to the approval of electrified vehicles. These efforts helped accelerate the standardization of EMC (electromagnetic compatibility) testing procedures and laid the foundation for harmonized approval processes across Europe.

Despite these achievements, the project faced major regulatory and logistical challenges. Approval processes across European countries remained fragmented and inconsistent. Each country required separate tests and documentation, making it impossible to design a system that could be approved across multiple jurisdictions without repeated modifications and re-certifications.

In July 2023, WASCOSA officially discontinued the project [33]. The decision was based on several factors:

- The lack of clear, harmonized approval requirements from national infrastructure operators.
- Inability to meet the 36-month timeline for multinational certification.
- High-cost risks due to the need for repeated national approvals.
- Concerns about long-term service quality, particularly regarding maintenance and spare parts logistics.

In conclusion, the current legal and regulatory framework is insufficient to support the economic approval of electrified freight wagons from the ground up. Two potential paths forward were proposed: first, to use reference technology from already-approved passenger rail systems to ease the approval process; and second, to wait for a more mature legal framework, possibly post-2026, when standardized EMC requirements might be fully integrated into the European Railway Agency's Technical Specifications for Interoperability (TSI).

3.3.3 Comparative Evaluation

The SWS-PowerBox and Head-End Power (HEP) offer two contrasting solutions for powering refrigerated rail wagons. The SWS-PowerBox is a self-contained, wagon-mounted system that generates electricity through an axle-driven generator and stores it in onboard batteries. This makes it fully autonomous, easy to retrofit, and provides greater flexibility for cross-border logistics. In contrast, HEP relies on a centralized power supply from the locomotive, distributing electricity through the train. While this solution promises high energy efficiency, a homogeneous power transmission across all wagons as well as an efficient loading of the e-car train remain major obstacles. An operational advantage of the SWS-PowerBox is that in operation, no handling of high-voltage equipment is required. When it comes to regulatory approval, HEP must meet strict interoperability and electromagnetic compatibility standards across countries while the SWS-PowerBox, being a self-contained system, is likely to face fewer approval hurdles. This will be discussed in the next section

3.4 Approval process & regulatory challenges

3.4.1 Regulatory bodies

In the European railway approval process, several key entities ensure safety and interoperability: the European Union Agency for Railways (ERA), National Safety Authorities (NSA), Notified Bodies (NoBo), Designated Bodies (DeBo), and Assessment Bodies (AsBo).

The **European Union Agency for Railways (ERA)** [35] oversees the harmonization of railway systems across the EU. It issues safety certificates and vehicle authorizations and ensures compliance with Technical Specifications for Interoperability (TSI).

National Safety Authorities (NSA) [36] are national authorities responsible for safety oversight and authorisation within their own Member State. If the area of use is limited to one country, the applicant may choose the NSA as the authorising entity instead of ERA.

Notified Bodies (NoBo)[37] are independent organizations that assess whether railway components and systems meet the TSIs. They issue EC certificates of verification, which are essential for EU-wide interoperability.

Designated Bodies (DeBo) evaluate compliance with national technical rules not covered by TSIs. They ensure that systems are compatible with local infrastructure and regulations, often working alongside NoBos.

Assessment Bodies (AsBo) focus on safety. They assess risk management processes under the Common Safety Method for Risk Evaluation and Assessment (CSM-RA), ensuring that all hazards are identified and mitigated.

Together, these bodies form a structured process: the applicant prepares documentation, the AsBo evaluates safety, NoBo and DeBo assess technical compliance, and either ERA or NSA grants final approval. This collaborative framework ensures that railway systems are both safe and interoperable across Europe.

3.4.2 Possible routes of approval

When considering the regulatory approval of onboard charging equipment for rail freight applications—such as the SWS-PowerBox —there are no clear rules in the TSI WAG (Technical Specification for Interoperability for Freight Wagons). As a result, several potential approaches to approval exist, each with different implications for cost, complexity, and legal certainty. It is suggested to refer to the official ERA Guideline (ERA1209/200) [38] for practical arrangements and interpretations under Regulation (EU) 2018/545. The applicable approval route depends on how the equipment is classified (as a load or as part of the vehicle), the nature of the change, and who initiates the process.

The first route applies when the charging equipment is treated as a removable load and the change is initiated by the original equipment manufacturer (OEM). This is considered a non-significant change under Article 15(1)(b) of Regulation (EU) 2018/545. The equipment is not integrated into the wagon's design but rather mounted as cargo. The approval process involves a NoBo and an AsBo but does not require a new authorisation from the ERA. This route is attractive for its speed and low cost, as it builds on existing authorisations. However, it carries residual legal and operational risks due to the lack of clear regulatory provisions for such configurations, which may lead to uncertainties in post-approval operations.

The second route also treats the equipment as a load and falls under Article 15(1)(b), but the change is initiated by a party other than the OEM. This route includes a formal check by the ERA to ensure the completeness of the documentation. It offers a moderate balance between cost and regulatory oversight. While it reduces some procedural risks compared to the first route, it still shares the same fundamental legal ambiguity regarding the classification of the charging equipment.

The third route is more comprehensive and applies when the charging system is considered an integrated part of the wagon. The head-end power solution mentioned in Section 3.3.2 is likely to fall under this category. This falls under Article 15(1)(e) and requires a full authorisation process. It involves assessments by NoBo, AsBo, and DeBo in each country where the wagon is intended to operate. This route is both more time-consuming and costly. However, it eliminates the residual risks associated with the first two routes and ensures full regulatory compliance across multiple jurisdictions.

It is important to point out that all possible processes above entail significant administrative and financial burdens. These processes typically require several months or can even span over more than a year. During the interviews, stakeholders from the rail ecosystem commented that prior to the implementation of the 4th Railway Package [39], the authorisation of freight wagons was generally more straightforward, efficient, and clearly defined. While European standard-setting bodies may assert that the current framework simplifies procedures and reduces regulatory complexity, practical experience suggests that the process has, in fact, become more demanding and less predictable for applicants.

3.5 Discussion of ZEFES Use Cases

3.5.1 Use Case Description

In total there are three use cases that include trailer transportation by rail between Le Bolou (France) and Dudelange/Bettembourg (Luxemburg), see Table 3. In Use Cases 4 and 8, Primafrio is transporting temperature-controlled goods from Huelva (Spain) to Le Bolou using an e-truck from SCANIA and then

again from Dudelange to Halmstad (Sweden) using an e- truck from Volvo. The e-reefer is provided by Schmitz Cargobull and is equipped with a 32 kWh battery and a CEE charger.
In Use Case 9, where automotive components are transported between Martorell and Heilbronn (Germany), the trailer does not require charging, hence this use case is not relevant for this study.

Table 2: Overview of use cases that involve transport by rail.

TASK	USE CASE	ROUTE	OEM	BEV	TRUCK INFORMATION	TRUCK CHARGER	TRAILER + CHARGING	TRANSPORTED GOODS
7.2.3-2	4	**Le Bolou - Halmstad** Le Bolou - Dudelange Travemünde – Trelleborg/Malmö)	VOLVO	BEV-2	Battery capacity: 728kWh Range: 600km	CCS2 (ISO 15118 - 2 2016) MCS (ISO 15118-20)	E-reefer, SCB (S.KOE Cool) Battery: 32kWh (530-660 VDC), 4.5h operating time Charger: CEE 22kW (400V, 32A, 50Hz), 2h charging time	Temperature-controlled goods
7.3.3	8	**Huelva - Dudelange** Le Bolou – Dudelange	SCANIA	BEV-4	Battery capacity: 728 kWh Max. cont. power (mech.): 400 kW	CCS2 (ISO 15118 - 2 2016) 375 kW MCS (ISO 15118-20) 750 kW	E-reefer, SCB (S.KOE Cool) Battery: 32kWh (530-660 VDC), 4.5h operating time Charger: CEE 22kW (400V, 32A, 50Hz), 2h charging time	Temperature-controlled goods
7.3.4	9	**Martorell - Dudelange** Le Bolou - Dudelange	SCANIA	BEV-5	Battery capacity: 624 kWh Max. cont. power (mech.): 400 kW	CCS2 (ISO 15118 - 2 2016)	Lowliner trainer + dolly NO CHARGING REQUIRED	Automotive components

The train is operated by VIIA, a subsidiary of SNCF. The traction of the train is provided by CFL Cargo. The cargo train takes approximately 15 hours for the 1’054 km long route. There are 3 to 4 departures a day. The CFL Multimodal Terminal in Dudelange is equipped with two e-truck charging stations (100 kW DC and 200 kW DC) [57].

3.5.2 Discussion

As highlighted in Chapter 3.3.3, there are various advantages of the SWS-PowerBox compared to other charging concepts, in particular the flexibility and ease of deployment it offers. While regulatory approval is expected to be easier compared to the HEP solution, collecting all necessary approvals is seen as one of the main risk factors for a successful execution of the test.

In a first step, the described use case focuses on charging e-reefers, however, in the future also e-trailers acting as range extenders may be used on this route. Compared to e-reefers applications, these wagons are equipped with battery capacities ranging up to 200 kWh, considerably larger than the e-reefers discussed here. According to SWS, there is currently research performed to deliver higher output with the SWS-PowerBox and a first market-ready product is expected on the market within the next two years.

4 Conclusion and Recommendations

4.1 Conclusion

This deliverable has explored the technical, operational, and regulatory feasibility of implementing charging infrastructure for electric heavy-duty vehicles (e-trucks and e-trailers) during ferry and rail transport. The analysis reveals that while the concept of opportunity charging during multimodal transport is promising, its practical implementation faces significant challenges.

Offering onboard charging for electric trucks on ferries presents significant challenges due to sustainability concerns especially for diesel-propelled ferries, the high-power demands of large vehicle batteries, limited deck space, and stringent safety requirements. Charging heavy-duty EVs during shorter trips requires megawatt-level infrastructure, which is costly and difficult to integrate into the original design of the vessel. Although electric ferries offer a more sustainable platform for such applications, their battery capacity is typically optimized for propulsion, leaving little margin for additional loads like truck charging. Safety concerns, particularly around fire risks, necessitate specialized equipment and trained staff, further increasing operational complexity. Additionally, low utilization rates and high fixed costs make profitability difficult, especially without subsidies. As a result, terminal-based charging is generally more feasible for trucks than onboard solutions.

In the rail sector, the emergence of battery-electric reefer trailers and range-extending e-trailers has created a demand for in-transit charging solutions. Among the concepts evaluated, the SWS-PowerBox offers a flexible and self-contained solution with fewer regulatory hurdles compared to head-end power systems. However, the fragmented and complex approval processes across EU member states remain a major challenge on the path to deployment.

While the SWS solution is currently the only available option on the market and will be utilized for the upcoming tests, it is recommended that future developments aim to ensure full independence and autonomy for each individual wagon. This approach is particularly important to facilitate flexible train formations without disrupting the cold chain and to optimize energy supply with minimal losses.

4.2 Recommendations

Based on the findings of this study, following recommendations can be made:

Prioritize Terminal-Based Charging Infrastructure

Given the technical and operational limitations of onboard charging, investments should focus on enhancing terminal-based charging facilities, particularly at key multimodal hubs. These installations can leverage existing grid connections and offer more scalable and maintainable solutions.

Support Modular and Self-Contained Rail Charging Solutions

Technologies like the SWS-PowerBox should be prioritized for pilot deployments due to their flexibility, ease of retrofitting, and lower regulatory complexity. These systems can serve as a bridge solution while regulatory frameworks for more integrated systems mature.

Monitor and Evaluate Emerging Technologies

Continuous monitoring of battery technology advancements, charging standards (e.g., MCS), and vessel electrification trends is essential to reassess feasibility and update infrastructure strategies accordingly.

Accelerate Regulatory Harmonization

The lack of standardized approval processes across EU countries is a critical bottleneck. Stakeholders should advocate for clearer, harmonized guidelines under the Technical Specifications for Interoperability (TSI) and support initiatives by the European Union Agency for Railways (ERA) to facilitate and streamline certification.

5 Risks and interconnections

5.1 Risks/problems encountered

D3.4 is a feasibility study and provides recommendations regarding the feasibility of different charging solutions on ferry and rail. For truck charging operations on ferries, the main obstacle remains the grid-distant nature of vessels and hence the need to store sufficient energy for this application. In the case of trailer charging on rail, the collection of approvals for new charging equipment remains a considerable risk.

5.2 Contribution to project (linked) Objectives

The work described in this deliverable is linked to O3.5 of WP3, as it summarizes the most critical challenges for charging opportunities on ferry and rail.

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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
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23.3	PGG	PROCTER & GAMBLE SERVICE GMBH
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32	GSS	Grupo Logistico Sese
33	HIT	Hitachi ABB Power Grids Ltd.
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