

Project deliverable D2.2

System-level requirements for the pilot sites



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Editor/Lead author	Odbratt, Johanna (Lindholmen Science Park)				
Co-authors	Danebergs, Janis (Lindholmen Science Park), Gosavi, Sneha (Lindholmen Science Park), Herrmann, Florian (Lindholmen Science Park), Kruse, Ted (Lindholmen Science Park), Ohlin, Gunnar (Lindholmen Science Park)				
Peer reviewers	Safdarian, Amir (Kempower), Sprei, Frances (Chalmers University of Technology), Todorov, Yancho (VTT)				
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EXECUTIVE SUMMARY

This report, Deliverable D2.2, defines system-level use case requirements for the pilot sites in MACBETH and for the mass deployment of megawatt charging systems (MCS) for battery electric heavy-duty vehicles (HDVs). Initially nine main challenges associated with mass deployment of interoperable MCS chargers was identified based on project insights and the stakeholder needs identified in D2.1 (*Stakeholder needs on the exploitation of MCS*). These were categorised into three domains representing significant barriers: Operational and Economic, Safety and Site Design, and Energy and Grid.

10 system-level use cases were identified from these challenges to reflect real interactions at charging hubs. This shifts the focus from abstract goals (mass deployment of MCS) and the barriers (the challenges) to how this is achieved through real-life interaction. Classified as digital, physical, or energy-related, they describe essential interactions between key actors (e.g., truck drivers, fleet managers, or CPOs) and elements (e.g., chargers, trucks, or EMS). Additionally, several sub-use cases linked to their respective main scenarios have been explored.

From these use cases, system-level requirements, that a charging hub needs to fulfil to assist the future needs and challenges, have been derived from a step-by-step approach. The requirements are classified as “must have”, “should have” or “nice to have” depending on their importance for future charging hubs from a long-term perspective. Further, the requirements have been classified for the Swedish and Belgian pilot sites to clarify the scope of what different components and functionalities to be demonstrated.

Within the *digital* domain, two use cases have been identified and addressed. The first (UC1) deals with dynamic time booking and the second (UC2) with transparent communication of the charger's status and efficient authentication. For both use cases, the primary challenge is to make sure that the different systems (e.g. vehicle, e-Mobility Service Provider (eMSP), booking system, and charging hardware) work together smoothly so that data is shared in real-time. With an increased level of digitalisation and system interaction, charge point utilisation may be increased and logistic losses reduced.

The *physical* domain incorporates interaction scenarios for five additional use cases (UC3-UC7). Prioritising operational efficiency by avoiding the time-consuming process of uncoupling trailers, requiring sites to meet specific length specifications (minimum 16.5m) and drive-through designs is specified in use case 3 (UC3) which also deals with how to accommodate variations in vehicle configurations. The fourth use case (UC4) addresses the challenge of balancing high throughput charging with spatial limitations, prioritising site flow and safety to prevent congestion. Operational efficiency is maximised through high charger uptime, rapid authentication, and powerful grid connections, ensuring physical densification does not compromise driver manoeuvrability or safety. The following physical use case (UC5) focusses on safety aspects related to integrated and flexible multipoint truck charge points at which also LDVs are allowed to charge under certain conditions. Enabling charging for both LDVs and HDVs at the same charge points introduces additional requirements to ensure safety and to not disturb HDV logistics flows. From a business point of view, the potential income generated from higher utilisation must be weighed against direct and indirect costs needed to fulfil these additional requirements. Automatic plug-in charging with the help of a robot arm (UC6) highlights the critical need for precise user guidance and safety protocols when introducing automated hardware into the charging ecosystem. While the long-term vision emphasises a "Must Have" status for most integration and communication requirements, the Belgian Pilot Site adopts a more flexible "Nice to Have" approach for several items, allowing for iterative testing of the physical hardware before fully integrating the solution, as it will only be tested for a limited time at the pilot site. The final use case in the “physical” domain is about charging in challenging operational conditions (UC7). It deals with how to operate under severe weather conditions but also with how to handle e.g., internet failure and vandalism. Since environmental and human

induced events will vary by geographical conditions – the CPO is responsible for identifying and mitigating the local threats and challenges.

The last three use cases relate primarily to the *energy* domain. They focus on the management of site power peaks and load balancing as well as on integrating MCS charging with the grid, incorporating innovative approaches like energy communities, variable access to power from the grid or self-produced renewable energy. Use case 8 (UC8) utilises battery energy storage systems (BESS) and energy management systems (EMS) to enable fast charging while avoiding high grid fees through peak shaving. To maintain grid stability during high demand, the EMS coordinates load balancing, which may require clear communication with customers regarding potential temporary reductions in charging power. A more futuristic scenario is outlined in use case 9 (UC9), which explores how large MCS stations can be closely integrated with the electricity grid from a system-of-systems perspective. While the main use case is providing price signals to the hauliers and transport planners for them to act on, system integration can also be made and organised in other ways such as described in the sub-use cases. The CPO is the main actor and enabler in this use case but collaboration with many more actors is necessary to make an efficient integration of the vehicles, the charging station, and the grid possible.

Finally, use case 10 (UC10) enabling the provision of verified emission reductions has been identified. The use case touches upon systems that are much larger than the charging station: how the electricity is provided, the voluntary and mandatory reporting of emissions by hauliers, transport buyers and beyond as well as EU regulations which creates additional revenue streams for the CPO. The digital layer of the energy system, specifically for tracking greenhouse gas emissions and leveraging that data to create added value, will remain critical for the foreseeable future, as the full decarbonisation of transport and electricity production will be a long-term process. It creates a possibility for the CPO to provide a premium product to customers (selling renewable electricity and/or detailed emission accounting) and new revenue streams in form of selling renewable energy credits within REDIII regulations. This area is expected to develop further following changes in related legislation and the type of verified emission data requested by the CPO customers.

In the end recommendations for future activities have been outlined where future charging infrastructure must prioritise modularity and resilience to adapt to evolving logistical trends, such as e-trailers, autonomous vehicles, and increasing grid constraints. To ensure economic viability and operational reliability, recommendations focus on integrating automated charging systems, leveraging digitalisation for smart energy management, and "climate-hardening" hubs against extreme weather and security threats

LIST OF ABBREVIATIONS AND ACRONYMS

Acronym	Meaning
ADAS	Advanced Driver Assistance Systems
AFIR	Alternative Fuels Infrastructure Regulation
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
C-ITS	Cooperative Intelligent Transport Systems
CCS	Combined Charging System
CMS	Charge Management System
CPO	Charge Point Operator
CPM	Charge Point Manufacturer
CSRD	Corporate Sustainability Reporting Directive
DSO	Distribution System Operator
EMS	Energy Management System
eMSP	e-Mobility Service Provider
EV	Electric Vehicle
FMS	Fleet Management System
HCT	High-Capacity Transport
HDV	Heavy-Duty Vehicle
LDV	Light Duty Vehicle
MCS	Megawatt Charging System
SoC	State of Charge
TSO	Transmission System Operator
UC	Use case
V2G	Vehicle-to-Grid
WP	Work Package

1 PURPOSE OF THE DELIVERABLE

1.1 Attainment of the objectives and explanation of deviations

Task 2.2 addresses the aspect of achieving improved designs of future integrated multipoint megawatt charging system (IM-MCS) hubs, in support of future battery electric trucks (BETs) mass deployment, by defining a number of highly relevant use cases and their corresponding system-level requirements for the MACBETH pilot sites.

Deviations: It has not been possible, in all cases, to get a clear statement from the two CPOs on whether they see a requirement as a must-have, a should-have, a nice-to-have or if the requirement is not applicable. This is shown specifically in the dynamic booking use case in 6.1 where the statements remain to be decided.

1.2 Intended audience

This deliverable is intended for a broad and diverse audience, reflecting the collaborative nature of the transition toward high-power EV charging. It is open to all who are interested in understanding and shaping the future of mass deployment of interoperable MCS charging.

Key stakeholders include professionals from the truck and vehicle industry, who are directly impacted by the development of charging infrastructure and standards. It also addresses the needs of those working in the charging technology sector like CPOs but also including developers and suppliers of charging solutions, who require a clear understanding of future requirements for interoperability, functionality, and scalability. The energy industry plays a critical role in enabling this transition, and this document provides valuable insights for them to align their infrastructure and services with the demands of high-power EV charging. Academic institutions and research organisations will find relevant information to support studies in electrification, energy systems, and sustainable mobility.

Finally, regulatory bodies and policy agencies are also a key audience, as they are responsible for creating frameworks and standards that will guide the deployment of charging technologies.

1.3 Structure of the deliverable and links with other work packages/deliverables

Work package 2 (WP2) is the initial and important part of the MACBETH project, establishing the basic parameters that guide much of the subsequent technical and demonstration work. It is closely linked to Task 2.1, with shared inputs and mutual dependencies, and will serve as a key input for Deliverable 2.3.

The structure of this report is as follows:

Chapter 2 provides the background and context for this deliverable.

Chapter 3 identifies the challenges associated with the mass deployment of the MCS standard

Chapter 4 defines the relevant use cases, including the main scenarios and alternative scenarios.

Chapter 5 translates these use cases into system-level requirements forming the technical foundation for hub design.

Chapter 6 outlines the requirements for the innovations to be implemented at the pilot sites and in the long term.

Chapter 7 contains the References, listing all the sources, research articles and supporting materials cited throughout this deliverable.
Chapter 8 contains the appendix.

2 BACKGROUND

The transport sector urgently needs to reduce the CO₂ emissions to meet global climate goals. The key to doing this is by mass adoption of Electric Vehicles (EVs). This transition is partly hindered by the inability of the current Combined Charging System (CCS) standard to charge large truck batteries fast enough without incurring logistic losses, mandating the emergence of the high-power MCS standard. This is essential for the efficient decarbonisation of the logistics transport sector.

The MACBETH project (Multipoint MegAwatt Charging for Battery Electric Truck Hubs), supported by European funding, aims to address these challenges. The project's ambition is to pilot and showcase user-centric MCS charging hubs combined with tools that can facilitate the rapid and mass deployment and scale up of such systems in Europe. MACBETH directly contributes to the achievement of broader environmental goals of the Paris Agreement, and the EU Green Deal by 90% reduction of emissions by 2040. To ensure scalability, the project is defining requirements for interoperability and vehicle integration. The aim of this report (D2.2) is to define system-level requirements needed for the pilot sites and for long-term mass deployment of the MCS for electric HDVs.

The description of stakeholder & user perspective was started early in the project through Task 2.1 by identifying and clustering the stakeholder needs and potential use case deployment scenarios for MCS. This was done by identifying stakeholder groups across the charging value chain followed by interviews. MACBETH industry partners, associated partners to the project and external industry representatives were interviewed. More than 60 interviews have been conducted to define current challenges, identify specific needs of each stakeholder group (including CPOs, fleet operators, and research institutes), and assess possible use cases for MCS in logistics. The detailed findings from the interviews are summarised in Deliverable D2.1, "Stakeholder needs on the exploitation of MCS". As WP2 is the central technical translation for the MACBETH project, the high-level needs serve as important input to Task 2.2, where they are translated into system-level requirements. Task 2.2 is designed to consolidate these requirements and use cases for the pilot demonstration sites in WP6, thereby acting as the bridge between high-level needs identified in Task 2.1 and the actual demonstration.

The project will validate its system-level requirements across two distinct pilot sites, ensuring the final MCS concept is robust against varying operational and geographic contexts. At the Belgian pilot site, Milence will focus on the implementation of MCS in a charging station exclusively for commercial vehicles along a critical European transport corridor. In the Swedish pilot site, Plugit will establish a charging station for both light duty vehicles (LDVs) and HDVs. The HDV charge points and surrounding infrastructure will be designed to allow LDVs to charge during times of low HDV charging demand, e.g., during weekends. The system-level requirements defined in D2.2 will therefore indirectly serve as a technical input to both pilot demonstration sites.

3 CHALLENGES FOR MASS DEPLOYMENT OF INTEROPERABLE MCS CHARGERS

The stakeholders and users have a unique perspective on the challenges that now need to be faced to be able to make reality of MCS for electric truck mass deployment, which is the core aim of the MACBETH project. The stakeholder analysis was conducted in T2.1 and has served as important input to this work. In this chapter, the challenges are described based on project insights, forming the basis for identifying potential system-level use cases that can occur at the pilot sites and align with the aim. The pilot sites aim to showcase innovative approaches that support the transition toward mass deployment of electric heavy-duty vehicles across Europe. The pilot sites are public charging stations and therefore the focus of the following report is on public charging stations.

Mass deployment of MCS requires navigating significant barriers across three major domains: Operational and Economic, Safety and Site Design, and Energy and Grid (CharIn White Paper, 2025). The following challenges, see Table 1, form the core of this analysis and directly drive the use cases and system requirements.

Table 1. Major domains of challenges for mass deployment of EV trucks

Domain Category	Challenge
Operational and Economic Aspects	- The logistics system has small margins in time and cost - Provide charging for both CCS & MCS - Provide charging for different truck combinations including e-trailer - Find suitable locations and get permits
Safety and Site Design	- Safety risks with mixing LDVs & HDVs - Large and heavy hardware - Space and sizing constraints
Energy and Grid	- Limited grid capacity (Electricity produced and infrastructure) - Fluctuating supply and demand of energy

There is a question of how to address these challenges today, given the current state of the market, and how to manage them in the future when there most likely will be more EVs, both HDVs and LDVs, on the roads and the demand and competition for charging will be higher. There can also be geographical differences in Europe that affect the different challenges.

3.1 Challenges related to Operational and Economic Aspects

The logistics system has small margins in time and cost

The logistics systems operate within small margins in both time and cost, which means that there is little room for errors, unexpected delays, or unexpected expenses. It is important to avoid waste of time, and to ensure reliability, predictability, availability, and flexibility, which puts high demands on the performance of the charging infrastructure. Additionally, charging must be provided at an acceptable cost.

Provide charging for both CCS & MCS

MCS and CCS are two different standards for charging, and the primary ones in Europe, with the major difference that MCS supports higher power levels than CCS. In the future, MCS may become the dominant standard for truck charging, as it can deliver both the power levels offered by CCS and substantially higher ones. It is also considered to offer a more robust communication interface and a higher level of cyber security. However, future developments remain uncertain. In the near term, both CCS and MCS compatible trucks will coexist on the market. Consequently, CPOs must develop strategies to accommodate and manage this dual-standard environment effectively.

Provide charging for different truck combinations including e-trailers

Although the most common truck trailer combination in Europe is the **40-tonne articulated truck** (tractor and semi-trailer), there is considerable variation in truck configurations and trailer types, influenced by the transported goods. Examples include HCT (High Capacity Transport) combinations, tankers, refrigerated trailers, and e-trailers. Some of these, such as refrigerated and e-trailers, may also require charging, which introduces additional complexity in how to achieve that in a time- and cost-efficient way. Furthermore, truck combination lengths vary significantly across Europe due to differing national regulations, particularly regarding maximum allowable lengths and turning radius requirements. These factors impose critical design constraints on charging hubs, which must be capable of accommodating a wide range of vehicle configurations and operational needs.

Find suitable locations and get permits

A significant challenge in developing new charging hubs is securing a suitable location and navigating the complex permitting process. Finding a viable site is the first hurdle. A location must be strategic, typically in a high-traffic area, while also meeting several crucial technical and financial requirements. These include, among others, sufficient grid capacity, reliable internet connectivity, a reasonable land price, and ground conditions suitable for construction. In MACBETH, Tasks 3.2 and 3.3 will develop tools for understanding the demand for charging in different areas and locations.

Once a potential site is identified, the permitting phase presents its own set of difficulties. The application processes can often be unclear and time-consuming. This challenge is compounded by regulatory variations, which exist not only between countries but often between different regions within the same country. Applying for grid capacity is a particularly common bottleneck, especially when deploying high-power charging solutions. Many CPOs have experienced difficulties obtaining grid connections for building new charging hubs or even obtaining a response from energy companies within a reasonable timeframe. This is an especially pressing challenge now, as deploying high-power MCS often requires higher grid power connections than earlier CCS stations. Furthermore, the way to apply for grid capacity also varies throughout Europe and there are even many different Distribution System Operators (DSOs) in many countries, for example Sweden has more than 160 DSOs and Germany has more than 850 DSOs. Standardising or at

least harmonising these procedures would benefit the deployment of new charging hubs and the way forward for the electrification of trucks.

While this challenge addresses one important topic to realise mass deployment of EVs, it falls outside the scope of this specific task (Task 2.2). Task 2.2 does not cover the search for new locations; rather, it focuses on matters related to the actual interaction at the charging hub and its physical layout. Therefore, this challenge will not be investigated further in this report.

3.2 Challenges related to Safety and Site Design

Safety risks with mixing LDVs & HDVs

One challenge in designing charging stations for both light and heavy-duty vehicles, is how to manage safety risks associated with mixing the two vehicle types. At existing fuel stations, for example, fuel pumps for LDVs and HDVs are often separated to reduce interactions between passenger vehicles and large trucks. Specifically important is to prevent kids, travelling with their parents in LDVs, from running in front or around the HDV. This is also applicable for rest areas along the highways.

However, combining chargers for both vehicle types can increase the utilisation of the charging station and reduce the overall footprint. This creates a tension between maximising space and infrastructure utilisation while ensuring safety. The key question becomes whether a station layout can be designed to safely accommodate both LDVs and HDVs, and to what extent shared infrastructure, such as grid connections or amenities, can be used without compromising safety.

The Swedish pilot sites will allow for both HDVs/LDVs while the Belgian will allow for HDVs and for small commercial vehicles e.g. vans.

Large and heavy hardware

MCS hardware is significantly larger and more robust than CCS hardware because it is designed for a much higher power output, which necessitates a larger cable diameter and more advanced cooling systems to safely manage the significant energy transfer. This can be a challenge as one wants to maximise the use of the space of the charging station. Another aspect is that the MCS cables are stiffer and more difficult to handle, which can make the charging process cumbersome for drivers.

Space and sizing constraints

To make long-haul electric trucking viable, existing motorway assets must be used. The primary challenge is spatial: parking spots are already too few. Further, the free land may not have the right form for an optimal charging hub and require layout compromises. A notable example is the limited availability of land along the autobahn network in Germany, where space is often constrained. Consequently, the design of charging hubs in such areas must prioritise spatial efficiency. To optimise costs, it is generally advantageous to maximise the number of chargers per square meter, while still meeting technical, regulatory, and user accessibility requirements. This challenge will be more relevant for the future scale-up. For now, there are a limited number of BEVs on the roads in Europe. However, as the number of BEVs increases, the demand for charging and the space needed for it will grow.

3.3 Challenges related to Energy and Grid

Fluctuating supply and demand of energy

A key challenge for high-power MCS deployment is their significant draw on local grid capacity. Power peaks are costly in the early stages of using MCS when the number of trucks is low. In many cases, implementing power peak shaving strategies becomes necessary to mitigate these costs. From a business perspective, managing these peaks presents a complex challenge for CPOs and may slow down the transition.

Energy demand for charging also varies throughout the day. Many drivers need to charge at the same time, for example during lunch hours, to utilise the downtime while the truck anyway stands still. At an individual vehicle level, energy demand fluctuates due to environmental factors. For instance, driving in extreme cold or in strong winds increases consumption. In some locations, these conditions are common for significant parts of the year, leading to seasonal fluctuations in energy demand.

Looking ahead, reliance on renewable energy sources will increase. A key challenge with wind and solar power is their intermittent supply which causes large variations in energy prices. EU Regulation 2019/943 sets rules for the internal electricity market, focusing on fair, transparent, cost-reflective network tariffs for Transmission System Operators (TSOs) and DSOs. This will come into effect by January 1st 2027, and the network tariffs may become more dynamic to manage the grid. Therefore, it will be crucial for the MCS charging infrastructure and the vehicles to adapt and play a supportive role within this evolving ecosystem to balance the supply and demand of energy.

Limited grid capacity (Electricity produced and infrastructure)

As the whole society moves towards more sustainable solutions, the need for electric energy will increase and different sectors in the society will need to compete for the energy. This means the grid and energy production need to be increased. This challenge compared to the one before is more related to long term and expensive investments for building out the grid and energy production. This requires significant lead time, however, electrification of trucks and MCS charging need to be deployed now. This creates a difficult gap between what we need today and what the grid can handle, solutions that are discussed are for example self-produced energy and conditional electricity contracts.

4 SYSTEM-LEVEL USE CASES

By mapping the challenges we face with mass deployment of interoperable MCS chargers and learning from them we can better understand which new use cases will emerge as significant issues to understand the requirements for the hubs in the future. While more routine use cases will also occur at the charging hubs, these have not been explored in depth within this report, as effective solutions already exist. Instead, this deliverable and the system-level use cases focus on examining how the two pilot sites and the MACBETH initiative can prepare for the large-scale deployment of interoperable MCS chargers taking into consideration unsolved challenges and future demands. In the following, 10 use cases are presented, each focusing on a different system interaction of the main actors. The selection is based on an internal assessment and was supported by discussions with MACBETH partners and comprehensive desk research.

The use cases have been classified as digital, physical, and energy related as shown in Table 2.

Table 2. Overview of the selected use cases

Use cases	
Digital	1. Dynamic time booking
	2. Transparent communication of charger's status and efficient authentication
Physical	3. Charge without decoupling trailers
	4. Charging on a highly utilised site with maximised charging infrastructure capacity under spatial limitations
	5. Safe LDV charging at an integrated and flexible multipoint truck charge point
	6. Automatic robot arm plug-in charging
	7. Charging in extreme operational conditions
Energy	8. Managing site power peaks
	9. Innovative integration of MCS charging with the grid
	10. Provide verified emission reductions

In Table 3, an overview of the use cases is presented highlighting the connected challenges, actors and elements. The (x) means that the factor is relevant in some possible situations however not always.

Table 3. Overview of challenges, actors and elements for the selected use cases.

Use case Overview	Digital		Physical					Energy		
	UC 1	UC 2	UC 3	UC 4	UC 5	UC 6	UC 7	UC 8	UC 9	UC 10
Challenges										
The logistics system has small margins in time and cost	X	X	X	X	X		X	X	X	(X)
Provide charging for both CCS & MCS				X	X					
Provide charging for different truck combinations including e-trailer			X	X	(X)					
Safety risks with mixing LDV & HDV				X	X					
Large and heavy hardware				X		X				
Space and sizing constraints			X	X	X		X			
Fluctuating supply and demand of energy	X						(X)	X	X	X
Limited grid capacity (Energy produced and infrastructure)							(X)	X	X	
Actors										
Truck driver	Main user	Main user	Main user	X	Main user	Main user	X			
Fleet Manager									X	Main user
CPO (incl. owner of the truck stop and land)	X	X	X	Main user	X		Main User	Main user	Main user	Main user
TSO									X	
DSO								X	X	
Transport planner	Main user	Main user							X	
Electricity retailer									X	X
eMSP	X	X						X	X	X
Passenger car driver		X			Main user					
Elements										
Chargers (incl CMS)	X	X		X	X	X	X	X		X
Truck	(X)		X		X	X	X			
Passenger car					X					
Local grid (incl. Battery storage systems, PV, etc.)								X	X	
EMS								X	X	
Client server (app, website etc.)	X	X	X			X		X	X	
Physical infrastructure (roads, bays, parking places)	(X)		X	X	X	X	X			
Route planning software									X	
Electricity market									X	
FMS	X							X	X	(X)
Automatic robot arm						X				

Below, the 10 different use cases are described in more detail. The structure for describing the use cases is as follows:

1. Use case description - Which dimensions (accessibility, predictability, flexibility, availability, low cost) and challenges are addressed?
2. Actors and elements – Which actors and elements are part of the addressed system?
3. Preconditions – What are the major preconditions that must be given?
4. Main scenario – What is the main scenario of the use case? What is the trigger and which postconditions result from it?
5. Sub-use cases – What important sub-use cases exist once there is a deviation from the main scenario?

In this chapter, the system-level use cases have been examined to be able to research the connected requirements. However, while this individual focus is necessary, it is crucial to also consider the larger system. In a real-world application, these use cases will run concurrently. This creates significant implementation challenges, as some use cases and requirements will conflict with others, complicating their coexistence. This presses the need to find solutions that take multiple perspectives into consideration.

4.1 Use case 1: Dynamic time booking

The logistics system operates with very tight time margins, making the availability of charging and the right amount of power when needed critical. As the number of electric trucks increases, competition for chargers will grow, further emphasising the need for reliable access. To ensure charging availability when needed in the future, a booking system for chargers is a potential solution. However, logistics operations are often affected by unpredictable factors such as traffic, making it difficult to determine the exact arrival time at the charging hub. Therefore, a dynamic booking system, one that allows flexibility in arrival and charging start times, could potentially improve usability and efficiency.

From the CPO's perspective, a booking system also enhances predictability. It enables better forecasting of power demand, such as estimating required power levels and planning when to utilise systems like Battery Energy Storage Systems (BESS). This helps optimise energy usage and reduce operational costs, which ultimately benefits logistics companies as well. When booking, it's valuable for the CPO to receive information such as the truck's expected duration of stay, connector type, vehicle type and desired SoC upon departure or needed charging. This allows for more accurate power planning and contributes to a more efficient and sustainable charging ecosystem.

Moreover, DSOs would appreciate such predictability, as it helps prevent excessive demand on the grid by smoothing out demand peaks.

The scope of this use case intentionally excludes commercial considerations, such as the modelling of costs associated with user behaviour (e.g., no-show fees). These elements are considered internal business decisions for the individual CPO.

This use case primarily applies to the Belgian pilot site, due to an identified greater need for a booking system at that location for the time being. Milence, the CPO, identifies this as important in the future and is developing a plan for this, however, whether it will be tested at the pilot site has not yet been decided.

Related challenges: *The logistics system has small margins in time and cost, Fluctuating supply and demand of energy*

Actors and elements

Table 4 describes the actors and elements that are part of the use case and defines their roles in this use case.

Table 4. Actors and elements in use case 1

Actors & Elements	Description
Truck driver	The operator of the vehicle, typically interacting via a display in the truck, tablet, or mobile application.
Transport planner	A user responsible for planning routes and managing a fleet of trucks, typically interacting via a web portal or FMS.
CPO (incl. owner of truck stop, land)	The entity that runs the charging hub. In this use case we assume that the CPO is responsible for and is the main manager of the booking system.
Booking system	Manages the booking including information about the physical charging hardware, availability, and status. In this use case we assume that the CPO is responsible for and is the main manager of the booking system.
FMS	Fleet management system. Provides vehicle data (SoC, location, route) and may trigger the booking process automatically.
eMSP	e-Mobility Service Provider. In this use case it's defined that the eMSP helps the users to book charging, in some cases the CPO acts as eMSP.
Client server (app, website, API, etc.)	The eMSP's application (mobile app, website) used by the truck driver and/or transport planner to interact with the booking system.
Chargers (incl CMS)	The physical charging hardware and its local Charge Management System.
Physical infrastructure (roads, bays, parking places)	The physical infrastructure can be an active part of the use case as it can play an important role in signalling and ensuring that a spot is booked, the size of the bay and which vehicle size that fits to charge. However, as this is connected to some specific solutions, this element is not covered in the main scenario.
Truck	It can be that vehicle data goes directly from the vehicle and not through the FMS. However, as this is connected to some specific solutions, this element is not covered in the main scenario.

Preconditions

- The user (Driver or Transport planner) has an eMSP application that they use, for booking. The application for booking could be integrated in the truck already by the OEM, or a third party booking solution.
- The user (Driver or Transport planner) is authenticated within their respective application.
- The FMS has access to the truck's data, including wanted SoC at departure based on planned routes, connector type, estimated arrival, staying time.
- A valid payment method is associated with the user's account.
- The booking system has a live data feed from and to the CMS regarding charger status and availability.

Main scenario:

Trigger: The user initiates a booking request. This can be done manually or be triggered automatically by the FMS when it predicts the truck will need a charge to complete its journey or during a mandatory rest stop.

1. The user (Transport planner / Truck Driver) or the FMS specifies the booking requirements through the client server distributed by the eMSP:

- Time: Estimated arrival time and departure time/charging duration (e.g., 45 minutes).
- Energy Need: Required energy in charged kWh
- Connector type (CCS or MCS)
- Vehicle type (e.g. truck, HCT, etc.)

2. The eMSP queries the CPO's booking system and identifies available charging slots that match the request. It filters based on power level, connector type, and availability. When a suitable slot is found a reservation is made in the booking system, and it sends the feedback back to the eMSP.

3. The eMSP notifies the user that a slot has been booked.

4. The driver arrives in a reasonable timeframe from estimated time of arrival and authenticates and the vehicle gets charged. (e.g. +/- 15 minutes from estimated time of arrival)

Postcondition: The charger was available when arriving at the charging station and it charged the truck to the SoC that it needed.

Sub-use cases:

- **Sub-use case 1.1: Estimated time of arrival is not correct:** The time dynamic booking system will handle this problem, however, there must be a timeframe for when the availability of the charging cannot longer be guaranteed if there are other customers that also need to charge and have bookings after.
- **Sub-use case 1.2: Estimated SoC/Charging need is not the same as communicated (e.g. Detouring):** If this information is wrong this needs to be communicated to the booking system in some way. There must be a way for the CPO to go around what has been communicated during the booking.
- **Sub-use case 1.3: Booked spot not accessible (Infrastructure failure, booked spot blocked):** The booking system reports a fault with the reserved charger. The booking system immediately notifies the driver and attempts to re-book another charger at the same hub or at a nearby location.
- **Sub-use case 1.4: Booking can be cancelled:** The user can cancel the booking. The booking system must then delete the booked time and make it free again. How this will be handled from a business case perspective will not be considered.

4.2 Use case 2: Transparent communication of chargers' status and efficient authentication

The logistics system operates within narrow margins in both time and cost already today, which places high demands on an efficient charging process. Transparent and reliable communication of chargers' status, static and dynamic, to avoid any kind of disturbances in the charging process will be a key factor to take the correct

actions both when planning the charging as well as to act and make adjustments when unexpected events occur.

Typical information includes location of charging station, real-time status of each charger, charging power, connector type, pricing, and payment methods. A dedicated app or website is usually the information interface that is provided for the CPO by the eMSP.

Furthermore, from the CPO's perspective, transparent and reliable communication of chargers' status creates trust, avoids unhappy customers, and should in the end lead to a better business.

This use case should be valid for both the Swedish and the Belgian pilot.

Related challenges: *The logistics system has small margins in time and cost*

Actors & Elements

Table 5 describes the actors and elements that are part of the use case and defines their roles.

Table 5. Actors and elements in use case 2

Actors & Elements	Description
Truck driver	The operator of the truck.
Transport planner	A user responsible for planning routes and managing a fleet of trucks, typically interacting via a web portal or FMS.
Passenger car driver	The operator of the passenger car.
CPO	The entity that runs the charging hub.
eMSP	The eMSP provides the EV charging services by providing an EV charging app and web portal, handling payments, invoicing, reporting, analytics, support etc.
Chargers (incl CMS)	The physical charging hardware and its local Charge Management System.
Client server (app, website etc.)	The application (mobile app, website) used by the Truck Driver and/or Fleet Manager to interact with the booking system.

Note also that in some cases a CPO could also offer services that typically are provided by an eMSP, such as providing a charge app, managing access, payment etc.

Preconditions

- The user (Transport planner / Truck Driver / Passenger car driver) has access to the relevant eMSP's client server to connect to the charging hub.
- Transport planner, truck driver or passenger car driver have an account in case of specific pricing structure and have in that case been authenticated.

Main scenario:

Trigger: The transport planner, truck driver or passenger car driver needs to charge, or plan charging for a route.

1. The user (Transport planner / Truck Driver / Passenger car driver) checks charger availability in the app.
2. Information is shared from the eMSP for the specific CPO:
 - Real-time availability status and number of connectors available
 - Connector types and charging power
 - Location and navigation information
 - Pricing and payment information
 - Plug'n'charge functionality if available
 - Booking/reservation functionality if available
3. The user selects which charging hub to go to.
4. At the charging hub, the user parks the vehicle at an available charger and connects it to the charger.
5. The driver or vehicle is authenticated based on the available charging and payment functionalities.
6. Charger informs about estimated time to reach fully charged.
7. During charging the driver can follow the charging progress in the client server.
8. Charging ends at the desired SoC or direct termination by the driver.
9. After completed charging the driver receives a summary of the charging including location, time, cost etc.

Postcondition:

The vehicle is charged to the desired SoC.

Sub-use cases:

- **Sub-use case 2.1: Connection is down:** When connection to the eMSP is down no access to information is available. If the connection between the eMSP and a specific charging hub is down, information about other charging hubs could still be available. If the connection between the CPOs backend and a specific charging hub is down, information about other charging hubs, belonging to the same CPO, close to that location and their status should be shared when possible.
- **Sub-use case 2.2: Charger is blocked:** When a charger is blocked by another vehicle information about whom to contact for technical support is needed as a minimum requirement. To be able to share information about that another vehicle is parked at the station without being connected to the charger could be a nice to know to be able to avoid that charger. The same information could also be used at the hub to be able to address and solve the blocking situation. If not possible to detect a blocking situation signage in connection with on-site or mobile patrol could be a solution.
- **Sub-use case 2.3: Cost of charging:** Share information about different cost models and pricing dynamics when available.

4.3 Use case 3: Charging without decoupling trailers

A critical use case for the logistics industry is the ability for trucks to charge without decoupling the trailer from the tractor unit. Logistics operators run on tight schedules, and the time spent for decoupling and reattaching a trailer just to be able to charge would be a waste of time and resources. This can be the case, for example, when there are not designated charging spots for trucks because then the charging bays could

be dimensioned for a car. For drivers, the need to decouple is not only time-consuming but also a major source of frustration, as finding a safe and suitable place to leave the trailer while charging can be difficult. Beyond simply fitting in the charging bay, the whole combination needs to be able to enter and leave the bay in a practical way. Therefore, it's often recommended for trucks not to have a dead-end charging and instead have a drive through solution to minimise reversing and have a more traffic safe layout.

From the CPO's perspective, this will limit the design freedom of the charging hub. The accepted truck lengths are different in different parts of Europe and can change over time. Therefore, this places special requirements on the design, connected to the location and country in which the charging hub is deployed.

There have been cases when truck drivers need to decouple the trailer to fit in the charging bay. If they do not have time to decouple, they may stand in multiple of the charging bays blocking them for other customers. This can be a significant problem for the CPO as it means that they might lose income from other customers and as well as it can anger other customers.

This use case is interesting for both the Swedish and the Belgian pilot. However, as the allowed truck combinations are longer in Sweden this use case is particularly connected to the Swedish pilot.

Related challenges: *The logistics system has small margins in time and cost, Provide charging for different truck combinations including e-trailer, Space and sizing constraints*

Actors and elements

Table 6. Actors and elements in use case 3

Actors & Elements	Description
Truck driver	The operator of the vehicle and performing the charging.
CPO (incl. owner of truck stop, land)	The entity that owns and maintains the charging hub.
Truck	The vehicle consists of an electric tractor unit and one or multiple trailers
Physical infrastructure (roads, bays, parking places)	The physical infrastructure is in This case an element as it plays a significant role in if it's possible to manoeuvre and charge the truck with trailers.
Client server (app, website, API etc.)	The application (mobile app, website) used by the Truck Driver and/or Transport planner to interact with the booking system. The client server provides information about which truck combinations (e.g. HCT, e-trailers, length, etc.) that the site is adapted to.

Preconditions

- The truck driver has identified a charging hub that is adapted to trucks.

Main scenario:

Trigger: The Truck Driver has identified a need to charge the electric tractor unit.

1. Driver arrives at the charging hub and can drive to the charging point

2. Driver positions the coupled truck combination in a marked charging bay at the charging point
3. The driver can plug in the charger
4. The truck charge

Postcondition: Vehicle departs on time with target SoC, never decoupling the trailer.

Sub-use cases:

- **Sub-use case 3.1: Charge tractor unit and e-trailer:** An e-trailer is a trailer equipped with its own drivetrain that assists the tractor unit, which can significantly extend the vehicle's operational range. While these trailers can recapture energy through regenerative braking, they still require periodic charging. This presents a logistical and financial challenge, as the tractor's charging inlet is at the front of the vehicle, while the trailer's is at the rear. Currently, e-trailers are not yet authorised for general use as a common EU regulatory framework for these unique vehicles does not yet exist. However, testing is occurring across Europe. As these developments proceed, the use of e-trailers will likely increase, creating a significant issue that CPOs must address to satisfy their customers.
- **Sub-use case 3.2: Charge HCT:** HCT are truck combinations that exceed standard size and weight standards, which are used to reduce transports and through that CO2 emissions. The sheer size of an HCT creates a massive logistical problem for charging. A 34.5-meter vehicle cannot use a standard car-style charging bay. They are difficult to reverse, and it's not recommended from a safety view if there are many people running around. Therefore, a layout for easy manoeuvring is a must. The rules of the accepted vehicle combinations length and weight vary from country to country and therefore it puts different requirements on the CPO depending on where they are building their station.
- **Sub-use case 3.3: Charge truck carrying dangerous goods:** A key gap exists in the current Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) framework: there are no specific rules for the public charging of an electric truck after it's been loaded with dangerous goods. While recent ADR updates approve the trucks themselves, the charging procedure is not defined. This means the burden of safety falls on the operator. One path forward is to conduct a formal risk assessment that combines charging standards with ADR's core principles of ignition prevention and emergency response. Future ADR updates must be actively monitored, as new rules for this can occur.
- **Sub-use case 3.4: Charge tractor unit and refrigerated trailer:** Charging an electric tractor and a refrigerated trailer simultaneously is a complex task as it requires supplying power to both the tractor's propulsion batteries and the trailer's separate cooling unit. This dual-charging process demands specialised stations with multiple connection points.
- **Sub-use case 3.5: Charge tractor unit in trailer swapping operation:** In the case of trailer swapping it can make sense to decouple the trailer. However, this solution often enables the truck to return to depot, where it in many cases can charge to a lower cost. Furthermore, for now this solution is not widely applied and used in the logistics system.

4.4 Use case 4: Charging on a highly utilised site with maximised charging infrastructure capacity under spatial limitations

This use case focuses on, a future scenario where there is a high volume of electric trucks, a site that has as many chargers as possible per square meter, with respect to space limitations set by user experience,

regulations and available area. The need for that many chargers is necessary because the site is highly used, and it is important to accommodate as many vehicles as possible. However, a key constraint is that the station's surface area is restricted and cannot be increased.

The charging infrastructure capacity of a location has a significant impact on its economic efficiency. Particular importance is paid to locations that are limited in space. Various challenges, some of which interact with each other, must be addressed at such locations. This concerns, for example, the provision of different charging options (CCS & MCS) and configurations (charging for different truck combinations including e-trailer) while simultaneously eliminating safety risks with mixing LDV & HDV.

While from the CPO perspective the question of how the charging infrastructure capacity can be maximised with respect to space limitations is crucial this use case addresses the interaction with the user.

Use case 4 is closely connected to *use case 3 Charge without decouple trailers*, *use case 5 Safe LDV charging at an integrated and flexible multipoint truck charge point* and *use case 10 Charging in extreme conditions*. These use cases are linked because they all have a significant impact on the physical layout of the charging hub. Specifically, they impose limitations that require a large amount of space, for example, to allow HCTs to manoeuvre. Especially difficult could be to both fulfil the requirements from UC3 and UC4, as that implies accommodating the different truck combinations but still keeping the space footprint low.

Even though this use case still has limited relevance due to the low number of electric trucks on the roads, it becomes increasingly important as adoption scales. Therefore, the thoughts on the design and innovation aspects should be incorporated into our present planning and future activities to test and validate concepts.

This use case is relevant for both pilot sites. The Swedish pilot site will also need to take HCT-combinations accepted in Sweden into consideration.

Related challenges: *The logistics system has small margins in time and cost, Provide charging for both CCS & MCS, Provide charging for different truck combinations including e-trailer, Safety risks with mixing LDV & HDV, Large and heavy hardware, Space and sizing constraints*

Actors & Elements

Table 7 describes the actors and elements that are part of the use case and defines their roles.

Table 7. Actors and elements in use case 4

Actors & Elements	Description
Driver	The operator of the HDV or LDV
CPO (incl. owner of truck stop, land)	The entity that owns and maintains the charging hub.
Chargers (incl CMS)	The physical charging hardware and its local Charge Management System.
Physical infrastructure (roads, bays, parking places)	The physical infrastructure addresses the spatial dimension for this use case and therefore determines the degrees of freedom and constraints related to the charging infrastructure installation on site.

Preconditions

- The driver has identified this charging site
- The site is space optimised for charging infrastructure capacity
- The site is frequently used

Main scenario:

Trigger: The vehicle needs charging.

1. The driver enters the hub and approaches the charging bay without any advanced manoeuvring and interruptions.
2. The driver parks at the charging bay not obstructing other vehicles' path or other chargers.
3. The driver needs to have room to open doors and get out of the vehicle.
4. The driver plugs in the charger and starts charging.
5. The driver can walk from the vehicle to amenities and to stretch out his/her legs in a traffic safe manner
6. When the charging process is completed, the vehicle can drive away without other traffic hindering its departure.

Postcondition: Vehicle departs with targeted SoC

4.5 Use case 5: Safe LDV charging at an integrated and flexible multipoint truck charge point

The electrification of road traffic is steadily increasing, and this applies to both LDVs and HDVs. The first public charging stations were dedicated to LDVs simply because of the earlier deployment of electric cars. When the first battery electric trucks were introduced on the market, they could occasionally be seen using LDV charge points, due to the total lack of dedicated truck charging infrastructure. This is sometimes still the case, but we also see the opposite, e.g. LDVs using HDV charging infrastructure. In Sweden national funding schemes have supported a nation-wide build-up of some 250 public charging stations, designed and dedicated for truck charging, in line with Alternative Fuels Infrastructure Regulation (AFIR). These charging stations are open also to LDVs. The stations are attractive to LDV users because they offer high power and are also available most of the time due to the low number of electric trucks on the roads. However electrified logistics will be highly dependent on charger availability and LDVs cannot be prioritised or allowed to delay the HDVs. The lower amount of energy for LDVs that can be transferred also makes it important for the CPOs to prioritise HDV charging to receive a reasonable return on investment. Nevertheless, to maximise the use of the infrastructure and to provide more charging possibilities for LDVs when demand is high, there may be a potential in allowing LDVs to use HDV charge points although strict separation of light and heavy-duty traffic at rest areas, gas stations etc, is considered safe and best practice. This use case describes system interactions when charging an LDV in a safe way at an integrated and flexible multipoint HDV charge point taking into consideration the herewith related challenges. Multiple LDVs could fit and charge simultaneously in a single HDV charging bay. This is important for increasing utilisation; since LDVs often charge at a lower power, multiple LDVs can, potentially be equivalent to one truck in terms of energy charged, maximising both space and charger utilisation.

More concretely this use case will focus on how to design charging stations dedicated to HDVs in such a manner that also LDVs can use the charging infrastructure at times of high LDV charging demand but low

HDV demand. The potential value in realising this use case is for the CPO to achieve a higher utilisation of chargers and space. For the LDV user the potential value lies in more available charge points. However, mixing LDVs and HDVs is associated with safety risks, especially when LDV users and passengers, including children, that are not used to be in the vicinity of HDVs, leave their vehicles during charging.

In some countries and on certain weekdays, HDVs are banned from the highways/streets. Sundays and public holidays are the most common bans, see more in Appendix 1: Truck driving bans in Europe, where the driving bans per country are listed. On those occasions allowing LDVs to charge on HDV spots would be an optimal solution to maximise infrastructure utilisation. Further, there is also a pattern that more LDVs might be on the roads in those times, making the need for charging that type of vehicle higher (Enedis et al, 2024).

The Swedish pilot site will provide charging also for LDVs of all types but to which extent, when and where, the LDVs will be allowed to charge at HDV charging points is still to be determined. Therefore, this use case is not directly related to the Belgian pilot site, since Milence's focus is HDV charging. It would though be interesting to investigate the possibility of allowing e.g. LDV commercial vans to charge at the site during periods of low HDV charging demand.

Related challenges: *The logistics system has small margins in time and cost, Provide charging for both CCS & MCS, Provide charging for different truck combinations including e-trailer, Safety risks with mixing LDV & HDV, Space and sizing constraints*

Actors & Elements

Table 8 describes the actors and elements that are part of the use case and defines their roles.

Table 8. Actors and elements in use case 5

Actors & Elements	Description
Truck driver	The operator of the vehicle.
LDV driver	The driver of the vehicle, e.g. passenger car.
VRUs/LDV passengers	Vulnerable road users e.g. humans, children, roaming around the vehicle.
CPO (incl. owner of truck stop, land)	The entity that owns and maintains the charging hub and is responsible for the safety
Chargers (incl CMS)	The physical charging hardware and its local Charge Management System.
Truck	The vehicle - a rigid truck or an electric tractor unit with one or multiple trailers
Passenger car	The vehicle – may be an LDV, a mobile home, a car with caravan, etc.
Physical infrastructure (roads, bays, parking places, traffic signs, incl dynamic signage)	The physical infrastructure defines to some extent how people are directed to move and can move safely within the area

Preconditions

- LDVs need charging at times of low HDV charging demand
- LDV users check for available chargers
- The site has one or more bays that can accommodate LDV charging technically
- Time-based access (HDV high charging demand to low demand (e.g. based on when HDVs are allowed on the roads) or real-time or scheduled “demand defined” access to different sections of the charging station.

Main scenario:

Trigger: LDV needs to charge

1. CPO makes the entire station or sections of the station available for LDVs.
2. The CPO's system displays the charger availability for LDV users
3. Local hub signage activated to highlight charging possibility at hub
4. LDV user decides to charge at hub
5. Signage activated to direct LDVs to correct bay
6. LDV enters, parks.
7. Local hub signage directs the safe and fluent flow of people back and forth
8. LDV charges
9. LDV exits, directed by hub signage

Postcondition: The LDV leaves the charging station with the proper SoC and without any inconvenience, damage, or injuries.

Sub-use cases:

- **Sub-use case 5.1: A passenger (maybe the driver or a family member, etc.) must go to the toilet, to the restaurant or other areas e.g. for recreation:** From a traffic safety perspective this use case is important. While there might be a higher traffic activity in a limited space there need to be special / active elements to prevent traffic accidents with vulnerable road users. This can be solved with a thoughtful hub design taking into consideration techniques to prevent accidents (smart sensors, cameras, interactive signage, traffic flow simulations, etc.).
- **Sub-use case 5.2: An LDV tries to enter and charge at times when no LDVs are allowed to charge:** This case is relevant because it might happen quite frequent. In those situations, there should be guidance for the driver on how to solve the situation (e.g. with special signage). It also depends on the design of the site what different options there might be (e.g. drive-through vs. turn around, etc.). To avoid those situations, it is important to provide clear information to the driver before entering the site.
- **Sub-use case 5.3: An LDV charges at a charging station with partially integrated and flexible charging infrastructure but with separated LDV and HDV charge points:** In this case the two vehicle types are strictly separated but they share the same grid connection and maybe other charging infrastructure (e.g. local smart grid elements). To maximise the revenues from additional services (food, toilets, etc.) they share the same amenities. To realise this a suitable hub design layout is necessary.

4.6 Use case 6: Automatic robot arm plug-in charging

The automatic robot arm charging leverages mechanisms to ensure precise connections, enhancing operational efficiency and in addition supports the industry's gradual shift towards automation.

Since a robotic arm solution adds relatively costly hardware to the charging station it's likely in the near future that only a limited number of charging outlets will be combined with a robotic arm solution. One can also imagine a future where the automatic robotic arm is moved or moves between the charging outlets based on need. However, in this use case we base the description on the fact that a limited number of the charging outlets are combined with a robotic arm solution for plug-in charging, like the solution developed by the project partner Rocsys..

The Rocsys automatic robot arm will be tested at the Belgian pilot site.

Related challenges: *Large and heavy hardware*

Actors & Elements

Table 9 describes the actors and elements that are part of the use case and defines their roles.

Table 9 Actors and elements in use case 6

Actors & Elements	Description
Truck driver	The operator of the vehicle.
Chargers (incl CMS)	The physical charging hardware and its local Charge Management System.
Truck	The vehicle - a rigid truck or an electric tractor unit with one or multiple trailers
Physical infrastructure (roads, bays, parking places)	The physical infrastructure addresses the spatial dimension for this use case and therefore determines the degrees of freedom and constraints related to the installation (and when relevant the movement) of the robotic arm on site.
Client server (app, website etc.)	The application (mobile app, website) used by the Truck Driver and/or Fleet Manager to interact with the eMSP present at the charging hub.
Automatic robot arm	The physical robot hardware and software.

Preconditions

- Sites with a robotic arm plug-in charging solution exists in the truck operation area.

Main scenario:

Trigger: A need for charging via an automatic robot arm has occurred.

1. The user finds station with automatic robot arm charging capabilities in the client server.
2. The user selects relevant charging station and plans the route accordingly.
3. The user is informed about where to park the vehicle to be able to use the robotic arm for charging.

4. The user knows about the requirements regarding parking to be able to utilise the robotic arm.
5. The user is informed about the need to secure that the vehicle is stopped and is not allowed to be moved.
6. The user authorises the vehicle for charging.
7. The user starts the docking process.
8. The user can interrupt the docking process.
9. Robotic arm is docking with the vehicle and shares the status of the docking process
10. Charging starts automatically after docking.
11. System and user can stop the charging as usual (i.e. user trigger, reached target SoC, etc.)
12. Undocking starts when charging conditions have been met.
13. System starts undocking.
14. The user is informed that the undocking has been completed and that the vehicle can be moved or picked up.

Postcondition: The vehicle leaves the charging station.

Sub-use cases:

- **Sub-use case 6.1: Reservation of Automatic robot arm:** When a user finds a charging station with automatic robotic arm capabilities in the app/client server, the user is also informed about the possibility to reserve the robotic arm and available time slots. The user can then decide to make a reservation for a specific time. The user is informed about the reservation and how to go to the right charger bay within the charging station.

4.7 Use case 7: Charging in challenging operational conditions

This use case details MCS charging operations within the challenging environments typical of Europe's diverse climate zones, ranging from harsh cold to intense heat and heavy precipitation. These climatic differences lead to different requirements depending on the location, for example, managing extreme cold in Northern Europe versus intense heat in Southern Europe. Consequently, CPOs must adapt their hub designs and operational plans to specific local conditions.

While CPOs often aim for standardised, modular layouts to reduce costs, total standardisation is not always feasible. For instance, a charging station roof in Northern Europe must be structurally engineered to withstand winter snow loads. Therefore, this use case highlights how geographical location adds an extra dimension to hub design, dictating necessary variations in layout and appearance across Europe.

The main scenario and the first two sub-use cases will concern challenges related to weather. Additionally, this use case covers challenging situations like internet failure and vandalism. The primary goal is to ensure the charging station remains fully functional during challenging but operational conditions. For the logistics sector, the downtime due to this is unacceptable as it directly impacts tight business margins.

This use case also prepares the system for extreme situations where conditions exceed safe operating limits, requiring a controlled shutdown and rapid, automated recovery to minimise downtime. This has been described in sub-use case 7.X Extreme conditions. Rising climate changes will lead to extreme situations like extreme heat, wind, and flooding to increase (Climate-ADAPT,2025). High ambient temperatures push cables and power units toward their thermal limits, necessitating power throttling or shutdowns, while heavy rain and flooding require robust drainage and preventive power-offs to avoid short-circuits. Building "future-proof" stations with advanced cooling or on more flood resisting locations might add significant capital costs, creating a conflict with the logistics industry's low-margin business model. While CPOs must invest in

resilience to guarantee up time, excessive costs may lead to higher charging tariffs that slow down electrification of the commercial vehicles.

The Swedish site (Pilot 1 by Plugit), located in the Nordics, will deal directly with the challenges associated with cold and harsh winter conditions, where operational designs must contend with requirements dealing with this challenge. Meanwhile, the Belgian pilot (Pilot 2, led by Milence) is focused on a dedicated charging hub for HDVs along a critical European transport corridor, and will handle other challenging conditions for instance how to handle internet failure and vandalism while still maintaining a high throughput capacity.

Related challenges: *The logistics system has small margins in time and cost, Space and sizing constraints, Fluctuating supply and demand of energy (might be), Limited grid capacity (Energy produced and infrastructure) (might be).*

Actors & Elements

Table 10 describes the actors and elements that are part of the use case and defines their roles.

Table 10. Actors and elements in use case 7

Actors & Elements	Description
Truck driver	The operator of the vehicle who must safely handle the charging cable and interface despite harsh environmental conditions (wet, cold, etc.)
CPO	The entity responsible for managing the charging hub
Chargers (incl CMS)	The physical charging hardware and its local Charge Management System.
Truck	The vehicle, including its Battery Management System, responsible for pre-conditioning and adjusting the charging rate based on the battery temperature.
Physical infrastructure	The physical environment, including protective canopies, non-slip surfaces, and drainage systems, is essential for safety and access.

Preconditions

- The charging station is built according to the rules and regulations (guidelines, IP standards, drainage systems, etc.).
- The charging elements are built or designed considering the cold climate and the equipment's have heating elements. (rephrase)
- The outside temperature is within the charging equipment's specified operating range.

Main scenario:

Trigger: The truck needs to charge in heavy snowfall and cold temperatures.

1. The truck driver arrives at the charging station in harsh winter conditions
2. The truck driver needs to navigate to the right charging bay and be able to read the signage that is visible/ readable even when the ground is covered with snow.
3. The excess snow on the ground/driveway has been removed by the snowplough and temporarily gathered and placed outside the driving route, so it is easy for the driver to manoeuvre the truck and access the charger.

4. The driver plugs in the charger into the vehicle in a safe and convenient way. There has been made anti-slip protection by putting gravel or salt on the ground. The charging bay comprises of heating elements to avoid the snow/ice accumulation.
5. The charger's user interface is designed to minimise the drivers time spent outside. Either as fast authentication through responsive screen or automated solutions.
6. The charging session is completed successfully, and the driver leaves the station without any hazard/accidents.

Postcondition: The charging was complete even in harsh winter condition.

Sub-use cases:

- **Sub-use case 7.1: Scorching heat and sun:** High ambient temperatures cause critical components (cables, power unit) to reach their thermal limit. The chargers are designed to withstand these temperatures and still deliver full power output as the charger's cooling system has sufficient capacity. For a more pleasant experience for the drivers as well as alleviating the cooling systems of the chargers, the station has a roof for shading.
- **Sub-use case 7.2: Heavy rainfall and hailstorms:** Operations must continue uninterrupted despite intense precipitation or hail. To ensure safety and accessibility, the site should use sufficient drainage and also consider ongoing climate changes with "future-proof" drainage systems capable of handling water flow significantly above historical averages, preventing pooling around high-voltage equipment and walkways.
- **Sub-use case 7.3: Internet failure:** The default internet connection at the charging site is lost, but the power grid remains operational. If available, the system shifts over to an alternative way to access the internet e.g. from wired internet access to cellular network or to a second provider of the cellular network. If no back-up solution exists or does not work, the chargers/CMS enters an offline mode, allowing pre-authenticated vehicle (e.g. using Plug & Charger, Fleet RFID etc.) and if possible other vehicles to start/continue charging.
- **Sub-use case 7.4: Vandalism resistance:** A common challenge is that the charging cables are cut off and stolen due to their copper content. To prevent it, charger cables are physically more protected (for example metal sleeve and/or fenced charging site with access control) at the same time as the charging premises is well designed in terms of lighting, and CCTV cameras. These measures make it less attractive to attempt to steal the copper cable.

In case an intent to cut cables is made a security alarm system is activated, and a message will be sent to the CPO.

- **Sub-use case 7.X: Extreme conditions -**

This use case deals with the extreme conditions that can occur and will lead to the charging station to shut down. The most important thing is to minimise the downtime to make sure the chargers are up and running as soon as possible and that it is made in a safe way. There might occur different events which leads to shut down, there are some common steps to handle the charging station.

The charging system detects hazardous conditions and shuts down power supply, or a grid outage occurs.

The charging cables are automatically unlocked from the connected vehicles.

The system utilises on-site back-up power to keep in operation lighting, signage posts and CCTV

After the extreme event and with access to grid power, the CPO inspects the sites conditions through CCTV and repowers the system remotely if assessed as safe. To prevent accidents the station is also designed according to lockout/tagout (LOTO) procedure.

Below are listed some cases which could force the station to shut down

7.X.1. Grid power outage: Due to local or national problems in electricity grid the site loses its grid power supply.

7.X.2. Flooding: Extremely high precipitations create flooding which affects a charging station. The site has a safety system which can detect rising water levels, and it proactively shut off the power supply to the charging stations.

7.X.3. Heatwave: Extreme heat which lies outside the designed operational range of the chargers forces the chargers to shut off to avoid damages on the power electronics.

7.X.4. Storm wind: Extreme winds affect the infrastructure as objects are falling and damaging the chargers or power supply.

4.8 Use case 8: Managing site power peaks

This use case is limited only to the site and how it handles power peaks from charging. The main actor is the CPO, who needs to strike a fine balance between offering attractive service to its customers and handle its grid connection wisely. The need to manage site power peaks arises for two different reasons. The first reason is to avoid exceeding the capacity of the grid connection. The second reason is to keep costs down by avoiding power peaks and thereby lowering the CPO's grid tariffs. The grid tariffs are a significant cost driver for CPO's, especially at low usage rate of a charging station. The latter case becomes even more important with the upcoming EU legislation on time-based network tariffs.

A power peak at a charging station can arise when many vehicles charge at high power simultaneously. The ideal way to handle this would be to spread out the need of energy over a longer period. In practice, so called load balancing is already applied at many charging stations, i.e. the power supplied to each vehicle is reduced which leads to longer charging sessions. However, this approach is challenging for the logistics sector. Commercial vehicles often run on tight schedules and a slower charging speed than anticipated may result in delays and extra costs for the logistic actor. Therefore, the use of a BESS to manage power peaks is identified as the main use case since, see illustration in Figure 1. Usage of BESS will maintain the charging power for the vehicles served and at the same time alleviate the CPO from grid constraints or reduce its grid tariffs.

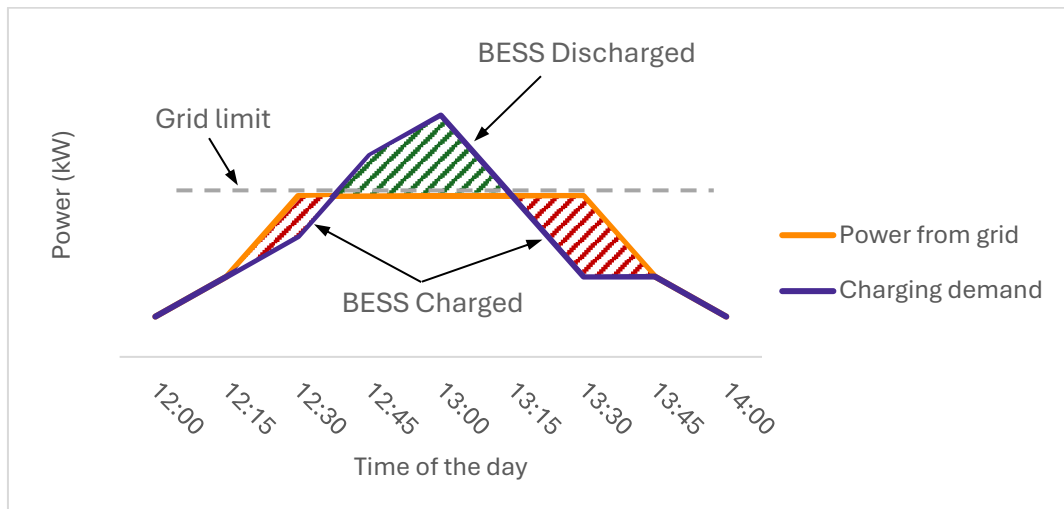


Figure 1. Concept illustration of peak power shaving from the grid during lunch time with the help of a BESS. The grid limit can be either a strict capacity limit or a set limit by the CPO to reduce the station's grid fees.

In a scenario where power peaks are shaved to manage grid costs, the CPO needs to predict when charging peaks will occur and how large they will be. To some extent, these predictions can and will be made based on historical data. But there are also clear synergies with UC1 Dynamic time booking where information about planned charging sessions is shared. Information such as truck estimated arrival time, planned time for charging, energy need and truck charging speed are valuable data points. This data will be helpful in optimising the use of the BESS for peak shaving but also to understand when and to what extent the BESS can be used for other purposes.

There is a clear advantage for the DSOs if the CPOs apply peak shaving because the grid is used more efficiently. In the short term, it may also reduce the need or urgency to build new grid capacity.

It is a relevant use case for both the pilot sites as in both host countries the CPO faces challenge to get access to grid and significant grid power fees.

Related challenges: *The logistics system has small margins in time and cost, Fluctuating supply and demand of energy, Limited grid capacity (Energy produced and infrastructure)*

Actors & Elements

Table 11 describes the actors and elements that are part of the use case and defines their roles.

Table 11. Actors and elements in use case 8

Actors & Elements	Description
CPO (incl. owner of the truck stop, land)	The entity that owns and maintains the charging hub. Has the responsibility to keep the power withdrawal below the limit agreed with DSO. Pays grid fees which partly is based on peak power withdrawal from the grid.
DSO	Electric grid distribution system operator
Charger (incl. CMS)	CMS throttles chargers power based on steering signals from EMS

Local grid (incl. Battery storage systems, PV, etc.)	The available assets behind the meter, such as BESS.
EMS	Controls BESS and is the main control unit for peak shaving. For grid fee reduction it estimates power peaks to deploy BESS most efficiently.
eMSP	The eMSP is responsible for client servers which indicate which chargers' power may be throttled.
Client server (app, website etc.)	If the CPO needs to limit its power by load balancing, the information regarding which chargers' power is throttled is communicated to customers through the client server.

Preconditions

- A BESS is installed at the charging station
- The EMS has the capability to forecast power peaks, e.g. based on historic data, for when peak shaving should be done to keep power withdrawal lower than the installed grid connection.

Main scenario:

Trigger: The power demand is about to exceed the grid connection, or the EMS has identified a power peak which could increase grid fees.

1. The EMS ensures that power withdrawal from the grid is kept below a certain threshold by providing steering signal to BESS to deliver certain amount of power.
2. Trucks are charged at highest possible speed

Postcondition:

The CPO offered highest possible charging speed for its customers at the same time as it kept the power withdrawal from the grid below the limit or reduced its grid fees.

Sub-use cases:

- **Sub-use case 8.1: Load balancing:** The CPO needs to apply load balancing as the power peak is larger than the battery capacity or the site lacks a BESS. The EMS or CMS reduces the charging power of predefined chargers. The CPO has communicated in advance with customers which chargers may be power throttled due to load balancing.
For truck drivers and fleet managers, peak shaving through load balancing is a two-sided solution. On one hand, if the CPO can offer a lower charging price, thanks to reduced investment and low operational costs, this is of course attractive to truck drivers and fleet managers who work with small margins. On the other hand, they are on a tight schedule and need to receive enough energy within the planned charging session to maintain their promises to their customers.

4.9 Use case 9: Innovative integration of MCS charging with the grid

Use case 9 takes a broader approach to the transport system and CPO integration with the electricity system, involving more actors and elements compared to UC8. The UC9 suggests how mass deployment of MCS trucks on the road, large MCS charging stations and a high share of intermittent power generation (solar, wind etc) can work effectively together. Even though the use case may become most relevant in a future mass deployment scenario, the proposed solutions may be used and provide value already today.

The UC9 builds upon future trends that will transform the systems from their current state. For example, the electrification will most probably also speed up the digitalisation of the hauliers' operations. In the future the power grid is expected to be subjected to larger stresses as the share of renewable energy will increase creating more frequent periods of surplus and shortage of energy. In addition, the broad electrification of our society, including the transport sector, constrains the grid. These transformations create an opportunity for the digitalised and electrified hauliers to integrate and optimise even further their operations to support the grid and to a larger extent harvest cheap surplus energy or at times of high cost for power or energy minimising their charging need. A precondition for flexible charging behaviour is to have a larger battery capacity and to allow higher charging power levels when needed.

Today, the CPOs have relatively fixed charging prices and with that they are acting as a buffer between the energy and transport systems. The CPOs offer a predictable service to the hauliers at the same time as they absorb fluctuating electricity prices and grid fees. However, to facilitate the scale up of MCS stations and to create an efficient future grid, more synergies could be created between the hauliers, CPOs and the electricity grid from a system of systems perspective.

In a more integrated system, the CPO could by applying a more dynamic pricing indirectly forward stresses and opportunities of the electricity grid to the hauliers in order for them to charge (or charge more) when there is a surplus electricity production or when the grid has low utilisation. This interaction between hauliers and a CPO is closely linked to Use case 1 – Dynamic time booking.

An efficient way to forward information about stresses and opportunities is through price signals and therefore it is the main use case. However, the integration can go beyond price signals in the form of providing information about variable power availability at the different charging stations forwarded to hauliers or active participation of the CPO in auxiliary grid services.

This use case is relevant to both pilot sites, as the seamless integration of high-power MCS into constrained grids is a pan-European challenge.

Related challenges: *Fluctuating supply and demand of energy, Limited grid capacity (Energy produced and infrastructure), (The logistics system has small margins in time and cost)*

Actors & Elements

Table 12 describes the actors and elements that are part of the use case and defines their roles.

Table 12. Actors and elements in use case 9

Actors & Elements	Description
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Fleet manager	The professional in charge of overseeing a company's entire vehicle and driver operations.
CPO (incl. owner of the truck stop, land)	The entity that owns and maintains the charging hub and is in charge to forward steering signals (variable prices or available power) from the electricity grid to its customers.
TSO	Electric grid transmission system operator. Responsible for the grid stability and owner of markets where auxiliary grid services are purchased.
DSO	Electric grid distribution system operator. Responsible for safe operation of the distribution grid including main responsible to specify available power which the CPO can withdraw from the grid.
Transport planner	The back office professional in charge of planning vehicle and driver operations and handling logistics to boost efficiency and minimising fuel costs. In this use case taking into account the steering signals which the CPO is providing.
Electricity retailer / Energy supplier / Energy provider	The company from which the CPOs buys the electricity
eMSP	An intermediate who can help the fleet manager, transport planner, FMS, in finding alternative charging opportunities
Local grid (incl. Battery storage systems, PV, etc.)	In case there are local assets such as BESS or PV, control them in an optimal manner to minimise the charging stations impact on the electricity grid or even provide services to it.
EMS	The energy management system controls and optimises the power across the whole truck stop including potential local energy production systems and storage.
CMS	The charging management system distributes available power among multiple chargers, adjusts charging speeds (dynamic load balancing), schedules charging, and handles billing.
Client server (app, website, etc.)	The tool of eMSP, including capabilities to communicate the steering signals from the CPO
Route planning software	The tool used by transport planner, including capabilities to take into account the steering signals from the CPO.
Electricity market	It creates electricity prices which reflects constraints or surpluses in electricity production.

Preconditions

- Variable electricity prices and grid costs can be set and communicated to the CPO customers

Main scenario:

Trigger: The day-a-head electricity prices are announced

1. The CPO updates its charging price based on the announced day-a-head electricity prices. If applicable, a variable grid cost component is added with aim to reduce charging power during peak power hours which occurs at the site, distribution grid or national grid.

2. The client server reads out the day-a-head charging costs from the CPO and forwards it automatically into the transport planners route planning system.
3. Where possible, the routes and charging patterns are adapted to the optimal trade-off for cost minimisation while still ensuring that goods are transported upon agreed pick-up and delivery time windows.

Postcondition:

The vehicles visiting the CPO and who had the possibility to alter their charging behaviour based on price signals from the electricity grid, did so. It facilitates the optimisation of the entire system including transport buyer, haulier, CPO, DSO, electricity market, electricity producer.

Sub-use cases:

- **Sub-use case 9.1: Energy community:** To handle strained grid, to decrease grid fees and to increase locally produced energy the CPO participates in a local energy community with neighbouring buildings and industries. The neighbouring buildings or industries might have more flexible power demand, which can be used to increase peak power at the charging station during a limited period. There needs to be a clear framework of how flexibility is managed/purchased within the energy community as well as communication between the charging station EMS and the EMS of the other participants in the energy community. The grid usage is optimised locally increasing the usage rate of the distribution grid and lowering the operating costs of the grid and reducing the grid build out needs.
- **Sub-use case 9.2: Variable access to power from the grid:** The amount of power that the grid can provide is variable for different reasons, such as:
 - The CPO and DSO have signed an agreement where the CPO has variable access to power. During the hours of the day when the grid is constrained, the CPO is required to reduce its power withdrawal from the grid.
 - The DSO offers a dynamic grid power withdrawal due to variations of other electricity users or variable renewable power production nearby.
 - The availability of power is known in advance and communicated to the truck route planners, who can place an optimised charging plan for the truck considering the expected grid constraints along its route.
- **Sub-use case 9.3: Self-produced renewable energy:** A variation of the Sub-use case 8.3, with the differentiation that the renewable power production is made within the premises of the site. Thus, the local EMS takes into account the increased available total power output from the station based on the local power produced on site.
- **Sub-use case 9.4: BESS for grid support:** The CPO has a BESS that it uses to provide services to the electricity grid, in addition to peak shaving described in use case 7. The battery is optimised in the near term to create maximum value in the different services the battery can provide to the electricity markets while ensuring CPO power promises towards its customers are held. Thus, creating additional revenue streams or cost reductions.

4.10 Use case 10: Provide verified emission reductions

This use case describes the necessary system functionality to automatically collect, measure, and securely report emissions related to charging events. Such a system enables the CPO to provide additional value for its customers, differentiation of its products as well as additional revenue streams.

The CPO customer may be interested to know the emissions relating to the energy they charge. It could either be based on the regulatory mandates such as the Corporate Sustainability Reporting Directive (CSRD) or offer to transport buyers a verified transport alternative powered by low emission electricity only. This is selected as the main use case.

The CPOs can also create an additional revenue stream under the Renewable Energy Directive (RED III) by gathering data on the electricity dispensed through their chargers. The directive mandates that all EU Member States establish a credit mechanism for public recharging. This system obligates fossil fuel suppliers (gasoline and diesel) to meet increasing renewable energy or GHG-reduction targets. To fulfil these obligations, fuel suppliers can purchase renewable energy credits from CPOs who provide verifiable renewable electricity to electric vehicles. If a CPO can verify the volume of electricity and its renewable origin, they create a product to sell to the fossil fuel suppliers.

The option for CPO to sell renewable energy credits to fossil fuel suppliers can also benefit the hauliers indirectly as some of the CPO costs are recovered through the trading of renewable energy credits and not through the charging price.

This use case is relevant to both pilot sites, as the main drivers for the use case is present in both Belgium and Sweden.

Related Challenge: *The logistics system has small margins in time and cost, Fluctuating supply and demand of energy*

Actors & Elements

Table 13 describes the actors and elements that are part of the use case and defines their roles.

Table 13. Actors and elements in use case 10

Actors & Elements	Description
Fleet manager	Responsible for compliance and utilising verifiable data to manage the fleet's carbon footprint.
CPO (incl. owner of the truck stop, land)	The entity that owns and maintains the charging hub/ infrastructure. Responsible for accurately measuring and securing the kWh data for verification. The CPO may also generate revenue from selling renewable energy credits to fossil fuel suppliers within REDIII.
Electricity Retailer	The entity that has a contract with the CPO to supply electricity to the charging hub.
eMSP	Aggregates charging data across multiple hubs/countries and applies to the specific regulatory calculation methodology.
Chargers (incl CMS)	Tracks how much electricity was dispensed to which truck.

Preconditions

- CPO has a system to track emissions per charging session.
- The electricity retailer provides emissions data of the supplied electricity.

- The CPO has a system to report the data to the fleet manager

Main scenario:

Trigger: The CPO and fleet manager enter an agreement on providing low-emission electricity.

1. The CPO makes a deal with the electricity retailer to supply low-carbon energy to the charging hub (e.g. power purchase agreement or Guarantee of Origin).
2. The time period starts during which every charging session and its associated low emissions are logged.
3. The CPO collects and aggregates all session data.
4. The logging period ends, and the final report is compiled.
5. The final data is reported to the fleet manager in a CSRD compliant manner.

Postcondition:

The vehicles are charged, and the verified emission reductions are reported to the fleet manager.

Sub-use cases:

- **Sub-use case 10.1: Sell renewable energy credits within REDIII:** The process is similar to the main use case. Instead of emissions, the volume of renewable energy dispensed is tracked and sold to a fossil fuel supplier.

The differentiation from the main use is mostly bureaucratic. The CPO need to register as a trader of renewable energy credits at a national regulatory body. The same regulatory body also issues the credits once the amount of renewable energy dispensed is verified by a third-party auditor. The sub-use case is finalized as the CPO sells its credit directly, or through an aggregator, to the supplier of fossil fuels for road transport.

- **Sub-use case 10.2: Spatio-temporal requirements for grid emissions:** The process for achieving high-fidelity CO₂ reporting by moving beyond generalised emissions averages. The objective is to more accurately calculate the actual carbon footprint or the electricity used based on the specific location and time of consumption. The CPO agrees with the fleet manager or is obliged by regulations (more stringent than REDIII) to track the CO₂ emissions based on when and where the vehicles are charged.
 - i. The electricity retailer provides data about the CO₂ emissions with spatio-temporal resolution from the electricity consumed by the CPO.
 - ii. The CPO reports emissions based on when and at which charging station the fleet trucks were charged.
- **Sub-use case 10.3: On site Renewable Energy:** Maximising the financial and environmental value of charging by locally produced clean energy.
 - The EMS at the charging hub actively monitors and accounts for the locally generated electricity charged into trucks.

5 SYSTEM-LEVEL REQUIREMENTS FROM USE CASES

The system-level requirements have been derived from a systematic, step-by-step analysis of the use cases. This approach involved examining each step within a use case to identify and document the requirements necessary for its implementation. Each requirement has an ID based on which use case and main scenario or sub-use case that it is associated with and then distinguished with a letter from A-Z. The requirements have been classified dependent on how important they are to fulfil the use cases:

- Must have
- Should have
- Nice to have

This classification has also been divided into the classification for long term (when MCS has been mass deployed) and the classification for the two different pilot sites. Some of the boxes for the pilot sites have also been marked to be decided (TBD) and not applicable (N/A). It is also defined which actor is the one responsible for ensuring the requirement becomes fulfilled or which element it is that needs to fulfil the requirement. In dedicated workshops, the requirements have been discussed with partners from WP2 and in addition, further experts from the MACBETH consortium were included in the discussion.

5.1 Requirements, use case 1: Dynamic time booking

Table 14 presents use case 1: *dynamic time booking* and its related sub-use cases. The ID displayed here will help identify whether the requirements below are related to the main scenario or one of the sub-use cases.

Table 14. Main scenario and sub-use case in use case 1

ID	Use case	Scenario
1	Dynamic time booking	Main scenario
1.1	Estimated time of arrival is not correct	Sub-use case 1.1
1.2	Estimated SoC/Charging need is not the same as communicated (e.g. Detouring)-	Sub-use case 1.2
1.3	Booked spot not accessible (Infrastructure failure, booked spot blocked)	Sub-use case 1.3
1.4	Booking can be cancelled	Sub-use case 1.4

Table 15 presents the requirements that apply to use case 1 and its sub-use cases. The requirements are assigned to the booking system, CPO, and eMSP. The classification of the requirements for the pilot sites is marked as 'to be decided' (TBD), as it is not decided yet whether this is something that they will implement on the pilot sites or not.

Table 15. System-level requirement list for use case 1: Dynamic time booking

ID	Requirement	Actor/ Element	Long term	Swedish pilot site	Belgian pilot site
1.A	The booking system must be able to handle many users trying to book or change the booking at the same time.	Booking system/ client server	Must have	TBD	TBD
1.B	The booking system must provide authentication mechanisms for different user roles (e.g., Driver, Transport Planner, FMS) via their respective client applications.	Booking system	Must have	TBD	TBD
1.C	The booking system and CPO shall provide a mechanism for the driver to authenticate at the reserved charging station to begin the charging session.	Booking system	Must have	TBD	TBD
1.D	The booking system shall enable the FMS/vehicle to access and provide real-time truck data, including but not limited to: target SoC, connector type, estimated time of arrival, and planned staying time.	Booking system	Nice to have	TBD	TBD
1.E	The booking system must allow for booking at least one week ahead.	CPO	Nice to have	TBD	TBD
1.F	The booking system shall define and enforce an "approved time frame" for arrival times.	Booking system	Must have	TBD	TBD
1.G	The booking system shall report charger faults or inaccessibility (e.g. infrastructure failure) to the eMSP in real-time.	Booking system	Must have	TBD	TBD
1.H	The booking system should have a live data feed from the CMS regarding charger status and availability.	Booking system	Must have	TBD	TBD
1.J	The eMSP's system must have a real-time data feed interaction with the booking system.	eMSP	Must have	TBD	TBD
1.K	The eMSP must send a notification to the user upon successful confirmation of a booking.	eMSP	Must have	TBD	TBD
1.1.A 1.2.A	The booking system must allow the user or FMS to update the parameters of an existing booking (e.g., new ETA, different energy need/SoC requirement) before the session begins.	Booking system	Must have	TBD	TBD
1.1.B	The CPO must provide a support function that can be reached 24/7.	CPO	Must have	TBD	TBD
1.1.C 1.2.B	The booking system must provide an admin panel for CPO to manage bookings, resolve issues and receive information.	Booking system	Must have	TBD	TBD
1.3.A	The CPO should have a way to signal that a charging bay is booked in order to prevent other users from blocking the bay.	CPO	Should have	TBD	TBD

ID	Requirement	Actor/Element	Long term	Swedish pilot site	Belgian pilot site
1.3.B	Upon receiving a notification that a reserved charger is unavailable before the user's arrival, the eMSP should: 1. Immediately notify the user (Driver/Transport Planner) of the problem. 2. Automatically attempt to find and reserve a suitable alternative charger (at the same or a nearby location). 3. Alternatively, obtain information on when the selected charger will be up and running again and where they can wait.	eMSP	Should have	TBD	TBD
1.4.A	Booking can be cancelled.	Booking system	Must have	TBD	TBD

The primary challenge is ensuring the different systems work together smoothly. The vehicle, the eMSP, the booking system, and the charging hardware all need to share data in real-time to realise this use case. Having the booking system integrated directly with the vehicle is an innovative future outlook that will require technical advancements to be realised.

5.2 Requirements, use case 2: Transparent communication of chargers' status and efficient authentication

Table 16 lists the main use case and the three sub-use cases. The ID field in the table will help to identify whether the requirements below are related to the main scenario or one of the sub-use cases.

Table 16. Main scenario and sub-use cases in use case 2: Transparent communication of chargers' status

ID	Use case	Scenario
2	Transparent communication of chargers' status and efficient authentication	Main scenario
2.1	Connection is down	Sub-use case 2.1
2.2	Charger is blocked	Sub-use case 2.2
2.3	Cost of charging	Sub-use case 2.3

Several requirements in the Table 17 below are related to AFIR and are mandatory for all owners/operators of public charging stations to fulfil.

Table 17. System-level requirement list for use case 2: Transparent communication of chargers' status and efficient authentication

ID	Requirement	Actor/element	Long term	Swedish pilot site	Belgian pilot site
2.A	Available charging stations, real-time status of charger and additional information as specified in AFIR article 20 must be shared through an API.	CPO	Must have	Must have	Must have
2.B	Available charging stations and real-time status of chargers should be shared through CPO's app or website.	CPO	Should have	Should have	Should have

2.C	Booking/reservation support is shared through CPO's app and/or website.	CPO	Should have	TBD	Should have
2.D	Booking/reservation support is shared to eMSPs through an API.	CPO	Must have	TBD	Must have
2.E	The site shall support rapid authentication mechanisms, payment and other functions to minimise time-to-charge e.g. plug-and-charge.	CPO	Should have	Should have	Should have
2.F	During charging, information on the power level (kW), the energy charged (kWh) and the length of the charging session are displayed locally on the charger and shared through an API.	CPO	Should have	Should have	Should have
2.G	During charging the process can be followed through the CPO's and/or eMSP's app/website.	CPO/ eMSP/ Client server	Should have	Should have	Should have
2.H	When charging is complete, a summary of the charging session is shared including location, time, cost etc.	CPO/ eMSP/ Client server	Must have	Must have	Must have
2.1.A	If the connection between the CPOs backend and a specific charging hub is down, information about other charging hubs, belonging to the same CPO, close to that location and their status should be shared when possible.	CPO	Must have	Should have	Should have
2.1.B	If the connection between the eMSP and a specific charging hub is down, information about other charging hubs close to that location and their status should be shared when possible.	eMSP/ Client server	Nice to have	Nice to have	Nice to have
2.2.A	Information should be made available about whom to contact for technical support through phone/app/website and signage at the charging station.	CPO/ eMSP/ Client server	Must have	Must have	Must have
2.2.B	Detect and inform about a parked car or truck at station without being connected to the charger.	CPO	Nice to have	Nice to have	Nice to have
2.3.A	Transparent information about price, different cost models and price dynamics when available.	eMSP/ Client server	Must have	Must have	TBD

In conclusion, use case 2 is about information sharing and the responsibility to make that information available. The information is primarily used to enable efficient transport planning and connected planning of charging. By having updated, correct information of charger status and capacity, logistic losses can be minimised. Efficiency at the charging station is also considered related to information sharing between vehicle and charger for rapid authentication in req. 2.E.

In cases where booking or reservation of chargers is supported this could be shared directly by the CPO when they have an own customer app, and through the eMSP by supplying the information through an API.

The sub-use case 2.1 handles connection problems. Depending on where the connection is down different information sharing solutions are proposed. Sub-use case 2.2 handles a physical block of the charger. A nice to have solution in the latter case could be to have the possibility to detect if a vehicle is parked there without using the charger or else not authorised to be there, to be able to solve the situation before it leads to an actual problem. The sub-use case 2.3 is different from the other sub-use cases since it's not a problem as such, but more to highlight the importance of sharing price, cost models and price dynamics when such

mechanisms are used. The normal sharing of price through signage and digital information in an app are considered to be part of the main scenario.

5.3 Requirements, use case 3: Charge without decoupling trailers

Table 18 presents use case 3 and its related sub-use cases. The ID displayed here will help identify whether the requirements below are related to the main scenario or one of the sub-use cases.

Table 18. Main scenario and sub-use cases in use case 3

ID	Use case	Scenario
3	Charge without decoupling trailers	Main scenario
3.1	Charge tractor unit and e-trailer	Sub-use case 3.1
3.2	Charge HCT	Sub-use case 3.2
3.3	Charge truck carrying dangerous goods	Sub-use case 3.3
3.4	Charge tractor unit and refrigerated trailer	Sub-use case 3.4
3.5	Charge tractor unit in trailer swapping operation	Sub-use case 3.5

In table 19 the requirements that apply for the use case: *Charge without decoupling trailers* and its sub-use cases are presented. The requirements are primary assigned to the CPO, CPM and eMSP.

Table 19. System-level requirement list for use case 3: Charge without decoupling trailers

ID	Requirement	Actor/element	Long term	Swedish pilot site	Belgian pilot site
3.A	The physical dimensions (length, width, and turning radius) of the charging bays for a truck charging station and their access routes must at least accommodate standard EU tractor-trailer combinations of a minimum length of 16.5 m (Tralert, 2025).	CPO	Must have	17.5 / 35m	16.5 m
3.B	The site layout should be designed to prevent or inherently discourage the improper parking of vehicles.	CPO	Should have	Should have	Should have
3.C	It should be possible to find information before arriving at the charging hub about which vehicle specifications (length, e-trailer, refrigerated trailer charging etc.) the charging hub supports.	CPO/eMSP	Should have	Should have	Should have
3.D	The charging hub should be designed with at least one "drive-through" bay.	CPO	Should have	Should have	Should have
3.E	Signage should be used to help the driver navigate at the charging point.	CPO	Should have	Should have	Should have
3.F	If there is only one or few MCS chargers they should be located at the drive-through bay(s).	CPO	Nice to have	Nice to have	Nice to have
3.1.A 3.4.A	A charging bay should support multipoint dual charging for refrigerated and e-trailers.	CPO/CPM	Should have	Nice to have	N/A

3.2.A	The physical dimensions (length, width, and turning radius) of at least one of the charging bays and their access routes should accommodate the maximum legal tractor-trailer combinations for that specific country or region.	CPO	Should have	Should have	Should have
3.2.B	The hub design should be "future-proof," with sufficient spatial buffer to account for potential changes in vehicle length regulations over time.	CPO	Nice to have	Nice to have	Nice to have
3.3.A	For the charging of trucks carrying dangerous goods, the charging hub shall be designed to fulfil any additional requirements identified in a formal risk assessment that combines charging standards with ADR's core principles of ignition prevention and emergency response.	CPO	Nice to have	N/A	N/A
3.5.A	If "drive-through" or long enough bays are not feasible for all chargers, the charging hub should provide clearly marked, safe, and secure "trailer-drop" parking spots in close proximity to the charging bays.	CPO	Nice to have	N/A	N/A

In conclusion, use case 3 prioritises operational flow by eliminating the time-consuming process of uncoupling trailers. The requirements identify geometric accommodation as the critical success factor; sites must adhere to minimum length specifications (16.5m for standard units, extending up to legal limits for HCT) and prioritise drive-through configurations to minimise complex manoeuvring. Further, the physical layout requirements have to be complemented with requirements of pre-arrival information, such as support for extra-long vehicles or e-trailer charging, to prevent on-site congestion caused by incompatible vehicles.

For some of the requirements, like req. 3.1.A and 3.3.A, classification is dependent on how the development of e-trailers will proceed as well as the future development of the ADR. Furthermore, the final sub-use case regarding trailer dropping presents a contrasting scenario. It highlights that customers do not always need to charge with a trailer attached, adding an extra dimension to the requirements. Although this is not currently a common practice, the requirement's relevance may increase or decrease depending on future trends.

5.4 Requirements, use case 4: Charging on a highly utilised site with maximised charging infrastructure capacity under spatial limitations

Table 20 presents use case 4. This use case does not have any sub-use cases.

Table 20. Main scenario in use case 4

ID	Use case	Scenario
4	Charging on a highly utilised site with maximised charging infrastructure capacity under spatial limitations	Main scenario

Table 21 presents the requirements for the use case: *Charging on a highly utilised site with maximised charging infrastructure capacity under spatial limitations* with sub-use cases. The requirements are primarily assigned to the CPO, CPM and the DSO.

Table 21. System-level requirement list for use case 4: Charging on a site with maximised charging infrastructure capacity under spatial limitations.

ID	Requirement	Actor/Element	Long term	Swedish pilot site	Belgian pilot site
4.A	The site must be designed with clear entrance routes that allow a driver to approach a charging bay without complex manoeuvring or interruptions from other site traffic.	CPO	Must have	Must have	Must have
4.B	The site must be designed with clear exit routes, separate from queuing or entry traffic, to allow a vehicle to depart immediately after charging is complete.	CPO	Must have	Must have	Must have
4.C	Charging bay width must allow for enough space to open the door of the vehicle and allow for a safe evacuation route.	CPO	Must have	Must have	Must have
4.D	The physical layout must be geometrically optimised (e.g., angled drive-through bays) to fit the maximum number of truck-sized charging bays within the fixed surface area.	CPO	Must have	Nice to have	Must have
4.E	The CPO must clearly mark parking bays for charging to guide drivers into the correct position, preventing obstruction of traffic paths and other chargers.	CPO	Must have	Must have	Must have
4.F	To facilitate easy on-site manoeuvring, the site must be equipped with clear and easy-to-understand signage.	CPO	Must have	Must have	Should have
4.G	Minimise the charging hardware (the size of the equipment or modular design).	CPM	Should have	Nice to have	Nice to have
4.H	Integrate charging/energy hardware into the hub design, minimising the spatial footprint, e.g., vertical storage or above/below surface, and use the space that cannot be used by vehicles on site.	CPO	Should have	Nice to have	Should have
4.I	Minimise amenities and other support functions footprint.	CPO	Should have	Nice to have	Should have
4.J	There should be a dedicated spot for where to wait/queue when waiting for a free charging bay and where other traffic is not disturbed.	CPO	Nice to have	Nice to have	Nice to have
4.K	Provide as many high power (MCS) charging bays as possible, to be able to charge more vehicles per time unit.	CPO	Should have	Should have	Should have
4.L	The up-time of the chargers needs to be over 99%.	CPO/CPM	Must have	Must have	Must have
4.M	The DSO should support the charging need by providing high power grid capacity.	DSO	Should have	Should have	Must have
4.N	The site shall, support rapid authentication mechanisms, payment and other functions to minimise time-to-charge.	CPO	Should have	Should have	Should have

In summary, this use case addresses the critical challenge of balancing high throughput charging with strict spatial limitations. This results in the requirements prioritising site flow and safety, as must have elements to prevent congestion. While the physical optimisation of hardware (e.g., vertical storage or minimised footprints for MCS) is desirable to save space, the focus for the site requirements remains on operational efficiency. To compensate for the limited number of bays, the system must rely on maximising the utilisation of the available space through high charger uptime, rapid authentication, and high-power grid connections provided

by the DSO. Ultimately, successful implementation depends on ensuring that physical densification does not compromise the driver's ability to manoeuvre and evacuate safely.

The requirements for this use case may conflict with those of use case 3. Future sites prioritising both use cases will need to balance these competing demands according to the specific scenario, thereby increasing the complexity of charging site design and management.

5.5 Requirements, use case 5: Safe LDV charging at an integrated and flexible multipoint truck charge point

Table 22 presents use case 5 and its related sub-use cases. The ID displayed here will help identify whether the requirements below are related to the main scenario or one of the sub-use cases.

Table 22. Main scenario and sub-use cases in use case 5

ID	Use case	Scenario
	Safe LDV charging at an integrated and flexible multipoint truck charge point	Main scenario
5.1	A passenger (maybe the driver or a family member, etc.) must go to the toilet, to the restaurant or other areas e.g. for recreation	Sub-use case 5.1
5.2	An LDV tries to enter and charge at times when no LDVs are allowed to charge	Sub-use case 5.2
5.3	An LDV charges at a charging station with partially integrated and flexible charging infrastructure but with separated LDV and HDV charge points	Sub-use case 5.3

Table 23 presents the requirements for the use case: *Safe LDV charging at an integrated and flexible multipoint truck charge point* with sub-use cases. The requirements are primarily assigned to the CPO and the CPM.

Table 23. System-level requirement list for use case 5: Safe LDV charging at an integrated and flexible multipoint truck charge point.

ID	Requirement	Actor/Element	Long term	Swedish pilot site	Belgian pilot site
5.A	The charging bay for combined LDV/HDV charging is equipped with minimum two charging outlets.	CPO	Should have	Nice to have	N/A
5.B	The CPO must decide in which cases the LDVs can charge, e.g. based on fixed times (e.g., "LDVs allowed 10 PM - 6 AM") or in real-time based on measured hub demand.	CPO	Must have	Must have	N/A
5.C	The CPO should have an information system to communicate access permissions for different vehicle classes, pre-arrival.	CPO	Must have	Nice to have	N/A
5.D	The CPO must enforce access rules, preventing LDV charging sessions from being initiated when non-permitted.	CPO	Must have	Must have	N/A
5.E	The site shall have clear signage (static or dynamic) to direct the safe and fluent flow of both LDVs and HDVs.	CPO	Must have	Must have	N/A
5.F	The site must have clear signage (static or dynamic) to direct the safe and fluent flow of pedestrians between parking bays and site amenities.	CPO	Must have	Must have	N/A

5.G	The flexible charge point should have accessibility in mind when being designed, including availability for people in wheelchairs.	CPO/ CPM	Should have	Should have	N/A
5.H	The CPO should have a plan on how to manage the shared grid connection and balance or prioritise loads between LDV and HDV charging.	CPO	Should have	Should Have	N/A

In summary, Use Case 5 requires a robust integration of physical safety measures and digital access control. The primary responsibility lies with the CPO to enforce rules for when the LDVs can enter, ensuring that LDVs only utilise the infrastructure when it does not impede HDV logistics. The emphasis on safe pedestrian flow and accessibility highlights the need for a holistic site design that goes beyond simple energy delivery, ensuring a safe and inclusive environment for all user groups at the pilot sites. Furthermore, enabling charging for both LDVs and HDVs at the same charge points introduces additional requirements to ensure safety and to not disturb HDV logistics flows. From a business point of view, direct and indirect costs needed to fulfil these requirements must be weighed against the income generated from higher utilisation. The added value of sharing the resources may differ depending on where the charging station is located, close to urban environments, along highways with major traffic, or in remote areas.

5.6 Requirements, use case 6: Automatic robot arm plug-in charging

Table 24 presents use case 6 and its related sub-case. The ID displayed here will help identify whether the requirements below are related to the main scenario or one of the sub-use cases.

Table 24. Main scenario and sub-use case in use case 6

ID	Use case	Scenario
6	Automatic robot arm plug-in charging	Main scenario
6.1	Reservation of Automatic robot arm	Sub-use case 6.1

Table 25 presents the requirements for the use case: *Automatic robot arm plug-in charging* with sub-use cases. The requirements are primarily assigned to the CPO, Client server, vehicle operator and the automatic robot arm. The Swedish pilot site will not have an automatic robot arm and is therefore put to not applicable (N/A).

Table 25. System-level requirement list for use case 6: Automatic robot arm plug-in charging

ID	Requirement	Actor/ Element	Long term	Swedish pilot site	Belgian pilot site
6.A	Robotic arm charging capability at charging station should be shared in app or website.	CPO/ Client server	Should have	N/A	Nice to have
6.B	Information about where to park the vehicle to be able to use the robotic arm must be shared through signage, app or website.	CPO/ Client server	Must have	N/A	Nice to have
6.C	Information about parking requirements to be able to utilise the robotic arm must be shared.	CPO/ Client server	Must have	N/A	Nice to have

6.D	Information about the charging process requirements (vehicle immobilised, how to stop charging, how to undock) must be shared at the charging station and in the app/website.	CPO/ Client server	Must have	N/A	Must have
6.E	The vehicle operator must verify that parking and charging process requirements are fulfilled.	Vehicle operator	Must have	N/A	Must have
6.F	Communication between the vehicle and the robotic arm is needed to secure additional requirements for a fully automatic solution, e.g. secure vehicle immobilised certain time before connecting and after removal.	Vehicle/ Aut. robot arm	Must have	N/A	Nice to have
6.G	The MCS lane with the robotic arm should also have the capability to be used for manual connection of the plug.	CPO	Nice to have	N/A	Nice to have
6.1.A	The possibility to reserve the robotic arm automatic charging must be shared in app or website.	CPO/ Client server/ Aut. robot arm	Must have	N/A	Nice to have
6.1.B	Information about where to park the vehicle to be able to use the reserved robotic arm must be shared through signage, app or website.	CPO/ Client server	Must have	N/A	Nice to have

The requirements listed above highlight the critical need for precise user guidance and safety protocols when introducing automated hardware into the charging ecosystem. While the long-term vision emphasises a "Must Have" status for most integration and communication requirements, the Belgian pilot site adopts a more flexible "Nice to Have" approach for several items, allowing for iterative testing of the physical hardware before fully integrating the solution, as the automatic robot arm will only be tested for a limited time at the pilot site.

5.7 Requirements, use case 7: Charging in challenging operational conditions

Table 26 outlines use case 7 and its associated sub-use cases. The main scenario and most of the sub-use cases present ways how the charging station can be maintained operational during challenging circumstances. The sub-use case 7.X – extreme conditions focus on the requirements to repower a station efficiently after an extraordinary event.

Table 26. Main scenario and sub-use case in use case 7

ID	Use case	Scenario
7	Snow and cold	Main Scenario
7.1	Extreme heat and sun	Sub-use case 1
7.2	Heavy Rainfall and Hail	Sub-use case 2
7.3	Failure - Internet	Sub-use case 3
7.4	Vandalism	Sub-use case 4
7.X	Extreme conditions	Sub-use case X

Table 27 summarises the requirements for the main scenario and its five associated sub-use cases. To effectively navigate the diverse operational challenges and environmental event at a charging hub, the CPO

must implement a specific set of active mitigation strategies and rely on specific features provided by the CPM. On the other hand, when extreme conditions necessitate a complete power shutdown, the CPO relies on a more standardised and uniform set of requirements to manage the emergency state and facilitate a safe recovery.

Table 27. System-level requirement list for use case 7: Charging in extreme operational conditions.

ID	Requirement	Actor/ Element	Long term	Swedish pilot site	Belgian pilot site
7.A	The charging station is built according to the rules and regulations (guidelines, IP standards, drainage systems, etc.).	CPO	Must have	Must have	Must have
7.B	The charging equipment is designed for winter conditions with heating elements where necessary.	CPM	Must have	Must have	Must have
7.C	Snow/ice removal around chargers where the need for manual removal is minimised e.g. ground heating for the platform where charger is located.	CPO	Should have	Nice to have	Should have
7.D	There is a dedicated area for snow accumulation.	CPO	Must have	Should have	Should have
7.E	Signage must be designed and positioned to not be covered in snow .	CPO	Should have	Must have	Should have
7.F	Charging experience is designed to minimise the drivers' required time outside.	CPM/ CPO	Nice to have	Nice to have	Nice to have
7.1. A	Well-designed cooling system to maintain sufficient charging power.	CPM	Must have	Must have	Must have
7.1. B	Roof for shading of vehicle for enhanced customer experience.	CPO	Nice to have	Nice to have	Nice to have
7.2. A	Well-designed drainage also considering heavier rainfall due to climate change.	CPO	Must have	Must have	Nice to have
7.3. A	CPO offers charging even when there is an internet/network failure.	CPO	Must have	Must have	Must have
7.3. B	A backup system for internet access.	CPO	Nice to have	Should have	Should have
7.4. A	The chargers are designed to withstand vandalism.	CPM	Should have	Should have	Should have
7.4. B	The charging premises must be well designed in terms of lighting.	CPO	Should have	Should have	Should have
7.4.C & 7.X. A	CCTV cameras should be installed to monitor deviating activities.	CPO	Should have	Should have	Should have
7.4. D	There is an alarm system which notifies the CPO during a theft/vandalism situation.	CPO / CMS	Should have	Should have	Should have
7.4. E	The site is fenced with access control.	CPO	Nice to have	N/A	Should have
7.X. B	Back-up power for lighting, signage and CCTV.	CPO	Should have	Should have	Should have
7.X.C	CMS communicates the non-availability of chargers in case of a power outage or shut down.	CMS	Must have	Must have	Must have
7.X. D	The charging system is designed for remote restart of the system without any support from technician.	CPO	Should have	Should have	Should have

This use case outlines a comprehensive set of requirements that the CPO must evaluate through the lens of a site-specific risk assessment. Because the environmental and human induced events may vary by geographic conditions – the CPO is responsible for identifying and mitigating the local threats and challenges. This proactive assessment ensures that the chosen infrastructure is specifically hardened against the unique

challenges of its environment, whether they are natural (high precipitation, heat and cold) or man-made (vandalism).

These recommendations focus on ensuring the safety of both assets and personnel in the face of increasingly volatile European climates. To build a truly reliable electric truck charging network across Europe, hubs must evolve from simple power points into climate-hardened nodes adapted to their local environment.

5.8 Requirements, use case 8: Managing site power peaks

Table 28 presents use case 8 including the sub-use case 8.1. While the main use case addresses the aspect of having a BESS for peak shaving, the sub-use case adds load balancing as a strategy to reduce peak power on site.

Table 28. Main scenario and sub-use case in use case 8

ID	Use case	Scenario
8	BESS for peak shaving	Main Scenario
8.1	Load balancing	Sub-use case 1

Table 29 presents the requirements that apply to the main scenario *BESS for peak shaving* and its sub-use case. The requirements are mainly assigned to the CPO. In addition, some of the requirements also address the element of a client server as well as a CPM. The classification of the requirements for the Swedish pilot site is marked as 'to be decided' (TBD), as it is not decided yet whether this is something that they will implement on the pilot sites or not.

Table 29. System-level requirement list for use case 8: Managing site power peaks.

ID	Requirement	Actor/Element	Long term	Swedish pilot site	Belgian pilot site
8.A	A BESS is installed at the charging station.	CPO	Must have	TBD	Nice to have
8.B	The charging site's EMS has the capacity to forecast power peaks.	CPO	Should have	TBD	Nice to have
8.1.A	Clear communication from CPO to charging customers regarding which chargers can be power throttled.	CPO/Client server	Should have	TBD	Nice to have
8.1.B	The charging site's EMS can throttle chargers' output power.	CPO/CPM	Should have	TBD	Nice to have

In conclusion, Use Case 8 supports fast charging with limited grid connection or at reduced grid fees. It is a reality in which the CPOs work already today. The proposed main scenario is based on using a BESS for peak shaving towards DSO without affecting the charging experience of the customers of the CPO. The EMS capacities play a key role to create the greatest benefit of the BESS.

In some cases, the power to the charging vehicles needs to be reduced to manage power peaks. To realise this, it is important to establish a clear communication between the CPO and the customers of the possible variation in power output from some of the chargers. Also, for this sub-use case the EMS plays a central role to coordinate the load balancing.

5.9 Requirements, use case 9: Innovative integration of MCS charging with the grid

Table 30 presents use case 9 including the sub-use cases 9.1 – 9.4. While the main scenario addresses the aspect of having a variable charging price, the sub-use cases add additional innovative elements and functions to integrate the MCS charging with the grid.

Table 30. Main scenario and sub-use case in use case 9

ID	Use case	Scenario
9	Variable charging price	Main Scenario
9.1	Energy community	Sub-use case 9.1
9.2	Increased power from nearby renewable energy	Sub-use case 9.2
9.3	Self-produced renewable energy	Sub-use case 9.2
9.4	BESS for grid support	Sub-use case 9.4

Table 31 presents the requirements for the main scenario as well as for the four sub-use cases. To realise integration the use case involves more actors and elements which are digitally connected. The integration requires a broader scope and are focused on a more long-term impact.

Table 31. System-level requirement list for use case 9: Innovative integration of MCS charging with the grid.

ID	Requirement	Actor/Element	Long term	Swedish pilot site	Belgian pilot site
9.A	The CPO sets a dynamic charging price based on variable electricity price and grid fee structure.	CPO	Must have	Nice to have	Nice to have
9.B	The client server receives variable charging price signal from CPO.	Client Server	Must have	Nice to have	Nice to have
9.C	The transport planner has route planning systems which can account for dynamic charging costs.	Transport planner	Must have	Nice to have	Nice to have
9.1.A	The CPO participates in an energy community within which flexibility can be traded.	CPO	Nice to have	Nice to have	Nice to have
9.2.A	The DSO provides dynamic information of available max power withdrawal from the grid.	DSO	Nice to have	Nice to have	Nice to have
9.2.A	The EMS has capability to adapt limit of the allowed power withdrawal from the grid based on a steering signal from the DSO.	CPO, EMS	Nice to have	Nice to have	Nice to have
9.3.A	The EMS has capability to account for additional power from local energy production.	CPO, EMS	Nice to have	Nice to have	Nice to have
9.4.A	A BESS is installed at the charging station.	CPO	Nice to have	TBD	Nice to have
9.4.B	The EMS has capability to optimise and use BESS to provide various grid services.	CPO, EMS	Nice to have	TBD	Nice to have

In conclusion, Use Case 9 deals with how the MCS station can be more closely integrated with the electricity grid and soften the tension which a scale up of MCS stations could place on the grid. While providing price signals to the hauliers and transport planners for them to act on is the main use case, the integration can also be made in other ways such as described in the sub-use cases. The CPO is the main actor and enabler in this use case but a good collaboration with many more actors is necessary to make an efficient integration of the vehicles, the charging station and the grid possible.

5.10 Requirements, use case 10: Provide verified emission reductions

Table 32 presents use case 10 including the sub-use cases 10.1 – 10.3. While the main use case describes emission data delivery to the CPO customers, the sub-use case 10.1 addresses the potential to receive additional revenue stream of the verified renewable energy. The two last sub-use cases focus on more comprehensive way to account for emissions related to the dispensed electricity.

Table 32. Main scenario and sub-use case in use case 10

ID	Use case	Scenario
10	Provide verified emission reductions	Main scenario
10.1	Sell renewable energy credits within REDIII	Sub-use case 10.1
10.2	Spatio-temporal requirements for grid emissions	Sub-use case 10.2
10.3	On site Renewable Energy	Sub-use case 10.3

Table 33 presents the requirements for the main scenario as well as for the three sub-use cases. The CPO plays a central role also in this energy related use case. In addition, this use case depends on the electricity retailer which needs to provide information about the electricity it provides to the CPO.

Table 33. System-level requirement list for use case 10: Provide verified emission reductions.

ID	Requirement	Actor/ Element	Long term	Swedish pilot site	Belgian pilot site
10.A	The CPO has a system to track emissions per charging session.	CPO	Must have	Nice to have	Nice to have
10.B	The CPO has a system to report the data to the customer.	CPO	Must have	Nice to have	Nice to have
10.C	The Electricity retailer provides emission data of the electricity provided.	Electricity retailer	Must have	Nice to have	Nice to have
10.1.A	The Electricity retailer provides how large share of used electricity comes from renewable energy.	Electricity retailer	Nice to have	Nice to have	Nice to have
10.1.B	The CPO manages necessary bureaucratic steps to acquire and sell renewable energy credits.	CPO	Nice to have	Nice to have	Nice to have
10.2.A	The Electricity retailer provides emission data for the electricity provided with a pre-defined spatio-temporal resolution.	Electricity retailer	Nice to have	Nice to have	Nice to have
10.3.A	The CPO takes into account the emission reduction due to on-site produced electricity.	CPO	Nice to have	TBD	Nice to have

This use case touches upon systems that are far broader in scope than the charging station alone: how the electricity is provided, the voluntary and mandatory reporting of emissions by hauliers, transport buyers and beyond as well as EU regulations which create additional revenue streams for the CPO.

The digital layer of the energy system of tracking the greenhouse gas emissions of charging and to create added value of this information will be of importance for the foreseeable future as it will take a long time to fully decarbonise the transport system and the electricity production. It creates a possibility for the CPO to provide a premium product to customers (selling renewable electricity and/or detailed emission accounting) and new revenue streams in the form of selling renewable energy credits within REDIII regulations. This area

is expected to develop further following changes in related legislations and the type of verified emission data requested by the CPO customers.

6 FUTURE TRENDS AND THEIR IMPLICATIONS ON USE CASE REQUIREMENTS

The logistics system is a system of systems and the electrification adds complexity. As seen above, many different use cases can be identified relating to MCS charging stations. The importance of a certain use case depends on site specific conditions, user group and their charging demand. Because use cases and requirements may vary significantly by location, not all use cases or requirements are universally applicable. Some of the use cases may also disappear or become irrelevant, when new or improved technology is introduced. In addition to the work detailed above, where use cases and their system-level requirements have been identified and their importance estimated, this chapter aims to briefly address the fact that things will change. The electrification itself alongside the ongoing digitalisation and automation will affect limitations as well as possibilities. Climate change and geo-politic developments will affect decision making and prioritisations as well as available resources. Recommendations for future activities are presented below. They have been categorised into different themes that will shape the design and operation of future charging hubs.

Logistics fleet development

The transport industry is facing an exciting challenge in enabling mass deployment of electric vehicles. It is today difficult to achieve total cost of ownership (TCO) parity for electric trucks with conventional diesel trucks, largely due to the high investment cost of a battery electric HDV and the relatively low diesel prices. For long haul applications targeted in the MACBETH project, it is specifically important to have low running costs to offset the higher investment. In some countries, the transition is accelerated by a reduction in distance-based tariffs applied e.g. in Germany and similar legislation in Switzerland and Denmark. In the Netherlands, a broad implementation of zero emission zones drives the transition towards electric vehicles. In addition, there are also other ways to achieve a lower TCO and higher transport efficiency and it is likely that there will be developments in what the logistic fleet will look like in the future. Examples of changes that can be considered are e-trailers, longer truck combinations and adopting new business cases such as trailer swapping.

The potential large-scale rollout of e-trailers (trailers equipped with their own electric drivetrains and batteries) will necessitate a shift in charging station design. Specifically, this will imply a requirement for dual charging, the ability to provide two separate charging connections within a single vehicle bay, see requirements for sub-use case 3.1. This can be a strategic value for long-haul transport, as e-trailers may be a "game changer" because they effectively increase the total energy capacity of the vehicle combination. Therefore, it can reduce the need for additional charging stops outside of the driver's mandatory breaks. Installing secondary charging outlets per bay involves additional capital expenditure. When integrating this into station design, CPOs must decide on how to integrate it based on how high the demand is, from having dual outlets in only a few bays or to have it in all. However, the business case for dual-outlet bays extends beyond just e-trailers. The dual outlets may also be used for refrigerated trailers or for charging two LDVs in one long HDV charging bay.

There is a trend in Europe to allow longer and heavier truck combinations to be able to achieve higher transport efficiency. This is important for the total layout of the charging hub, as evidenced by the requirements from use case 3 which deals with the need to charge the entire truck combination without decoupling trailers.

Today, there is a shortage of truck drivers. Consequently, companies are trying to make the profession more attractive by improving working conditions. One approach is to enable drivers to return home daily rather

than taking long-haul trips, which can be achieved through different ways of “swapping”. In trailer swapping, the driver changes trailer midway and returns to the base. This requires additional space for the swapping operation but less space for the charging (Bouffard, 2025). Another way of swapping is to change driver for the entire truck-trailer combination. This can in turn be done in different ways e.g. with drivers returning back to their respective base located at the end stops A or B or with drivers living midway between A and B. A shift towards more swapping will probably have a significant impact on the design of charging locations.

In summary, the recommendation is to include modularity and flexibility in infrastructure design, ensuring the ability to adapt to evolving vehicle standards and logistical trends.

Charging infrastructure drivers

In the long term there is an inherent advantage in having relatively fewer large charging stations with many charging points/bays than the opposite. With more bays, the customers experience stronger confidence that there will be a charging bay available. It is theoretically easier to achieve a high degree of utilisation without the risk of having customers queueing. As the number of bays increases at a single site, the share of chargers using max capacity simultaneously decreases which allows to connect relatively more chargers to the same electricity grid connection. These future advantages of large sites need to be weighed against near-term investment costs and the availability of grid connections and land. If this were the future scenario, UC1 *Dynamic booking* would not be needed from the logistics perspective, as operators could confidently assume a free charging bay will always be available at these large sites. However, a booking system could still be valuable from the CPO side as a tool to predict energy and power demand.

One of the main challenges for the CPO is to get access to, and necessary power from, the grid. With increasingly higher demand of grid power for the scale up of MCS stations, the difficulties of getting enough power may increase. There could also be another future where MCS stations as well as the transport system works more in sync with the grid, reducing the MCS charging stations impact on the grid and even provide services such as to maintain grid stability and absorb surplus renewable energy, emphasising the future importance of UC9 - *Innovative integration of MCS charging with the grid*. With future even higher MCS charging power levels in combination with larger truck batteries, the logistics fleet may be viewed as a moving BESS, adding flexibility to the system which could help in creating smoother and cheaper electrification of the transport sector.

In summary the CPO needs to consider the future benefits of large charging sites when making investments now. Also, they need to be thoughtful of how future requirements of the stations’ resilience may impact the design. Finally, all actors involved in the electrification of the transport sector need to seek ways to align more with the fluctuations in the electricity system and thereby make grid integration easier and cheaper.

System integration through digitalisation

To address the challenges outlined in the beginning of this report, the future of the industry requires the entire charging ecosystem to collaborate to optimise operations and ensure cost-efficient decision-making. This involves connecting vehicles, charging infrastructure, and the power grid via data, creating smart ecosystems for efficient logistics, optimised energy use, and managing complex demands, enabling seamless operations, and new business models.

Achieving this will likely require innovative solutions and further technological development linked to the digital use cases (UC1-2) as well as the energy use cases (UC8-10) described in this report, but practically all use cases may be affected and improved by digital solutions. These solutions or innovations involve

system-level optimisation, which is largely software-driven, based on data-heavy systems for management of fleets, energy prices, and grid demands.

Main digitalisation aspects to address:

- Smart Charging & V2G (Vehicle-to-Grid) - Digital platforms manage charging times, aligning with grid needs and renewable energy availability, using EVs as mobile storage to balance supply and demand, reducing peak loads.
- Data & Analytics - Real-time data from vehicles and infrastructure optimises routes, predicts maintenance, and informs logistics, lowering costs and emissions.
- Interconnected Systems - Digital ecosystems link vehicles, chargers, and logistics software for seamless operation, especially for heavy transport.

Autonomous vehicles

The introduction of innovative connected, cooperative, and automated mobility (CCAM) can make a significant contribution to improving transport in Europe. It can lead to many positive societal effects such as safer and more efficient transport. The logistics sector is special because of the shortage of truck drivers, the pressure to reduce costs and the high utilisation of vehicles compared to private passenger transport. Therefore, profitable business cases due to the introduction of CCAM vehicles at SAE Level 4 (see Appendix 2: SAE J3016 Levels of driving automation™) the logistics sector are already very likely.

The European Commission's strategy (COM/2018/283) recognises that professional drivers would initially gain the freedom to perform additional tasks but could in the long-term no longer be needed in the vehicles. It could also help make driving jobs more attractive and remedy the current driver shortage. Next to that, the COM/2018/283 strategy emphasises the relevance of infrastructure support for introducing CCAM vehicles. Examples are high-quality road markings and signs and digital communication of road traffic information.

Early deployments of autonomous vehicles are already on the roads. However, it is becoming apparent that large-scale rollout will be slower than once anticipated. While previous and even some current forecasts state that autonomous vehicles will be widely adopted during the 2020s. Yet recent analyses suggest mainstream deployment will be slower than that, due to the many challenges and inherent technological, regulatory and economic complexities.

Autonomous trucks will revolutionise charging stations by demanding automated, high-powered, and intelligently managed infrastructure. This shift moves away from manual plug-ins to robotic systems that charge during off-peak hours for lower costs, necessitating more strategic station placement, integration with smart grids, and new standards for faster charging. Focus will shift from human-centric stops to vehicle-centric optimisation, requiring massive upgrades and new designs for depots and public corridors. But, at the same time the mix of autonomous and manually driven EVs must be supported during a very long timeframe.

In the shorter perspective advanced driver assistance systems (ADAS), like adapted cruise control, lane keeping assistance, emergency braking, and cooperative ITS systems (C-ITS) are being introduced to assist and help the driver during long haul operations on the motorway. If these systems can be proven efficient enough to make the drivers less tired, it could potentially affect the mandated rest times, adding flexibility on when to stop and charge.

Impact on charging stations in short:

- Automated charging - Manual connection becomes obsolete; robotic arms and automated docking systems are needed for driverless operation. This is detailed in UC6.

- Smart & Flexible Scheduling - Trucks can charge whenever electricity is cheap (e.g., overnight), optimising routes and grid load, rather than being tied to driver time regulations. This further underscores the significance of UC 1 and 9.
- Strategic Location & Density - Charging points must be strategically located along highway corridors and at logistics hubs, requiring significant infrastructure investment.
- Grid Integration & Management - Smart charging software will be vital to manage energy flow, prevent peaks, and coordinate with renewable energy sources. Highlighting the importance of the energy related use cases.

Climate change and geopolitical instability

With an increasing share of electric vehicles in the logistic system, a resilient and robust charging infrastructure will be a central and critical part of our society. Adding the ongoing climate change and potential geopolitical instability, the expectations on charging stations' capabilities to withstand extreme weathers and other extreme conditions will further increase. The stations' resilience capabilities need to be very broad, from flooding proof locations to withstand cyberattacks. To build a truly reliable electric truck charging network across Europe, hubs must evolve from simple power points into climate-hardened nodes adapted to their local environment. This means moving beyond basic weatherproofing to installing smart systems like predictive cooling that anticipates heatwaves, automated snow-clearing zones for winter access, and remote-controlled safety restarts to minimise downtime after a storm. Since high power cables are expensive targets for theft, future stations should combine physical protection like reinforced sleeves with digital sensors and better lighting to avoid vandalism. If the normal communication paths via fibre and similar fail, satellite internet and AI-driven maintenance can ensure that even in the toughest conditions, the charging station stays online, protecting the tight schedules and thin profit margins of the logistics companies that depend on them.

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8 APPENDICES

The appendix includes two parts. The first covers truck driving bans in Europe during 2025, and the second covers the different levels of automation driving.

8.1 Appendix 1: Truck driving bans in Europe

This appendix covers the driving bans that are applied for trucks in Europe in 2025 at specific times and days. Special cases often apply to these bans, such as for military vehicles, specific delivery routes, or regional permits. Additionally, since night bans are often intended to control noise levels, electric vehicles might be exempt due to their quieter operation. The information is retrieved from (DHL, 2025).

Country	Permissible total weight	Weekday bans	Summer specials	
			Date	Day / Time
Austria	from 7.5 t (semi-trailer trucks from 3,5 t)	Sun 00:00-22:00 Sat 15:00-22:00 Night between 22:00-05:00 Public holidays 00:00-22:00		
Croatia	from 7.5 t	Public holidays 14:00-23:00 Day before public holiday 15:00-23:00	Jun 15-Sep 15	Sat 04:00-14:00 Sun 12:00- 23:00
Czech Republic	from 7.5 t	Sun 13:00-22:00 Public holidays 13:00-22:00	Jul-Aug	Fri 17:00-21:00 Sat 07:00-13:00
France	from 7.5 t	Sun 00:00-22:00 Sat 22:00-24:00 Public holidays 00:00-22:00 The day before multi-day public holidays 22:00-24:00	Mid Jul-Aug	Sat 07:00-19:00
Germany	from 7.5 t	Sun 00:00-22:00 Public holidays 00:00-22:00	Jul-Aug On selected routes	Sat 07:00- 20:00
Hungary	from 7.5 t	Sun 00:00-22:00	Jul-Aug	Sat 15:00-24:00

		Public holidays 00:00-22:00 Day before public holidays 22:00-24:00		
Italy	from 7.5 t	Sun 07:00-22:00 (Jun-Sep) 09:00-22:00 (oct-may) Public holidays 07:00-22:00 (Jun-Sep) 09:00-22:00 (oct-may)	Jul Aug	Sat 08:00-16:00 Sat 08:00-22:00
Liechtenstein	from 3.5 t (semi-trailer trucks from 5 t);	Sun 00:00-24:00 Night 22:00-05:00 Public holidays 00:00-24:00		
Luxembourg	from 7.5 t	In Luxembourg they have direction dependent bans Direction France: Sun 00:00-21:45 Sat 21:30-00:00 Day before public holidays 21:30-00:00 Public holidays 00:00-21:45 Direction Germany: Sun 00:00-21:45 Sat 23:30-00:00 Day before public holidays 23:30-00:00 Public holidays 00:00-21:45		
Poland	from 12 t	Public holidays 08:00-22:00 Day before public holidays 18:00-22:00	Jul-Aug	Fri 18:00-22:00 Sat 08:00-14:00 Sun 08:00-22:00
Slovakia	from 7,5 t (semi-trailer trucks from 3,5 t)	Sun 00:00-22:00	Jul-Aug	Sat 07:00-19:00

		Public holidays 00:00-22:00		
Slovenia	from 7,5 t (or from a total length of 14 m)	Sun 08:00-21:00 Public holidays 08:00-21:00	Last week Jul- first week Sep	Sat 08:00-13:00
Switzerland	from 3.5 t	Night between 22:00-05:00 Sun 00:00-24:00 Public holidays 00:00-24:00		

8.2 Appendix 2: SAE J3016 Levels of driving automation™



SAE J3016™ LEVELS OF DRIVING AUTOMATION™

Learn more here: [sae.org/standards/content/j3016_202104](https://www.sae.org/standards/content/j3016_202104)

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	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in “the driver's seat”		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	

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	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions