



Guidelines – Charging Infrastructure for Truck Depots

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Nomenclature

AC	Alternating current
AFIR	Alternative fuels infrastructure regulation
CapEx	Capital expenditure
CCS	Combined charging system
CO2	Carbon dioxide
CPO	Charge point operator
DC	Direct current
EU	European Union
EV	Electric vehicle
GCWR	Gross combined vehicle weight rating
HDV	Heavy-duty vehicles
kW	Kilowatt
kWh	Kilowatt hour
LCA	Life cycle assessment
MCS	Megawatt charging system
SOC	State of charge
TCO	Total cost of ownership

1. Introduction

1.1. Reasons to go electric

All European countries, citizens, and businesses share a common mission to strive for sustainability. As part of this mission, all modes of transport, including commercial freight vehicles, must undergo electrification in order to reach national and European carbon dioxide (CO₂) emission targets.

According to the European commission, heavy-duty vehicles (HDV) contribute to more than a quarter of CO₂ emissions from road transport¹, although only representing 2.5 % of the road fleet². This means that the over 6.4 million medium and heavy commercial vehicles on EU roads play a major role in achieving sustainability. To promote truck electrification, the European Union (EU) will continuously strengthen legislation and requirements for vehicle emissions.

As such, in 2023, the European commission has proposed to strengthen the regulation on CO₂ emission standards for heavy-duty vehicles.³ The new regulation would aim at a 45% reduction in heavy-duty vehicle emissions (compared to 2019 levels) in 2030, and a 90% reduction in 2040. This means that converting to electric trucks ultimately will be a requirement and a prerequisite to participate and compete in the market.

Electrification, however, should not only be seen as a duty and a requirement. It is also an opportunity for truck owners and depot operators to proactively prepare for the transition to achieve economic benefits and a competitive edge. Despite the initial investment costs on vehicles and charging infrastructure, electric transportation holds long-term total cost of ownership (TCO) benefits, including lower maintenance costs for vehicles and lower fuel costs (current energy prices notwithstanding).

TNO - Traffic & Transport has found that, by 2026, 90% of all truck segments investigated will reach a lower TCO, assuming an increasing parity in truck acquisition costs⁴. This will happen faster for low or medium milage trucks compared to long-haul trucks, due to the lower investment cost of the lighter truck segments. For a truck in a specific segment, however, the overall TCO will improve compared to a fossil-driven alternative, the more that it is driven.

1.2. The importance of charging infrastructure

A sufficient and effective charging infrastructure is the foundation for electrifying transportation. This is also clearly visible though the large emphasis the European commission has put on charging infrastructure as a prerequisite to achieve electrification targets.

¹ https://climate.ec.europa.eu/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles_en

² <https://www.acea.auto/publication/report-vehicles-in-use-europe-2023/>

³ <https://eur-lex.europa.eu/eli/reg/2019/1242/oj>

⁴ https://www.tno.nl/publish/pages/3655/tno_2022_r11862 techno-economic_uptake_potential_of_zero-emission_trucks_in_europe.pdf

The Alternative Fuels Infrastructure Regulation (AFIR) sets targets for the available charging power and spatial distribution of charging infrastructure for light and heavy-duty EVs⁵.

Along the the Trans-European Network (TEN-T), charging options for heavy-duty vehicles should be no more than 60 km apart by 2025 and with power values of 1.4 MW by the end of 2030 and 3.5 MW by 2035, with at least one 350 kW station being required for each location.

Though this will help long-haul transport, the vast majority of HDV charging will happen at depots – making this the single most important infrastructure. According to the European EV Charging Infrastructure Masterplan⁶ for a 30% reduction scenario in 2030, around 84% of the 279,000 charging outlets needed for electrical trucks will be located at fleet hubs (opposed to “Public fast – highway” and “Public overnight”). In terms of energy, fleet hubs are expected to cover 53% of the total energy demand for electric trucks. For urban/regional trucks, addressed by this guide, the dependence on charging hubs (including private depots) will be even greater.

It is therefore important for fleet and depot owners to proactively prepare this depot infrastructure. A risk however is that initial costs and technical uncertainties will hold back this development. This guide is made to help getting started on electrifying truck depots.

1.3. How this guide can help

This guide will provide **information and guidance** to **companies owning and operating private truck depots** and aims at supporting **better and more informed decisions** on investing in **charging solutions**.

The guide is specifically aimed at **private depots** established to serve a single fleet of trucks **for hour-long inter-shift layovers in the daytime or during night** – and not charging hubs or logistics centers established to provide B2B charging, logistics and parking services.

The depots aimed at by this guide would service as base for trucks of a single company serving an urban or regional area.

Based on the above, we assume that the company owning the fleet and the depot to be the same, although this may not always be the case. While it may complicate the investment strategy and costs if the depot owner and fleet owner are different, we still believe the guide can provide help in such situations.

The guide is organized as follows:

First, we provide a brief overview of charging solutions for trucks in order to provide the reader with basic knowledge and terminology on the topic.

Next, we list the most important questions which the depot operator should start considering, all of which determine the type of charging infrastructure needed. This list is useful when communicating with possible providers of charging infrastructure and services.

The guide then describes the high-level phases of charging infrastructure procurement including timelines and CapEx. While most of the numbers are based on the authors’ experience from Denmark,

⁵ https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12251-Low-emission-vehicles-improving-the-EUs-refuelling-recharging-infrastructure_en

⁶ <https://www.acea.auto/publication/european-electric-vehicle-charging-infrastructure-masterplan/>

they are complemented with figures from European reports, where available. Next, the guide summarizes the main considerations to be made during the preparational phase, allowing to choose the best possible charging infrastructure. To this end, the infrastructure will meet the demand at the lowest possible cost while adhering to spatial constraints and the available grid capacity.

The most important steps in the preparational phase are to **(1) establish your charging needs**, to **(2) identify charging solutions**, and finally to **(3) assess the depot**. Throughout these steps the guide will also provide recommendations and tips which may provide improvements and savings when establishing the infrastructure.

Finally, we summarize the most important recommendations and lessons described throughout the guide in section six. We believe that the information provided will be useful for fleet and depot owners – and may accelerate the electrification of trucks in Europe.

2. Charging solutions – an overview

2.1. Charging options for trucks

The type of chargers chosen for a depot depends primarily on the charging power needed by the trucks to fulfill their daily energy requirements (driving, refrigerating, concrete mixing, refuse collecting, etc.). The two main categories of charging are so-called alternating current (AC) and direct current (DC) charging. AC charging is used for lower charging powers up to 43 kW – while DC can provide up to 350 kilowatts (KW) with CCS and several megawatts (MW) with MCS. While DC charging is more widely used and supported by trucks, and adds several additional advantages (see Section B below), the costs are also greater – keeping AC charging as a relevant option for lighter urban trucks.

This part of the guide will present three important aspects to charging. (A) The charging power that contemporary e-trucks typically support, (B) charging levels supported by the CCS and MCS plug, and finally (C) examples of real chargers and their physical characteristics.

We use the term *charger* to describe the entire physical asset/enclosure used to charge the vehicles. The term *charge point* is used to describe the individual outlets used to physically connect the trucks. Some chargers have two or more charge points allowing multiple trucks to share a single charger.

A. Supported charging powers in trucks today

Different models of trucks will support different charging power levels for AC and DC charging. For some trucks there are different options for charging powers that can be specified at the time of order or that can be added as a retrofit later. It is of course important to ensure that the trucks will match the charging equipment in terms of power.

Figure 1 illustrates a few examples of contemporary e-trucks and the charging power that they support.

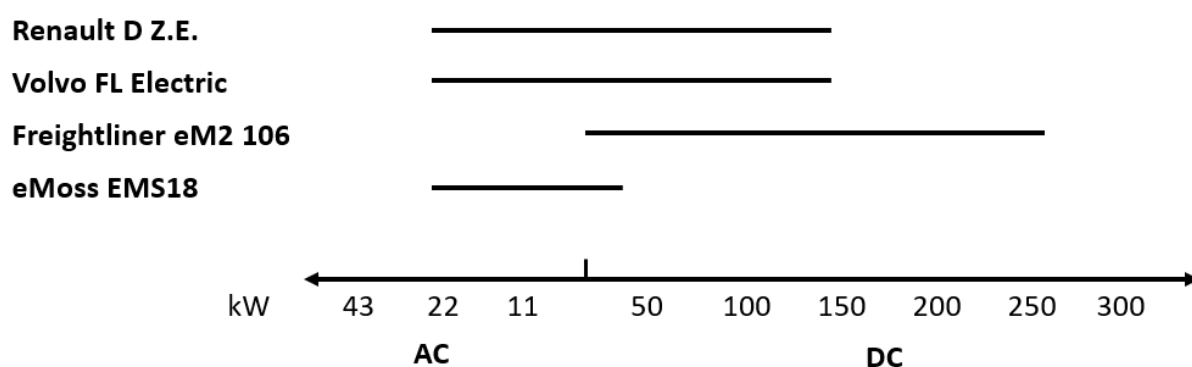


Figure 1: Examples of charging power in trucks.

Be aware that charging of above 22 kW AC or 150-200 kW DC is less common in contemporary trucks. Several trucks do not support AC – while DC charging support should be seen as mandatory.



Especially for high-power charging it is common that the experienced charging power will be lower than the nominal charging power specified by charging equipment and truck. This is determined by the so-called “charging curve” of electric vehicles and is influenced by the temperature, the state of charge of the battery, and several other factors.

B. Charging levels supported by the CCS and MCS plug

The majority of charging at depots is facilitated using the Combined Charging System (CCS) - type 2 inlet defined by the IEC 62196 standard. The inlet allows trucks to use both AC and DC chargers using the same physical plug opening.

The same association who has promoted CCS, CharIN, is also behind the development of a new charging standard to support higher charging powers, in the Megawatt range, especially designed for the heavy transport sector, including trucks. The Megawatt Charging System (MCS) standard will be more suitable to meet the demand from trucks in situations where short parking and layover periods will have to support the driving needs. This is especially relevant for long-haul transport where trucks charge along the route – or at destinations during loading/unloading.

Figure 2 shows some typical options for charging power, the corresponding charging speed, and associated cost range. The charging speed is based on the nominal charging power of the charge point and should be considered as the maximum charging speed obtained – the typical charging speed will be lower, especially for higher charging powers. Costs are based on ACEA estimates⁷.



AC charging vs. DC charging – what’s the difference?

- Our common electricity system runs on alternating current (AC) which must be converted to direct current (DC) needed by the truck batteries. This means that a conversion from AC to DC needs to take place before the electric energy can be delivered to the truck battery.
- If that conversion happens in the truck we call this AC charging – the charger simply delivers AC power to the vehicle which then takes care of the conversion. Conversely, if the charging station does the conversion, it is called DC charging.
- The power components taking care of the conversion will add cost and weight – this is why DC chargers are typically larger and cost more. Onboard chargers are typically small (with relatively limited power) to save costs and weight.
- The immediate benefit of DC charging is the increase in charging speed and the broader support among trucks. Moreover, the communication mode used in DC charging typically allows for more advanced options including pre-heating, pre-conditioning, and information on the battery SOC.

⁷ ACEA, Research Whitepaper, European EV Charging Infrastructure Masterplan, 2022

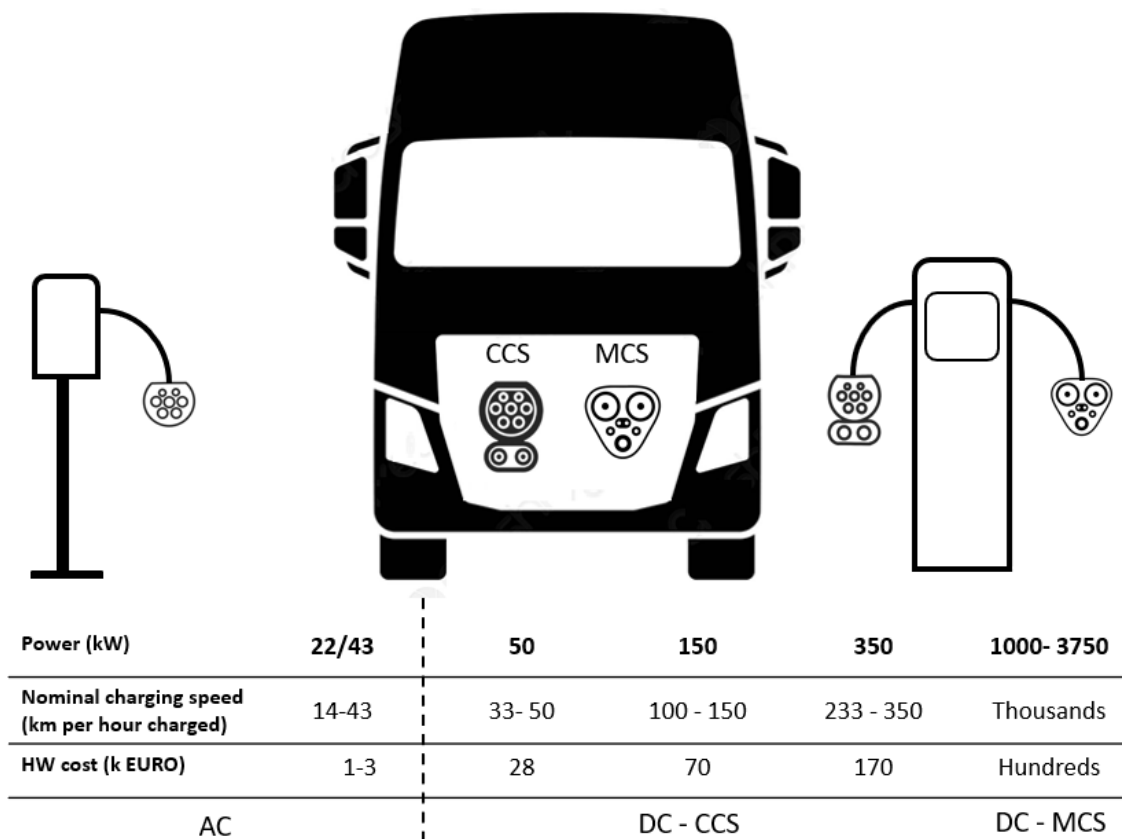


Figure 2: AC and DC charging using CCS and MCS inlet. Charging speeds are based on an assumed consumption of 1-1.5 kWh per km, the maximum/nominal charging power and cost provided by “European EV Charging Infrastructure Masterplan”, ACEA, 2022. The placing of the inlets on the truck is for illustrative purposes only.

In this guide, the emphasis is put charging powers between 22 kW AC and 150 kW DC charging, since this range represents best the needs encountered at private depots within the scope of this guide. If the fleet has an extraordinary charging demand and limited layover time available for charging at the depot – we recommend talking to a consultant about the possibility of 350 kW and MCS charging.

In case AC chargers are sufficient to meet the demand it is also worth considering including one or a few DC chargers to handle special events where a more pressing need for charging arises.

C. Charging solution examples – placement and physical footprint

Depending on the chosen solution, the physical charging hardware will have different dimensions which influence the placement and protection needed in the environment in which they are installed. While equipment is continuously developed and specialized to fit into many types of environments – depending on specific user needs and special constraints – we here define three main types as illustrated in Figure 3, supporting either AC type-2 (Mennekes) or CCS type plugs. The main difference between these categories is the space they will take up at the depot and the specific placement of the hardware relative to the trucks.



Figure 3 – Type 2 /CCS charger types and dimensions a) Charging box (AC Type 2) mounted on pole. Source:zapp.dk b) Free standing DC charger (DC CCS). Source: hypercharger.it c) Satellite chargers (DC CCS). Source: kempower.com

a) AC/DC Charging box

The small size of charging boxes allows for many placement options. The boxes are typically either mounted on a wall, or on a dedicated charging pole in sets of one-two. This design is typically used for AC charging – although charging boxes for DC charging are also available for moderate power levels (typically 50 kW). The charger in Figure 3 measures (H*W*D) 392 x 258 x 112 mm.

b) DC charger – free standing

The most common solution for DC chargers is the classical free standing version. The chargers are placed on the terrain relatively close to where the trucks can park. The “fridge” size of such chargers increases the considerations which must be made for the maneuverability of the trucks and takes up the most space estate compared to the two other categories. The solution illustrated in Figure 3 measures (H*W*D) 2250 x 420 x 854 mm.

c) DC charger - Satellite

An alternative solution is the option of collecting the power electronics in a separate enclosure which can be placed separately from the charging outlets themselves. This means that the charging solution will take up less space in the area where the trucks operate and can have advantages regarding safety and maneuverability. The solution shown in Figure 3 measures (H*W*D) 1500 x 300 x 300 mm.

2.2. Diagram of typical installation

When building charging infrastructure at a depot, the chargers will be integrated into the existing electricity installation. Figure 4 provides an overview of the components and key connection points. Commonly, depots are connected via underground cables to the public distribution grid. The connection point is equipped with an electricity meter measuring the consumption of the depot. The grid connection point is marked with number ①. The consumption of the already existing electric installation including all appliances is in the following referred to as the “base load”, indicated by ②. The chargers are integrated into the existing electric installation at point ③, which can be equipped with an electricity meter dedicated to measuring the aggregated consumption of the charging infrastructure.

One of the key questions when building charging infrastructure at a depot is if the existing electric installation of the building is sufficient for incorporating the additional load imposed by the chargers. The added consumption of the chargers at point ③ and the base load at point ② must always be lower than the power rating of the grid connection point ①. This topic will be, among other items, discussed in the following section.

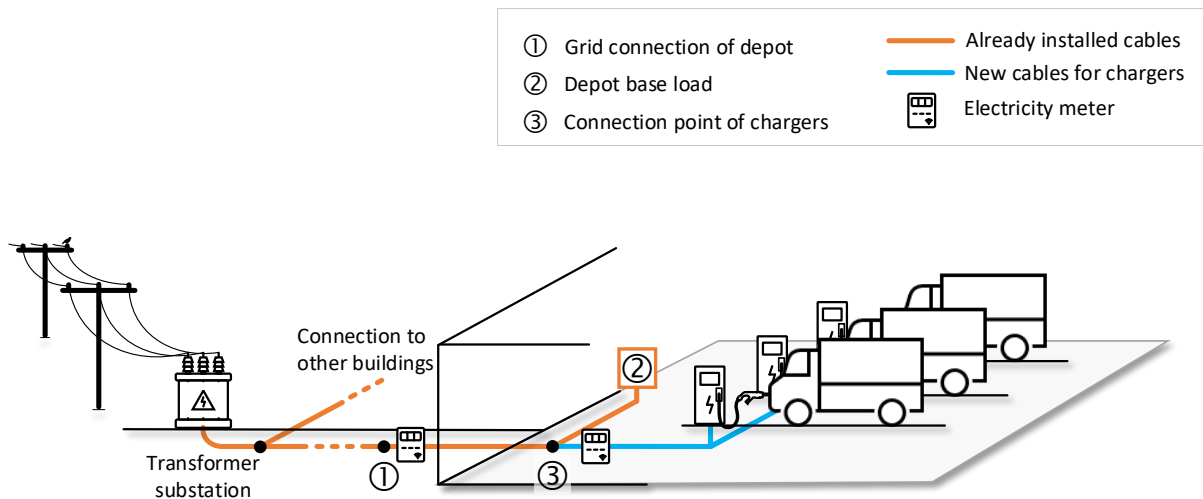


Figure 4: Overview of depot with charging infrastructure.

3. Key questions for your depot

Before choosing a charging solution for the depot there are a number of important questions that will determine the need in terms of chargers and grid connection. Having answers ready for most of these questions will help when going through the rest of the guide, but also when talking to potential subcontractors or consultants.

Establish your charging needs

- 1. How many electric trucks will use the depot now and in the future?**
Make a forward-looking plan for how much of your fleet you will electrify and when.
- 2. What are the usage patterns of the trucks using your depot?**
Determine how long the trucks are parked at the depot and when.
- 3. What distances do the trucks drive between visiting the depot?**
Both on average and “worst-case”.
- 4. How much energy are the electric trucks spending per km driven?**
Provided by truck manufacturer, but also take practical experience of other fleet operators into account.

Identify charging solutions

- 5. What charging power will the electric trucks be able to support for AC and DC charging, respectively?**
If you can customize the trucks charging options, you may first consider if you will charge AC or DC at the depot.
- 6. What are your long-term plans for charging opportunities at the depot?**
How many charging options will you ultimately need at the depot.

Assess the depot

- 7. What is the grid connection capacity at your depot?**
If in doubt, consult an electrician and your grid company.
- 8. Are there size constraints at the depot which may limit the possibility of placing chargers or having the trucks access them?**
Especially free-standing DC chargers take up space and custom solutions may be necessary.
- 9. What regulations and safety considerations apply for the depot?**
National/regional/local and technical regulations regarding the installation of charging infrastructure need to be consulted.
- 10. Is the depot co-located with PV or battery storage are there any plans for this?**
Both may decrease grid-associated costs and carbon footprint.

4. Establishing charging infrastructure – phases and costs

This guide is meant to support the first, preparational phase of establishing charging infrastructure. As illustrated in Figure 5 this guide focuses on the main steps that need to be taken to assess the best solutions for charging. We recommend contacting the local grid company even before making this assessment as the possibilities, costs and lead times that they can indicate will have a large bearing on the economy and time needed for the project.

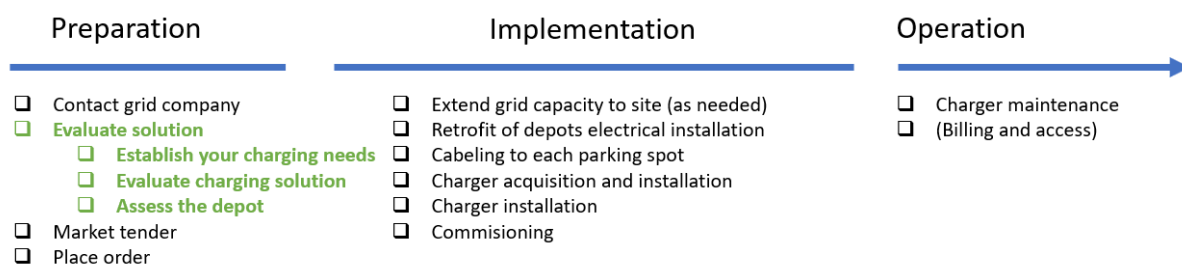


Figure 5: main phases of establishing charging infrastructure

In the following chapter “Choosing a solution” you can read about the considerations which will go into dimensioning the infrastructure to the depot’s particular needs – so you are better equipped when reaching out to consultants, technicians and your grid company.

In this section we will provide time and CapEx estimates for establishing a charging infrastructure

4.1. Timeline for deploying charging infrastructure

Establishing a charging infrastructure can take from a few months up to several years (worst case) depending on the chosen charger solutions and the grid’s ability to accommodate that demand.





A rise in demand for charging infrastructure means that bottlenecks may arise – and should be anticipated in the project plan. Establishing early contact and coordination with providers (charger providers, technicians, grid company) will provide the depot operator with a better estimate of the time needed.

The time it will take to establish a charging infrastructure depends on four main processes in the implementation phase⁸; delivery, permits, installation and potential grid extensions.

While the duration of each process varies significantly over time and for each country/region, we here provide examples from Denmark to provide a rough estimate on the order of magnitude which may be expected.

⁸ EU EV Charging Masterplan, expert interviews, Eurelectric, CLEPA

Table 1 - Estimated lead times for 22 kW AC and 150 DC chargers, Denmark 2023.


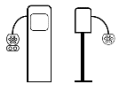
	AC 22 kW	DC 50 kW	DC 150 kW
 Time for delivering chargers: Especially high-power chargers may have longer lead times.	1-2 months	2-5 months	2-5 months
 Construction permits: For high-power charging, requiring larger re-constructions/depot retrofits, getting the appropriate permits may take time.	-	-	1-6 months
 Installation: Electricians with experience in charging infrastructure are in high demand.	2-3 months	2-3 months	2-5 months
 DSO approval and grid extension: Grid companies may have longer lead times for approving and delivering extra capacity due to high demand.	1-3 months	1-3 months	3-24 months
Total time	<u>3-6 months</u>	<u>4-8 months</u>	<u>6-24 months</u>

The table illustrates the differences time depending on the charging powers required – but also the uncertainties associated with the respective processes. It is assumed that some of the above processes can be carried out in parallel.

4.2. Infrastructure CapEx



The main determining factor to the CapEx is the size of the infrastructure in terms of numbers of charge points and the power rating of each. Faster chargers will in general cost more and result in larger costs for grid upgrades. The following table present estimates for the main costs of establishing a single AC or DC outlet based on numbers from ACEA⁹ supplemented by input from a Danish installation company.

The main costs of establishing a charging infrastructure are listed below.

	AC 22 kW	DC 50 kW	DC 150 kW ¹⁰
 Planning and administration	1 k€	1.5 k€	2 k€
 Charging equipment	1 k€	10 k€	70 k€

⁹ ACEA, Research Whitepaper, European EV Charging Infrastructure Masterplan, 2022

¹⁰ Source AFIR Impact Assessment 1/2 Table 48, https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12251-Low-emission-vehicles-improving-the-EUs-refuelling-recharging-infrastructure_en

		Installation	1 k€	5 k€	60 k€
		Cost per outlet (excl. grid upgrades)	<u>1.5 k€</u>	<u>16.5 k€</u>	<u>132 k€</u>
CASE: Denmark		Grid upgrades – from best to worst case. Based on Danish connection fees of ~130 EURO/Amp.	0–4 k€	0–10.5 k€	0–50 k€
		Cost per outlet (with grid upgrades)	<u>1.5–5.5 k€</u>	<u>16.5k – 27 k€</u>	<u>132–182 k€</u>

Danish customers would pay a fixed grid connection tariff per Ampere required at the facility – this will differ from country to country and it is best to receive an early cost indication from the grid company as soon as the power requirements have been estimated.



Key remarks on costs and installation times

- A 22 kW AC charger can cost 1.5–5.5 k€ and takes up to 6 months to install, a 150 kW DC charger can cost 132–182 k€ and takes up to 24 months to install.
- As such, it is important to establish an early understanding of the charging power requirement, as this will determine both CapEx and time needed to complete the charging infrastructure.
- Regardless of the charging infrastructure, depot operators should start the implementation process as early as possible to accommodate for possible delays and lead times in charger acquisition, installation, and grid upgrades.

5. Choosing a solution

When establishing charging infrastructure, three main steps are imperative:

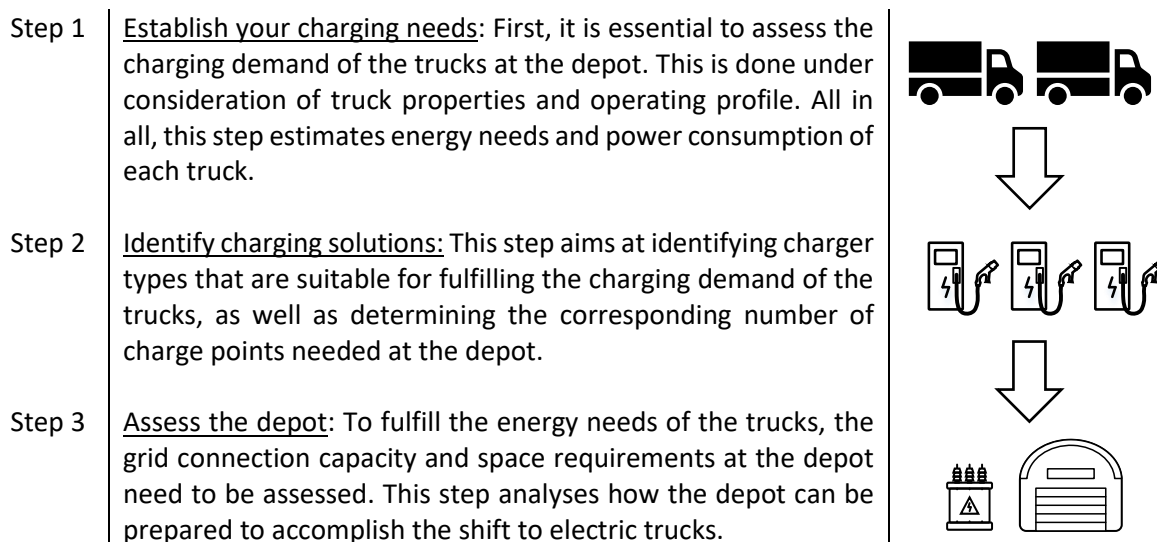


Figure 6: Establishing charging infrastructure in three steps.

The following subsections provide detailed information on each of the three steps. Although the steps build up on each other, the overall methodology is still considered part of the preparation phase. This means that decisions on the charging solution should only be made after the assessment of all three steps. For clarifying the theoretical aspects, an exemplary fleet profile is used to demonstrate each step.

5.1. Establish your charging demand

To determine the charging demand of a single truck, the daily driving distance (in km) and the consumption of the truck (in kWh/km) need to be considered. The energy demand E of the truck is calculated as:

$$E = \text{distance} \cdot \text{consumption} + \text{auxiliary}$$

While the driving distance is usually well known by the fleet operator, the consumption of the truck can be provided by the truck manufacturer. However, like for diesel trucks, the actual consumption can differ from the stated values. For this reason, practical experience and test drives can help identify the realistic truck consumption and provide important insights, since the consumption can largely vary with the driving style. If present, auxiliary systems of the truck should also be taken into account, for instance, refrigeration, concrete mixing, or refuse collecting.

The energy charged at the depot cannot exceed the usable battery capacity of the truck. For instance, if the daily driving distance is larger than the maximum vehicle range, public chargers or charging opportunities at logistic centers need to be used in addition to depot charging. In these cases, the

considerations for depot charging only take into account the truck's battery capacity as the energy demand, and not the overall consumption between depot charging.

Once the energy demand of a truck is known, the minimum charging power that needs to be provided at the depot is calculated. The calculation is based on the truck's energy demand at the depot, E (in kWh), the time at the depot t (in hours), and the charging efficiency η (in percent):

$$P_{min} = \frac{E}{t} \cdot \frac{1}{\eta}$$

The minimum power P_{min} indicates the power a truck would need to charge continuously at during its time at the depot to fulfill the energy needs. The equation shows that for shorter layover times at the depot, the required power level increases. Furthermore, the efficiency η takes into account the power losses in charger and truck battery. With lower efficiency, more energy needs to be provided by the depot to compensate for the losses during the charging process. The charging efficiency depends on various factors such as the specific battery type, the charger type, and charging power. To provide a simple figure, we recommend calculating with an efficiency of 90%.



In case the fleet comprises different types of trucks and/or different operating profiles, the method should be applied to each truck group individually. This is necessary since the different trucks might require different chargers to fulfill their individual energy needs.

CASE – exemplary fleet profile

The presented methodology is demonstrated with an exemplary fleet profile, presented in the following table.

Truck properties	
Category	Weight category 1, rigid
Weight	18 t. (GCWR)
Usable battery capacity	316 kWh
Consumption	0.95 kWh/km
AC charging power	22 kW
DC charging power	150 kW
Operation	
Distance between depot charging	130 km
Time at depot	17:00 – 7:00 (14 hours)
Number of vehicles	5



Source: www.volvotrucks.dk

First, the daily energy needs of a single truck are calculated based on the driving distance and the truck consumption:

$$E = distance \cdot consumption = 130 \text{ km} \cdot 0.95 \text{ kWh/km} = 123.5 \text{ kWh}$$

The battery capacity of 316 kWh is sufficient to cover the daily energy needs. Therefore, the daily charging demand at the depot is 123.5 kWh.

The minimum charging power is estimated based on the energy demand, the time at the depot, and the charging efficiency. For the present case, a charging efficiency of $\eta = 90\%$ is assumed, considering power losses in charger and truck battery. The minimum power is calculated as:

$$P_{min} = \frac{E}{t} \cdot \frac{1}{\eta} = \frac{123.5 \text{ kWh}}{14 \text{ h}} \cdot \frac{1}{90\%} = 9.8 \text{ kW}$$

The truck would need to charge continuously with an average power of 9.8 kW during the time at the depot to fulfill the energy needs. Building on this, the following section presents the selection process for the chargers.

5.2. Identify charging solutions

The decision on the charging infrastructure layout centers around two main questions, addressing the type and the number of charge points.

1) What type of chargers are needed?

In the previous step the energy need E per truck was estimated, as well as the minimum charging power P_{min} . This power corresponds to continuous charging between arrival and departure. The power rating of the charger should clearly exceed this value to ensure that the truck reaches its energy needs with a sufficient time buffer before departure.

The time buffer should be considered for several reasons. First, if the truck arrives late at the depot, the charger has less time to provide the required energy. Second, in case of increased energy needs on single days, e.g., due to traffic or unanticipated detours, the charger must recharge more energy in the given layover time at the depot. Third, a truck commonly reduces the charging power when the battery approaches its upper charge limit. Hence, the average charging power of a charging process is lower than the rated power of the charger.

When selecting an AC charger, the rated power should be at least 50% more than the minimum average power calculated in step 1:

$$P_{AC \text{ charger}} > 1.5 \cdot P_{min}$$

When selecting a DC charger, the rated power should be at least double the minimum average power calculated in step 1:

$$P_{DC \text{ charger}} > 2 \cdot P_{min}$$

The reason for this distinction lies in the overall higher power rating at DC chargers. Generally, trucks will reduce their charging power when their battery approaches 100% SOC. At high power levels, which are experienced at fast chargers, the truck will reduce the charging power from an earlier charge level, requiring a larger time buffer.

It should be noted that the values for $P_{AC \text{ charger}}$ and $P_{DC \text{ charger}}$ are minimum requirements for the power rating of the charge points. The rating can also be chosen higher to achieve more flexibility for shifting the charging processes to preferable time windows, for instance, to periods with lower electricity prices. Besides considerations on both investment and operating costs for the charging

infrastructure, it is indispensable to assess the existing electric installation at the depot including the grid connection capacity, which is further addressed in Section 5.3.

Another crucial aspect in the selection of suitable chargers is compatibility with the truck properties. For instance, assuming a truck can charge up to 22 kW at an AC charger, and up to 150 kW at a DC charger: If P_{min} was estimated at 25 kW, only DC charge points with 50 kW or more are suitable. In this example, AC charge points of 43 kW are not suitable since the truck would only charge at 22kW and therefore not reach the energy needs.

2) How many charge points are needed?

The number of charge points depends to a large extent on the fleet size, but is also influenced by their coincidence factor at the depot, i.e., if they are using the depot at the same time. For fleets with a homogeneous schedule where all trucks arrive and leave at the same time, a truck/charge point ratio of 1:1 is needed, meaning that there is one functional charge point per truck. For fleets where the trucks have different operating schedules the number of charge points may be chosen to be less than the number of trucks, presuming that their schedules allow to use the same charge points consecutively.

Special considerations apply to DC chargers, which are often built with two charge points (connectors/plugs) per charger. In this case, one charger can be used by two trucks simultaneously. When selecting the charger rating, it is important to consider that each of the charge points can provide the power levels required for fulfilling the trucks' charging needs. Assuming a scenario where the minimum power rating for the charger was estimated as $P_{DC\ charger} = 60\text{ kW}$. In this case, a DC charger with two connectors à 75 kW can charge two trucks simultaneously. Hence, the total power rating of the DC charger is 150 kW.

In case AC chargers are sufficient to meet the demand it is also worth considering installing one or more high-power DC chargers, depending on the fleet size. This can help to handle special events where a more pressing need for charging arises for individual trucks.



Heterogeneous fleets with diverse truck types and/or operating profiles might require a mix of AC and DC chargers.

CASE – exemplary fleet profile

In the previous step the minimum average charging power of the truck at the depot was estimated as 9.8 kW. This value corresponds to continuous charging between arrival and departure.

The power rating of the charge point should clearly exceed this value to ensure that the truck reaches the required energy with a sufficient time buffer. The minimum power rating of the charge point is estimated as

$$P_{AC\ charger} > 1.5 \cdot 9.8\text{ kW} = 14.7\text{ kW}$$

In the present example, an AC charge point with a rated power of 22 kW is suitable for fulfilling the charging needs. A charge point



Source: <https://new.abb.com/>

with a rated power of 11 kW should not be considered, as it does not provide a sufficient time buffer in case of delayed arrivals at the depot or an increased energy demand due to unanticipated detours. The following figure shows the truck charging profile at a 22 kW AC charge point. The truck arrives at the depot at 17:00 and leaves at 7:00 the next morning. The charging process is completed around midnight.

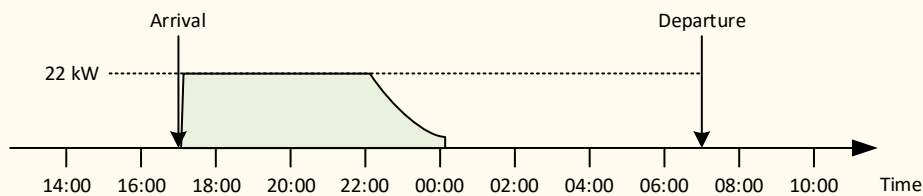


Figure 7: Charging profile of a single truck at a 22 kW AC charge point.

For the fleet of 5 trucks, a total of 5 AC charge points with a rated power of 22 kW each are needed. This corresponds to a truck/charge point ratio of 1:1. The aggregated consumption of all charging processes is crucial to assess in relation to the available grid connection capacity, which is addressed in the following section.

5.3. Assess the depot

To facilitate the successful implementation of charging infrastructure at a depot, both electrical and spatial requirements need to be considered. This step addresses related questions and further provides recommendations for the management and operation of the depot.

1) Is the grid connection sufficient?

When installing charging infrastructure at a depot, it is crucial to assess if the existing grid capacity is sufficient to incorporate the demand added by the chargers, under consideration of the already existing consumption at the depot. Assuming the “worst case” of simultaneous charging at the rated power of all chargers, the maximum total added load is calculated as

$$P_{charging} = \text{number of chargers} \cdot \text{power per charger}$$

The grid connection capacity must be able to satisfy both the charging needs and the base load consisting of the other appliances of the depot (e.g., lights, air conditioning units), as introduced in Section 2.2. If the additional load imposed by the added charging infrastructure cannot be incorporated in the existing electric installation of the depot, the grid connection needs to be upgraded. It is noteworthy that grid connection upgrades commonly entail significant investment costs for equipment and installation, as well as higher grid connection fees to the distribution grid operator (Section 4). Due to the high costs, it is essential to consider solutions for minimizing grid connection upgrades. This includes load management systems, which ensure that the collective power consumption of all chargers always stays below a certain limit – and that the available power is shared among the trucks.



Battery and photovoltaic systems can reduce both the grid impact and the operating costs. The battery system can be charged during hours with low electricity prices and with locally produced energy, and later discharged to cover parts of the truck demand.

CASE – exemplary fleet profile

In the present example we assume a grid capacity of the depot of 43 kW. This corresponds to a standard 3 phase grid connection of 230V and 63A.

The following figure illustrates the base load by other appliances, aggregated with the charging processes of the 5 trucks, assuming immediate charging after arrival at the depot. The trucks add an additional load of $5 \cdot 22 \text{ kW} = 110 \text{ kW}$ to the base load. As visible in the figure, the existing grid capacity of 43 kW is not sufficient to incorporate the additional load imposed by truck charging. Assuming a maximum base load of 15 kW during the time of truck charging, the grid connection must be increased to at least 125 kW, which is approximately three times the current grid connection.

The need for large grid connection upgrades can be reduced by using load management solutions for the chargers. This allows to actively control and coordinate the charging processes of all trucks, utilizing the temporal flexibility of the charging processes. The effect is also demonstrated in the following figure. By shifting the energy consumption of the chargers, the overall power consumption at the depot can be kept below a given threshold, in the given example below 70 kW. Despite the imposed power limit, the charging processes are finished around 2h before departure.

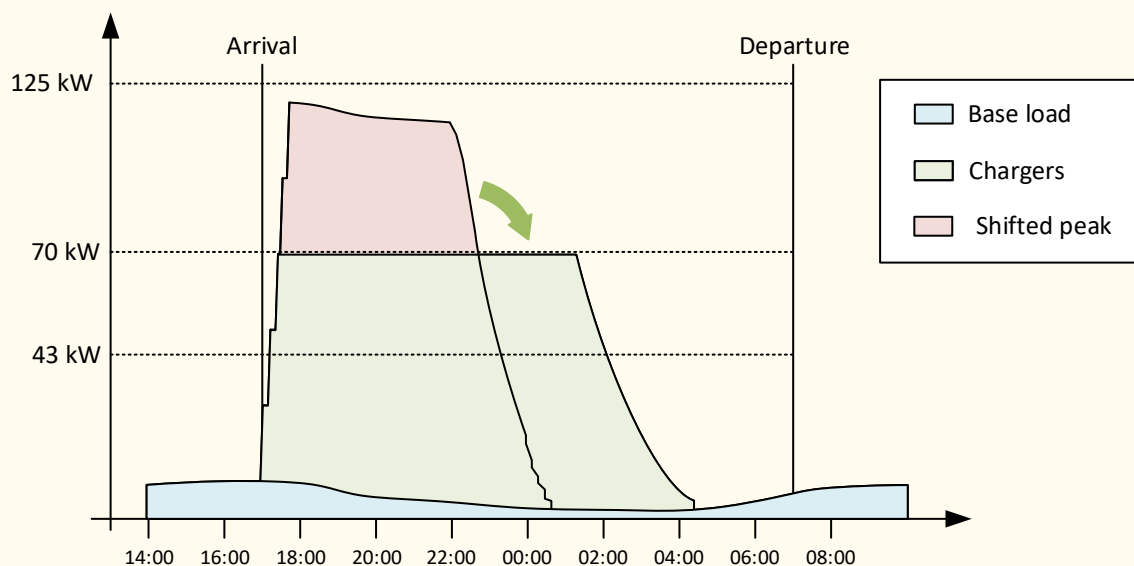


Figure 8: Truck charging with load management. The peak consumption can be effectively mitigated by shifting the load to later times, reducing the need for extensive grid upgrades.

To facilitate load management, it is important to select chargers that comply with application protocols, such as OCPP (Open Charge Point Protocol). The protocol allows chargers and central management systems to communicate with each other. This is particularly important if the chargers are from different manufacturers.

Besides limiting the overall power consumption to a desired threshold, load management solutions offer additional advantages. The controllability of the individual charging processes allows to shift the charging to preferable time windows, for instance, to hours with low electricity prices, or to hours of own solar production. This can reduce operating costs, especially with fluctuating electricity prices. As previously highlighted in Section 5.2, the temporal flexibility can be increased by selecting chargers

with connector power levels above the minimum values for $P_{AC\ charger}$ and $P_{DC\ charger}$ derived in Step 2. The considerations on the optimal power level for the chargers center around the following points.

The higher the power level of the chargers, the higher the flexibility to shift the charging processes to low-price time windows, which reduces operating costs. However, the investment costs for the chargers are higher, as illustrated in Section 4. Furthermore, the grid connection capacity must be suitable for utilizing this flexibility. Potential upgrades of the grid connection increase investment costs and may entail a significant implementation period. Moreover, preventing high power consumption at the grid connection point effectively reduces operating costs in case network charges to utilities consider the peak power during a given billing period. All in all, the optimal power rating of the chargers depends on various factors, which are location-specific and might change over time (e.g., electricity prices, tariffs). In this context, the minimum required power rating derived in Step 2 (Section 5.2) provides a lower bound to identify technically feasible solutions.

2) What are the space and safety requirements at the depot?

When planning the installation of charging infrastructure at a depot, space and safety requirements must be taken into account. The considerations center around the following aspects:

- The installation of chargers requires sufficient space for both the actual hardware and the accessibility of the trucks to the chargers. Considerations regarding the trucks' maneuverability at the depot are imperative, so parking and swing-out collisions are avoided.
- The exact charger position next to the truck's parking spot must be chosen carefully. The position of the plug inlet must be considered at the correct side (left/right), and with the correct distance from the front of the truck.
- Technical standards regarding the installation of charging infrastructure must be consulted. This concerns aspects such as maximum and minimum distances between technical components, or compliance with EMC (electro-magnetic compatibility) requirements.
- That depot must comply with national, regional, and local regulations related to charging infrastructure and parking of electric vehicles. It is recommended to get in dialogue with local entities such as fire brigades.
- Insurance policies should be checked for specific requirements concerning charging infrastructure.



When electrifying only parts of the fleet, it is worth considering to already prepare the underground infrastructure (cable tube) for additional chargers.

3) Management and operation

After assessing the depot with respect to electrical, spatial, and environmental requirements, a decision is to be made whether the installation of charging infrastructure is feasible at the given location. If not, it should be considered to move the depot site to a different location that can meet the requirements.

To ensure smooth fleet management, information on the charging processes of the individual trucks can be linked to the fleet management software used for planning and monitoring the fleet operation. In this way, the fleet operator receives updated information on the status of each truck, e.g., the connection status (not connected/plugged-in/charging), the charge level, and the estimated time when charging will be completed.

Closely tied to the selection of charging infrastructure and software solution is whether to contract with a charge point operator (CPO). CPOs are companies which are specialized in providing, installing, and operating charging equipment. The equipment can either be owned by the CPO or they can operate the equipment on behalf of a third party (e.g. the depot operator). While it is generally recommended that the depot has ownership of the hardware, it might make sense to let the technical operation and maintenance to an external company. This can either be a CPO or another company with the necessary technical expertise. The tradeoff is that the CPO can provide a package which simplifies the infrastructure acquisition and operation – but that adds operational costs long-term.

With the current electricity mix, the LCA emissions of electric trucks are already better than the ones of diesel trucks and continue to improve with increasing shares of renewables and improved production practices for battery cells. To further decrease their carbon footprint, fleet operators can select electricity retailers who offer green electricity options.



It is worth to consider offering public access to the chargers during times when trucks are on duty. If larger parts of the fleet are driving during the day and returning to the depot in the evening, the idle infrastructure could be operated as public chargers offering an additional source of income.

5.4. Selected cases

The methodology presented in Section 5 was applied to various fleet profiles, shown in Table 2. The blue section of the table summarizes the inputs and assumptions for each fleet. In addition to the operating schedule, exemplary truck properties such as the battery capacity and maximum charging powers were made. The green section of the table presents the results obtained by applying the three-step methodology from Section 5. If the driving demand exceeds the battery capacity of the truck, additional charging along the way is necessary, as previously highlighted in Section 5.1. For the calculation of the results, it was assumed that the fleet has a homogeneous schedule, i.e., all trucks have similar arrival and departure times. The selected DC chargers power levels were assumed with incremental steps of 25 kW. It is noteworthy that different manufacturers offer different product lines that may provide finer steps for the power rating. For the calculation of the total charging cluster load two values are given. The first value (“max”) indicates the maximum power consumption of the charging infrastructure assuming all trucks are charging simultaneously. The second value (“min”) provides a lower bound of the possible power consumption, under the ideal assumption that a load management system is used to control the charging processes of the different trucks.

Table 2: Overview of charging infrastructure examples for seven different fleet profiles.

Profile no.		1	2	3	4	5	6	7
Operation	Use case	Food retail – delivery to supermarkets		Non-food retail – delivery to retail outlets		Middle mile – between distribution centers		Long haul
	Fleet size	25	25	5	2	10	10	1
	Daily distance	175 km	450 km	130 km	240 km	240 km	360 km	1000 km
	Time at depot	14 h	8 h	14 h	12 h	16 h	10 h	12 h
Truck properties	Consumption	1.00 kWh/km	1.00 kWh/km	0.95 kWh/km	0.95 kWh/km	1.35 kWh/km	1.35 kWh/km	1.24 kWh/km
	Battery capacity	316 kWh	316 kWh	316 kWh	316 kWh	468 kWh	468 kWh	432 kWh
	Max. AC charging power	22 kW	22 kW	22 kW	22 kW	22 kW	22 kW	43 kW
	Max. DC charging power	150 kW	150 kW	150 kW	150 kW	375 kW	375 kW	250 kW
1) Charging demand	Truck energy demand	175 kWh	316 kWh	124 kWh	228 kWh	324 kWh	468 kWh	432 kWh
	Min. truck charging power	14 kW	44 kW	10 kW	21 kW	23 kW	52 kW	40 kW
2) Charging infrastructure	Charger type	AC 22kW	DC 100kW	AC 22kW	DC 50kW	DC 50kW	DC 125kW	DC 100kW
	Number of charge points	25	25	5	2	10	10	1
3) Grid infrastructure	Max. charging cluster load	550 kW	2500 kW	110 kW	100 kW	500 kW	1250 kW	100 kW
	Min. charging cluster load	350 kW	1100 kW	50 kW	42 kW	230 kW	520 kW	40 kW

6. Summary – main recommendations

1. Establish your charging needs



- ✓ Determine **how many trucks** will use the depot now and in the future. Identify key truck properties, such as the **battery capacity** and possible charging **power levels**.
- ✓ **Find the energy needed** by the trucks at your depot, based on how much they drive and consume between depot stops.
- ✓ You can then calculate the **average power needed** to meet the energy demand, in order to understand which power levels the chargers should support.
- 💡 In case the fleet comprises different types of trucks and/or different operating profiles, the trucks might require different chargers to fulfill their individual energy needs.

2. Identify charging solutions



- ✓ **Choose a charger type** with a power rating at least 1.5 times (AC) or 2 times (DC) higher than your average power demand estimated in the previous step.
- ✓ As a simple rule, we recommend **one charge point per truck**. However, if parts of the fleet have opposing schedules, the number of charge points may be chosen lower than the number of trucks.
- ✓ Select chargers with smart charging capability. This allows to control the charging infrastructure through a **load management system**.
- 💡 Especially for high-power charging it is common that the experienced charging power will be lower than the nominal charging power specified by the charging equipment and truck.
- 💡 AC charging is cheaper than DC, and may primarily be sufficient for use cases in urban areas. For higher charging demand, we recommend DC charging due to additional advantages in terms of charging powers and communication capabilities.
- 💡 Heterogeneous fleets with diverse truck types and/or operating profiles might require a mix of AC and DC chargers.

3. Assess the depot



- ✓ The grid company should be contacted immediately to discuss potential grid connection limitations. Upgrading the grid may take a significant amount of **time to complete** and has a **considerable cost** associated with it.
- ✓ Determine if the **grid connection capacity** is sufficient to support the charging infrastructure.
- ✓ A load management system may **reduce the grid capacity costs** significantly. On the other hand, underinvesting in grid capacity while relying on load management too heavily might constrain future extensions of the depot, and further reduces the flexibility for smart charging.
- ✓ It is important to identify potential **size constraints at the depot** which may impact the placement of chargers. Similarly, the access to the chargers needs to be assessed, taking into account the maneuverability of the trucks.
- ✓ Consult **technical and safety regulations** regarding the installation of charging infrastructure, as well as implications on **insurance policies**.
- ✓ It is worth considering delegating the operation and maintenance to a charge point operator.
- 💡 Battery systems and PVs are highly complementary. Investigate the potential of adding these to the depot.
- 💡 Be aware of national requirements regarding the installation of chargers and make a proactive plan for having enough to fulfill both legislation and your own needs.
- 💡 When installing the first chargers, prepare underground channels, tubes, and cables so you may continuously add chargers.

Relevant Literature

Reports and Guidelines

- [1] “Charging Handbook for Transport Depots – A practical checklist for e-truck charging infrastructure”, NAL (Nationale Agenda Laadinfrastructuur), November 2022. [Online link](#).
- [2] O. MacDonnell, Y. Qiu, X. Wang, S. Song, C. Dobbelaere, and C. Façanha. „Zero-Emission Truck and Bus Market Update“, CALSTART, October 2022, [Online link](#).
- [3] “Megawatt Charging System (MCS) – Recommendations and requirements for MCS related standards bodies and solution suppliers”, CharIN, Whitepaper, Version 1.0, 2022, [Online link](#).
- [4] “Connecting Your Fleet – A guide for businesses in Greater London”, Energy UK, October 2020, [Online link](#).
- [5] “Electric Trucks Recharged – Understanding commercial vehicle charging requirements”, Porsche Consulting, December 2019, [Online link](#).
- [6] “Electrifying the charge ahead – How eTrucks can join the transition on the road”, Heliox Energy, [Online link](#).
- [7] “Einfach laden an Rastanlagen – Auslegung des Netzanschlusses für E-LKW-Lade-Hubs”, Nationale Leistelle Infrastruktur, 2022, [Online link](#).
- [8] „Kosten laadinfrastructuur logistiek laden op privaat terrein“, Report on costs of charging infrastructure for logistics charging on private land, by NAL (Nationale Agenda Laadinfrastructuur), December 2022, [Online link](#).

Websites

- [9] “Electric Trucks”, North American Council for Freight Efficiency, June 2023, URL: <https://nacfe.org/research/electric-trucks/>
- [10] “Electric Depot Education”, Run On Less – by NACFE, April 2023, URL: <https://runonless.com/electric-depot/electric-depot-bootcamp/>
- [11] “Connecting electric vehicle chargepoints to the electricity network”, UK Gov., Department for Energy Security and Net Zero, and Department for Business, Energy & Industrial Strategy, URL: <https://www.gov.uk/government/publications/connecting-electric-vehicle-chargepoints-to-the-electricity-network>
- [12] “Heavy Vehicles”, Collection of reports by the International Council on Clean Transportation, URL: <https://theicct.org/sector/heavy-vehicles/>
- [13] “De werkgroep Logistiek van de NAL”, Collection of guidelines, roadmaps, and action plans, provided by the logistics working group of the NAL (Nationale Agenda Laadinfrastructuur), [URL](#).
- [14] M. Muratori and B. Borlaug, “Perspectives on Charging Medium- and Heavy-Duty Electric Vehicles”, NREL, IEA Public Webinar on Public Charging Infrastructure Deployment Strategies and Business Models, December 2021, URL: <https://www.nrel.gov/docs/fy22osti/81656.pdf>

Scientific publications

- [15] B. Borlaug et al. "Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems," In: *Nature Energy*, vol. 6, no. 6, pp. 673–682, 2021. [Online link](#).
- [16] J. Engelhardt, J. M. Zepter, T. Gabderakhmanova, and M. Marinelli. "Energy management of a multi-battery system for renewable-based high power EV charging." In: *eTransportation* 14, p. 100198, 2022. [Online link](#).
- [17] J. Engelhardt. "Reconfigurable Batteries in Electric Vehicle Fast Chargers: Towards Renewable-Powered Mobility", Technical University of Denmark, 2022. [Online link](#).
- [18] R. M. Jahn, A. Syré, A. Grahle, K. Martins-Turner, and D. Göhlich. "Methodology for Determining Charging Strategies for Freight Traffic Vehicles based on Traffic Simulation Results." In: *Procedia Computer Science* 184, pp. 656–661, 2021. [Online link](#).
- [19] J. Engelhardt, S. Grillo, L. Calearo, M. Agostini, M. Coppo, M. Marinelli. "Optimal Control of a DC Microgrid with Busbar Matrix for High Power EV Charging." In: *Electric Power Systems Research*, vol. 224, p. 109680, 2023. [Online link](#).
- [20] D. Nicolaides, D. Cebon, and J. Miles. "An Urban Charging Infrastructure for Electric Road Freight Operations: A Case Study for Cambridge UK," In: *IEEE Systems Journal*, vol. 13, no. 2, pp. 2057–2068, Jun. 2019. [Online link](#).
- [21] J. Engelhardt, J. M. Zepter, J. Sparresø, and M. Marinelli. "Real-life demonstration of a hybrid EV fast charging station with reconfigurable battery technology enabling renewable-powered mobility." In: *Proceedings of the 18th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES)*, 2023. [Online link](#).
- [22] T. Teoh, O. Kunze, C.-C. Teo, and Y. Wong, "Decarbonisation of Urban Freight Transport Using Electric Vehicles and Opportunity Charging," In: *Sustainability*, vol. 10, no. 9, p. 3258, 2018. [Online link](#).