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ELECTRIFYING EU CITY LOGISTICS
An analysis of energy demand and charging cost

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EXECUTIVE SUMMARY

The use of electric trucks in urban and regional logistics has great potential to cut emissions in the freight sector and accelerate decarbonisation of transport. With current advances in technology, logistics companies can electrify their fleets today. This report studies how logistics operators can charge electric trucks most cost effectively at the depot, while also capturing consumer and grid benefits by optimising their charging processes. The authors provide new insights by analysing the costs of charging an electric truck fleet, based on an estimation of their energy requirements. To identify strategies for smart truck charging, the study models charging scenarios assuming a fleet of 10 electric trucks charging at logistics depots in Germany. While the grid data is illustrative, it is based on real vehicle and charging data from logistics operators using electric trucks in operations today.

The study finds that logistics companies who want to electrify their fleets will benefit from understanding how to optimise charging. An operator of a 10-truck electric fleet can achieve considerable savings—up to 15,000 euros annually, or about 10%-15% of total energy costs, including charging—by designing optimal charging scenarios based on estimates of the combined costs for charging and grid use. To avoid the significant costs that result from unmanaged or suboptimal charging, depots will need to identify optimisation strategies now, while they have few electric vehicles in their fleets or are planning their purchase. To do so, it is important for operators to analyse what drives charging costs, beyond the electricity consumption of the depots and fleets.

A central finding of this study regarding charging costs is that cheaper electricity prices are not necessarily a solid basis for optimising charging. EV charging for depots is comprised of the electricity cost and network cost. Electricity cost is based on prices at the wholesale market, while network cost reflects the cost for delivery of electricity to the depot. Our study finds that network fees, which in most European countries currently are not reflective of actual capacity on the grid, pose the biggest challenge to charging electric heavy-duty vehicles at depots. If the operator decides to raise capacity (i.e., 43 kW versus 22 kW) to charge with cheaper energy, there is a risk that this action may cancel out any savings because it incurs higher network costs. Network costs in most countries are designed based on peak capacity, that is, the depot's highest consumption measured over a year. They are not designed to reflect when capacity is available on the grid. As a result of high network fees that are not aligned with grid benefits, it is currently more cost effective for fleets to charge at night and look for optimal charging windows during the day. If network charges were to be reformed, as we recommend, the most cost-effective time to charge may change.

Optimisation strategies for transport operators are likely to change with fleet size. Our additional estimates for an electric fleet of trucks imply that it may be relatively easy to optimise smaller electric trucks fleet around the depot's consumption. The larger the electric truck fleet, the more important it is to seek comprehensive load management solutions to optimise the fleet's electricity consumption.

Policymakers can support logistics operators in the electrification of their fleets by reforming network charges and moving to time-varying tariffs. Member States can accelerate this process by setting ambitions high when implementing recent electricity market reforms.

Heavy-duty vehicle electrification is evolving rapidly, and this study provides initial strategies and use cases that prepare the groundwork for further change. As with passenger electric vehicles (EVs), heavy-duty vehicles need more infrastructure, beyond depots, at freight centres and along highways. The European legislative framework for EV charging under review, the Alternative Fuels Infrastructure Directive, should therefore support the rapid build-out of additional charging options along roads and at destinations.

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INTRODUCTION

Electrification of heavy-duty vehicles is a promising pathway for decarbonising the freight sector. Trucks represent less than 2% of Europe's vehicles but cause 25% of emissions from road transport.[1] Freight emissions are growing due to increasing road freight volumes, resulting from online shopping, deliveries and the like. Different zero-emission technologies exist, including direct electrification of trucks with batteries, the use of green hydrogen in fuel-cell electric trucks, and electric road systems such as overhead catenary.[2] Research finds that, due to the declining costs of batteries and electric motors, electric trucks will be less expensive than diesel in the 2025–2030 time frame.[3] The use of electric trucks is particularly promising for replacing conventional truck use in urban and regional deliveries, where electric heavy-duty truck models (up to 26 tonnes) with ranges of up to 300 km are commercially available, and where operation from a home base enables depot charging. European CO_2 standards for trucks for 2025 and 2030[4] can be expected to accelerate supply and increase the range of more models available in the coming years.

Electrification of urban logistics carriers that supply retail stores, supermarkets, restaurants, construction sites and office buildings is low-hanging fruit for advancing the transport and energy transitions. Urban and regional delivery is currently served by road freight vehicles that travel a maximum of 300 km to 400 km per day and are housed in the same depot every night.[5] Although small parcel delivery vehicles tend to be the visible face of city logistics,[6] heavy-duty trucks above 12 tonnes of gross vehicle weight are the main source of CO_2, pollutants and noise.[7] Therefore, this study focuses on the electrification of heavy-duty truck fleets operating in urban environments.

How well we integrate the growing number of electric heavy-duty vehicles into power grids will also determine the costs of the energy transition for electricity consumers in general, and for logistics operators in particular. Similar to electric passenger vehicles, battery electric trucks offer valuable flexibility for the power grid if charged at optimal

1 Data based on European Automobile Manufacturers Association (ACEA). (2019). *Vehicles in use, Europe 2019*. https://www.acea.be/uploads/publications/ACEA_Report_Vehicles_in_use-Europe_2019.pdf#page=6; and European Environment Agency. (2020). *Annual European Union greenhouse gas inventory 1990–2018 and inventory* report *2020*. https://www.eea.europa.eu/themes/climate/eu-greenhouse-gas-inventory

2 Overhead catenary wires provide a continuous direct supply of electricity to trucks via a pantograph feeding from a system of overhead wires, requiring a network of energy infrastructure along roadways. For a comparison of technologies and infrastructure cost, see Moultak, M., Lutsey, N. & Hall, D. (2017). *Transitioning to zero-emission heavy-duty freight vehicles.* The International Council on Clean Transportation. https://theicct.org/publications/transitioning-zero-emission-heavy-duty-freight-vehicles

3 Hall, D. & Lutsey, N. (2019). *Estimating the infrastructure needs and costs for the launch of zero-emission trucks*. The International Council on Clean Transportation. https://theicct.org/publications/zero-emission-truck-infrastructure

4 The EU's current heavy-duty vehicle CO_2 regulation requires truck manufacturers to reduce fleet emissions by 15% by 2025 and 30% by 2030, and to include bonus-only incentives for the sale of zero-emission trucks. A revision could include zero-emission vehicle sales requirements, such as those recently announced in California (which would be equivalent to 8% of zero-emission vehicle sales in the EU in 2025 and 37% in 2030).

5 Half of the EU's total truck tonnes-kilometres are driven over distances of less than 300 km, which can be covered today by electric trucks. Mathieu, L. (2020). *Unlocking electric trucking the EU: Recharging in cities.* Transport & Environment. https://www.transportenvironment.org/publications/unlocking-electric-trucking-eu-recharging-cities

6 Logistics companies are investing in electrified fleets with electric vans, for example DPD in the UK. Schaal, S. (2020, 24 July). DPD erreicht E-Ziele in UK-Flotte früher als geplant [DPD achieves electrification goals with UK fleet earlier than planned]. electrive.net. https://www.electrive.net/2020/07/24/dpd-erreicht-e-ziele-in-uk-flotte-frueher-als-geplant/; and Amazon in Germany. Schaal, S. (2020, 31 July). Amazon baut 340 Ladestationen im Verteilzentrum Essen [Amazon built 340 charging stations at distribution centre in Essen]. e*lectrive.* https://www.electrive.net/2020/07/31/amazon-baut-340-ladestationen-im-verteilzentrum-essen/

7 Agora Verkehrswende. (2019). Ausgeliefert – wie die Waren zu den Menschen kommen. Zahlen und Fakten zum städtischen Güterverkehr [Delivered – how goods come to people. Facts and figures on urban commercial transport]. https://www.agora-verkehrswende.de/fileadmin/Projekte/2019/Staedtischer-Gueterverkehr/Agora-Verkehrswende_staedtischer-Gueterverkehr_03.pdf

times, unlocking tangible benefits for the grid.[8] This includes charging battery trucks when capacity is available and electricity is cheaper, for example overnight, which ultimately lowers the system costs paid by electricity consumers. In addition, managed truck charging can help to absorb variable renewable energy, for example excess wind energy overnight or solar energy during the day, and thus accelerate the use of clean electricity in transport. For logistics operators, assessing the full potential of truck electrification and developing optimisation strategies requires understanding the costs of grid integration. Costs in particular are difficult to estimate and few studies are currently available.

Our study addresses this knowledge gap by combining expertise from the transport and energy sectors.[9] The authors cover new ground in assessing the costs and optimisation potential of truck electrification and grid integration of those vehicles. The study first estimates the energy demand of a fleet of 10 electric trucks, modelled on real data from logistics companies in Germany (part 1). It then identifies optimisation strategies for logistics operators charging electric trucks at depots (part 2). The study concludes with recommendations for logistics operators as well as broader policy recommendations to accelerate electrification of urban logistics.

8 Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C., & Jahn, A. (2019). *Start with smart: Promising practices for integrating electric vehicles into the grid*. Regulatory Assistance Project. https://www.raponline.org/wp-content/uploads/2019/03/rap-start-with-smart-ev-integration-policies-2019-april-final.pdf; and Farnsworth, D., Shipley, J., Sliger, J., & Lazar, J. (2019). *Beneficial electrification of transportation*. Regulatory Assistance Project. https://www.raponline.org/knowledge-center/beneficial-electrification-of-transportation/

9 This is a joint project of the Regulatory Assistance Project (RAP) and International Council for Clean Transportation (ICCT).

PART 1: ENERGY REQUIREMENTS OF FLEETS

The electrification of city logistics fleets requires careful planning and execution. A necessary step in this process is gaining a deep understanding of the energy and power requirements of the future fleet of electric commercial vehicles. This poses a challenge, however, for fleet operators with limited experience or exposure to electric commercial vehicles. This section illustrates how this barrier can be overcome through a representative use case.

The hypothetical city logistics fleet studied consists of a small number, between 10 and 20, of heavy-duty trucks. The fleet carries out deliveries from its logistics centre located outside of the city, called a depot in this report, to one or several urban destinations. The logistics case is representative of diminishing load operation, where only drop-offs take place. The vehicle is close to empty on its return trip to the depot after the delivery route is completed. At the depot, the truck can either reload and begin an additional delivery route or can finalise its daily activity. The use case, illustrated in Figure 1, is representative of the supply chain of a number of businesses including supermarkets, retail stores and restaurants, among others.

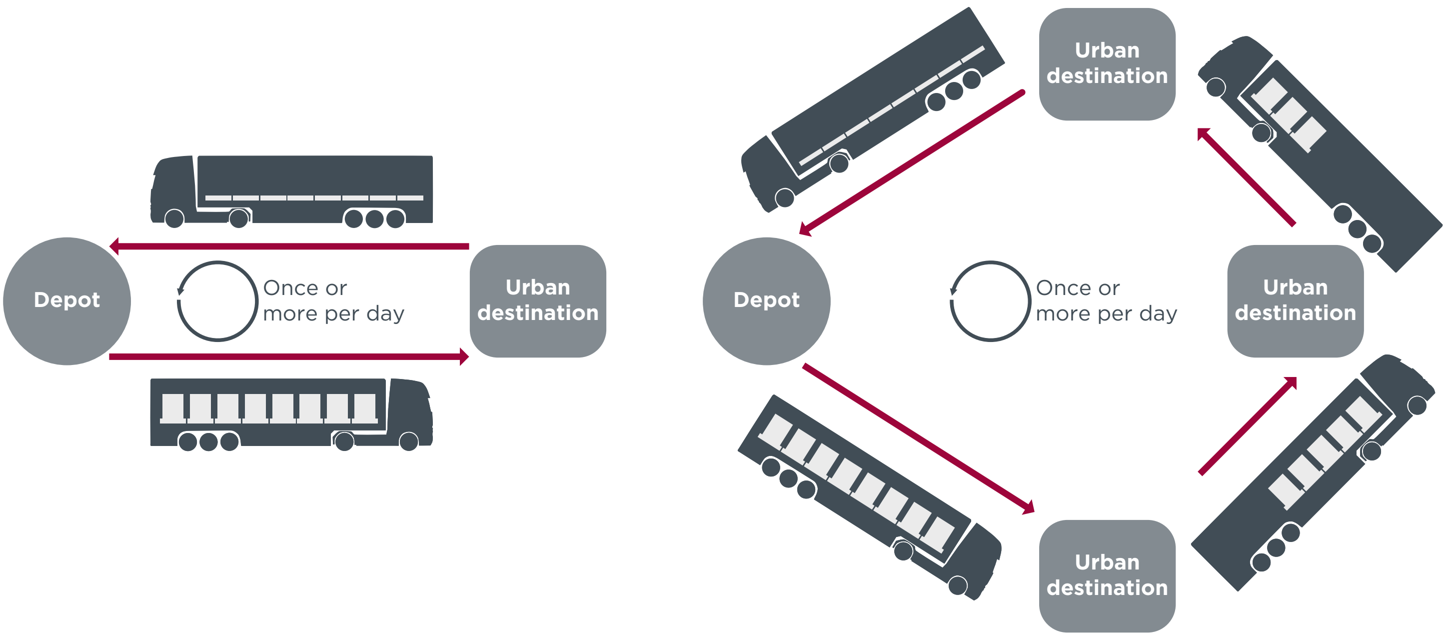

Figure 1. Mission profile of the city logistics case studied. The left side illustrates one destination per delivery route. The right side illustrates multiple destinations per delivery route.

VEHICLE ENERGY CONSUMPTION

The energy and power requirement of an electrified fleet is a function of the energy consumption of each individual electric truck, which in turn depends on several vehicle and operating parameters. Operators rely on fleet management systems to organise and coordinate their fleet of vehicles. Consequently, operators have a profound understanding of the driving profiles, daily distances covered, payloads carried and other operational nuances. However, such information on its own is not sufficient to estimate the energy consumption of the electric truck. The energy consumption of electric trucks—that is, their energy efficiency—varies significantly across types of operational and environmental conditions.[10] The factors influencing the energy consumption of electric trucks are summarised in Figure 2.

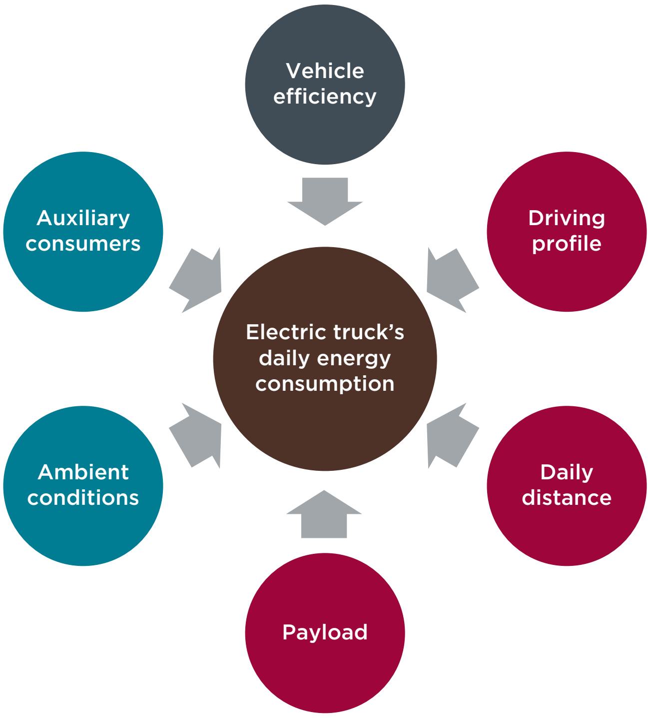

Figure 2. Factors influencing the energy consumption of electric trucks.

To perform a robust estimation of the energy consumption of an electric truck, it is necessary to move into the computational domain. By constructing a virtual model of the electric truck of interest, it is possible to simulate the performance of the vehicle across a wide range of operational and environmental conditions.

To construct the representative virtual models used in this analysis, we relied on the detailed vehicle specifications and real-world performance of an electric tractor-trailer and an electric rigid truck, currently being piloted by two different transport operators in Germany. These operators provided their insights and operational data to this project, and one of the fleets made available detailed vehicle data that enabled an accurate calibration of the vehicle models used in the simulation. Figure 3 presents the accuracy of the virtual models in simulating the energy consumption of one of the electric trucks considered in this study, over various individual trips. Each point in the figure indicates the energy consumption of a single truck over a single trip.

10 A good example of the latter is the ambient temperature, which not only affects the performance of the lithium-ion batteries, but also influences the heating, ventilation and air conditioning requirements of the driver's cabin, and of the cargo refrigeration when applicable.

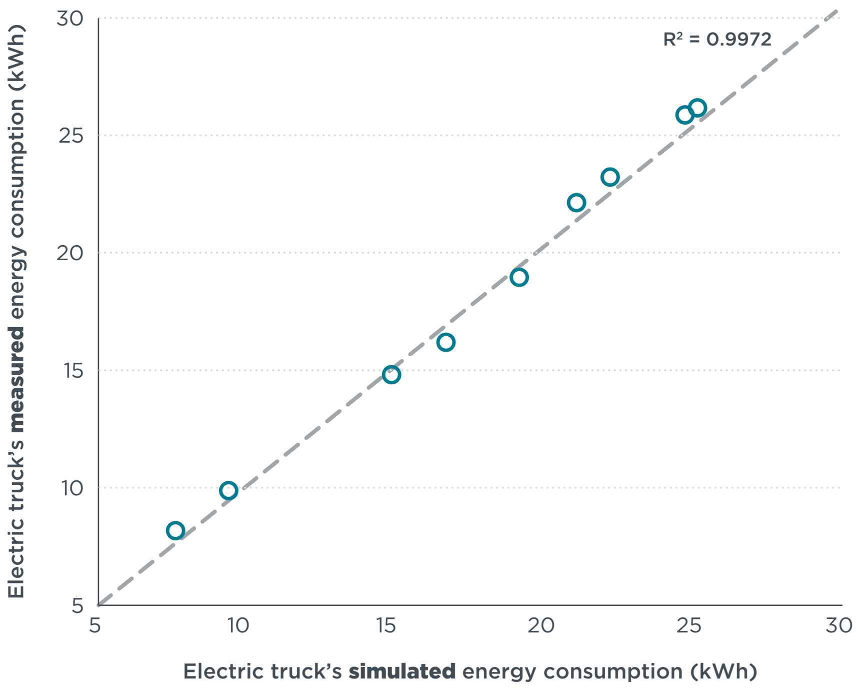

Figure 3. Comparison between real-world data and simulation results of the energy consumption of an electric truck.

DAILY ENERGY DEMAND OF THE FLEET

The daily charging energy demand for a given electrified fleet can be determined as the sum of the energy requirements for each vehicle during a given day. As described in the previous section, vehicle simulation enables the accurate estimation of the energy consumption of individual electric trucks over a specific trip. Given the inherent variability in operational and environmental conditions, however, it is necessary to analyse the fleet energy demand over a wide range of possible trips.

Analysis of the real-world operational data enables the statistical characterisation of the trip parameters that influence the energy consumption of the electric trucks. This statistical description of the trips can be used to simulate the fleet energy demand over a large number of randomly selected trip-scenarios. This approach, also called Monte Carlo analysis, in turn enables the statistical characterisation of the fleet energy demand. Figure 4 graphically illustrates this methodology.

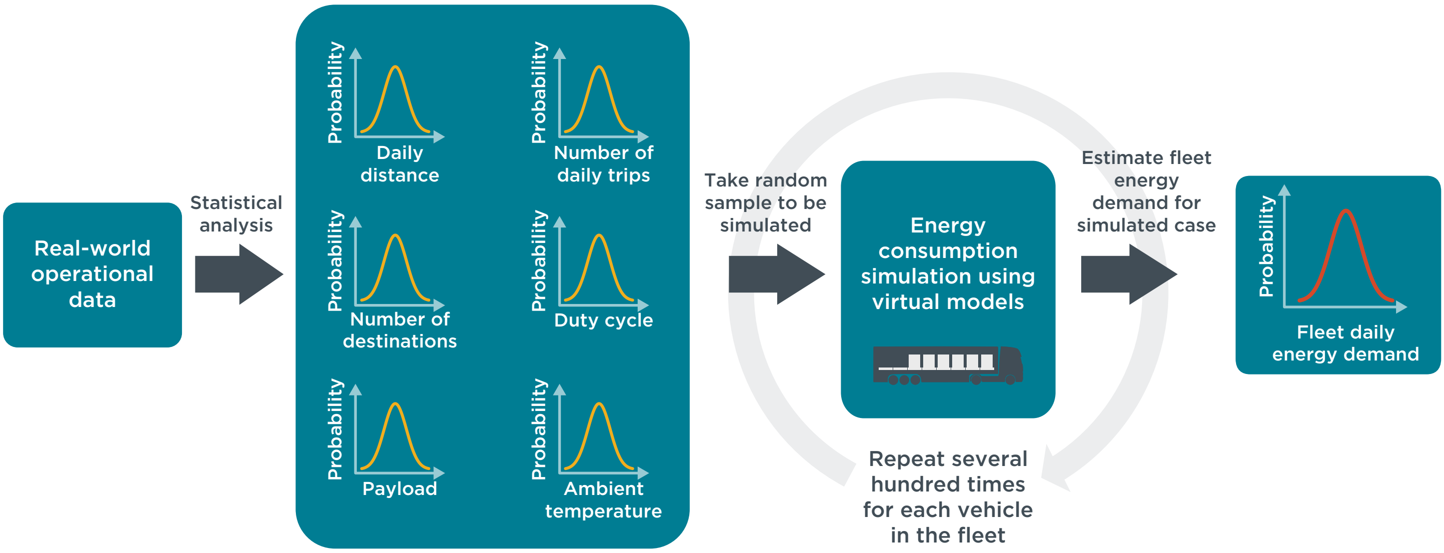

Figure 4. Graphical depiction of the Monte Carlo analysis method to determine the fleet daily energy demand.

The methodology described above, combined with the real-world operational data made available by a transport operator, was used to model the daily energy demand for two hypothetical fleets of electric trucks. The first fleet consists of 10 vehicles: Six electric rigid trucks and four electric tractor-trailers. The second hypothetical fleet is twice the size with 12 electric rigid trucks and eight electric tractor-trailers, representing a wider adoption of electric trucks by the operator. The size and composition of the two fleets selected were informed by discussions with transport operators already deploying electric trucks in their fleets. The main technical and operational characteristics of the fleet are summarised in Table 1. The technical specifications of the vehicles represent those of the electric trucks being piloted by the transport operators who supported this study. There was no attempt to optimise the technical characteristics of the trucks, in particular the battery capacity, to match the use case analysed.

Table 1. Key technical and operational characteristics of the hypothetical fleets analysed.

	Rigid truck	Tractor-trailer
Technical specifications of trucks	4x2 axle configuration 318 kWh battery 400 kW electric motor Refrigerated box	4x2 axle configuration, 3-axle trailer 260 kWh battery 400kW electric motor Refrigerated box
Energy consumption	Between 0.9 and 1.2 kWh/km, depending on the trip.	Between 1.3 and 1.9 kWh/km, depending on the trip.
Payload	Between 0 and 7 tonnes. Average payload is approximately 3 tonnes.	Between 0 and 20 tonnes. Average payload is approximately 9 tonnes.
Daily distance	Approximately 70 km on average, but can range between 30 and 130 km.	
Trip composition	Between one and three delivery routes per day, with two routes being most common. For each route, there are between one and four destinations, with one and two destinations being most common.	

The daily energy demand of the 10-electric-truck fleet is shown in Figure 5. The average daily energy demand of the fleet is approximately 1,100 kilowatt-hours (kWh), but energy consumption as low as 750 kWh and as high as 1,350 kWh are possible. However, 90% of the simulated cases exhibit daily energy consumption between 900 kWh and 1,250 kWh.

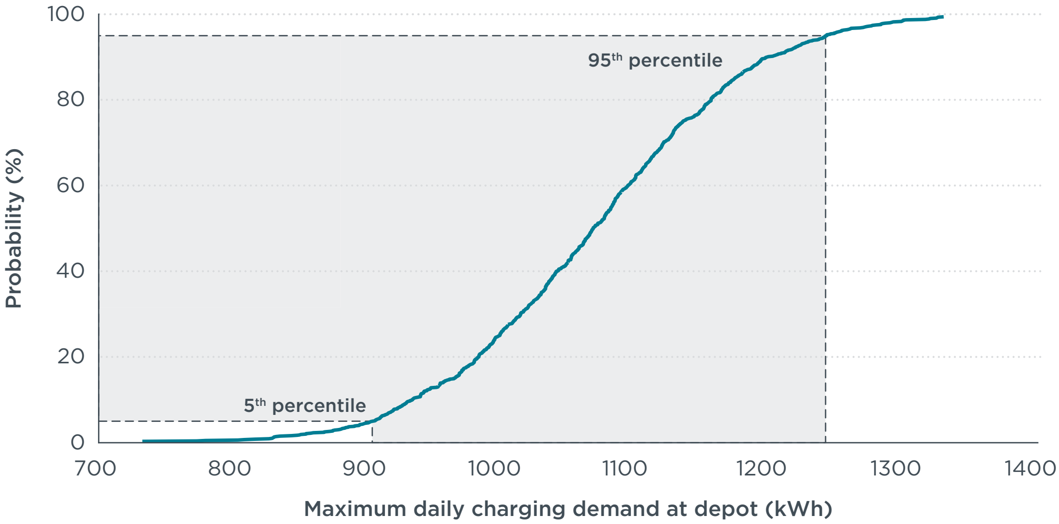

Figure 5. Cumulative probability of the daily energy demand for a fleet of six electric rigid trucks and four electric tractor-trailers.

CHARGING POWER DEMAND

The batteries used in electric trucks require direct current (DC) for charging. However, the electricity available in the public grid is delivered in the form of three-phase alternating current (AC). Thus, AC/DC rectifiers are needed to convert one to the other. There are two broad categories of charging, depending on where the AC/DC rectification takes place.

In DC charging, the AC/DC conversion happens at the charging station. The charging station communicates with the vehicle's battery management system to provide modulated DC voltage and current directly to the battery. In AC charging, the charging station simply delivers a fixed voltage source to the vehicle. The power electronics installed in the vehicle, also called an onboard charger, perform the AC/DC conversion while modulating the DC voltage and current that the battery requires.

In principle, electric vehicles can be charged using DC or AC charging stations. However, due to physical and economic constraints imposed by the onboard power electronics, the AC charging power is typically limited to 43 kW; that is, three phases, each supplying 63 amps at 230 volts. Given that the AC/DC rectification and DC power modulation take place within the vehicle, AC charging stations cost significantly less than DC charging stations. The advantage of DC charging stations, on the other hand, is that they are able to provide significantly higher power outputs, up to 350 kW, enabling faster battery charging.

Using the methodology described in the previous section, we estimate that the charging power required to meet the energy needs of the fleet would not exceed 50 kW per vehicle in a number of scenarios. This is a consequence of the electric range of the simulated trucks, which allows them to make their daily trips with a single charge and to use the overnight hours for their central charging strategy. In Germany, delivery trucks are not permitted to deliver goods between 10:00 p.m. and 6:00 a.m., guaranteeing a minimum of eight hours of overnight downtime for charging.

Given that the electric trucks modelled are either equipped, or can be equipped, with onboard chargers capable of handling up to 43 kW AC power, the study assumes that fleets would deploy AC chargers based on their lower cost. To estimate the scenarios with the lowest charging and infrastructure costs, we therefore opted to model overnight charging with AC chargers as the central approach. This decision was also supported by the information provided by one of the transport operators we interviewed, who currently operates an electric truck with 22 kW AC overnight charging. The overall aim was to reflect charging options available to operators of electric trucks today.

Although we modelled a number of charging scenarios, we only present detailed results for the two approaches that best exemplify the challenges and opportunities for optimising depot charging. The scenarios below are designed to provide a basis for understanding smart charging strategies[11] and were not optimised based on cost. Smart charging strategies for trucks are discussed in detail in the next chapter.

» **Scenario 1. Overnight charging starting at 10:00 p.m., with 22 kW of power, supported by opportunity charging:** The analysis of the real-world operational data indicated that once the vehicle returns to the depot after a route, there is a sufficient period of inactivity to allow for charging. To avoid disruptions in operations, charging between trips—referred to as opportunity charging in the remainder of the report—was limited to one hour. Overnight charging would commence at 10:00 p.m.

» **Scenario 2. Overnight charging starting at midnight, with 43 kW of power:** The higher charging power modelled in this scenario is necessary to compensate for the absence of opportunity charging and the later starting time.

Figure 6 shows the power load profile at the depot for the fleet of 10 electric trucks, being charged as described in scenario 1. We carried out one thousand simulations with varying trip characteristics. The results shown in Figure 6 reflect that the charging power will fall within the range shown with 90% probability. Each additional truck being charged increases the power demand by 22 kW (for charging scenario 1).[12] The mean charging power demand is depicted as a smooth curve, as it is the average of all simulation runs. This mean curve is used in the subsequent analysis.

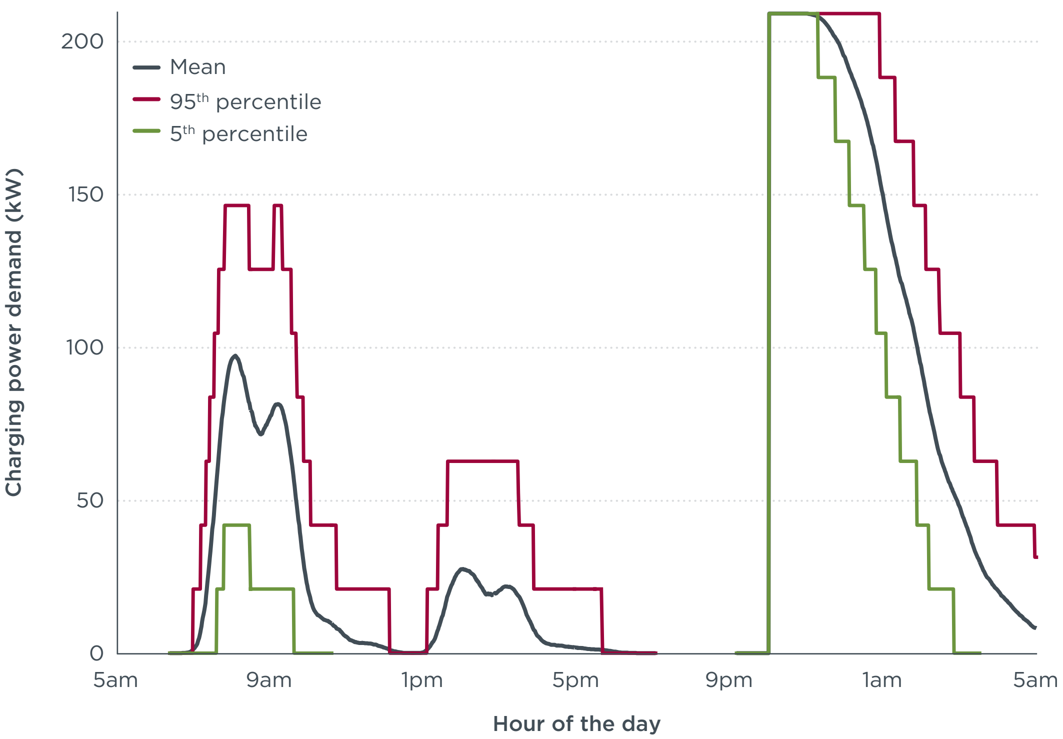

Figure 6. Depot power load profile from charging an electric truck fleet consisting of four tractor-trailers and six rigid trucks, using charging scenario 1.

11 The term "smart charging" means charging electric vehicles when and where it is most beneficial for the power system while meeting consumers' mobility needs at an affordable cost.

12 The stepwise character of the confidence interval is a consequence of the discrete nature of the charging demand.

PART 2: CHARGING REQUIREMENTS AND COSTS

This section analyses costs for charging the electric logistics fleet in the two scenarios described above: (1) overnight charging with opportunity charging during the day and (2) overnight charging only.

We first analyse cost drivers for charging the fleets. When connected to the charger at the depot, trucks add to the amount of electricity consumed by the depot, which is connected to the electricity distribution grid. This structure is depicted in Figure 7. The cost of charging trucks will, therefore, include the expense for the electricity consumed and for the distribution of electricity to the depot in its total usage.

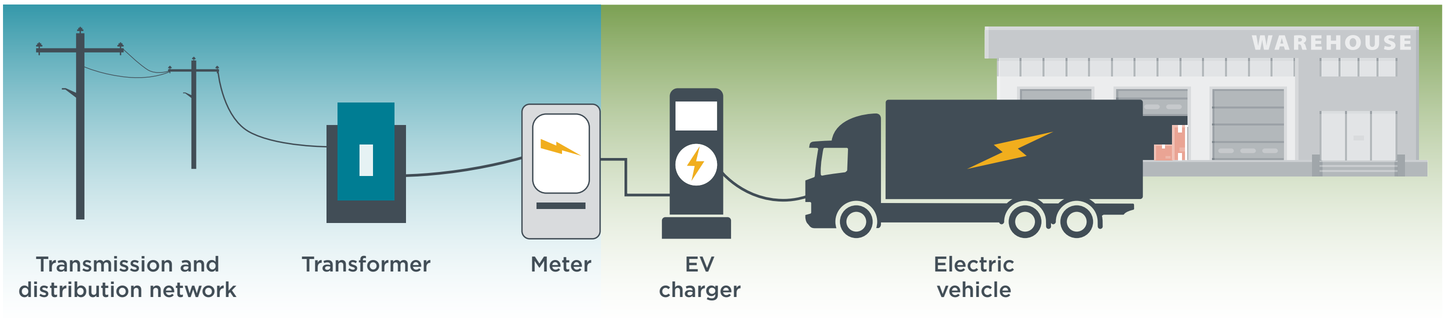

Figure 7. Overview of heavy-duty vehicle charging at a depot. Own illustration.

We then study how these costs can be optimised using the two scenarios to shift charging to 'cheaper' hours in the energy system. This takes into account that electricity prices and network prices for electricity delivery tend to be cheaper at times of more abundant electricity or network capacity. Based on cost estimates for these scenarios, we discuss the implications for depot operators. **The key question for logistics operators is how to harmonise their operations schedule with the opportunities inherent to an electric fleet. In other words, how can they time electric vehicle charging to take advantage of lower prices and excess renewable energy on the grid?** The main findings from the analysis show:

1. **Logistics operators** who want to electrify their fleet **will benefit from understanding how to optimise charging**. To avoid significant charging costs that result from unmanaged or suboptimal charging, depots need to identify optimisation strategies now, while they have few electric vehicles in their fleets or are planning their purchase.
2. **Cheaper electricity prices only are not necessarily a solid basis for optimising charging**. While overnight charging is generally preferable for recharging trucks at depots, a closer examination of the specific circumstances is crucial. As our analysis illustrates, longer overnight truck charging at lower capacity (i.e., 22 kW vs. 43 kW), supplemented by opportunity charging during the day, resulted in lower costs than overnight charging at higher capacity only. This is mainly due to the **largest cost driver for charging: electricity network costs**.

Policy implications are discussed in the conclusions section.

COSTS FOR TRUCK CHARGING AT LOGISTICS DEPOTS

In this study, costs for charging are defined as a combination of two components that represent the main part of consumers' electricity bills:

» Electricity cost, defined as wholesale market prices for electricity, and

» Network cost, defined as prices for delivery of electricity to the connection point (depot).

These are explained in further detail below. We do not include transaction costs, such as those for the installation of chargers, or network connection costs, which are location and case specific. Other end-user costs, such as taxes and levies, are also not considered in this report for two reasons. First, taxes and levies are a flat rate per kilowatt hour. In other words, they vary with the amount of electricity consumed, but do not change based on the time the vehicle is charged. Second, these costs are very customer specific and vary strongly from case to case, based on the depot, region and Member State, among other things. There are several tax exemptions in place for fuel taxes as well as for power demand. As a result, there are no uniform assumptions for the way transport fuels are taxed.[13]

For small industrial consumers such as logistics depots,[14] network costs represent about 25% of their electricity bill on average across Europe, as depicted in Figure 8. The wholesale cost for electricity represents almost 50% of the bill. These shares, however, can vary between Member States, depending on how the regulated parts of the bill, in particular network tariffs, are designed. In many EU countries, network charges for small industrial consumers are mainly based on the maximum capacity that can be delivered, not consumption.[15] This, by design, can increase the share of network costs in relation to the energy costs. This means that the figures can vary greatly depending on the consumption of the depot itself and the amount of additional truck charging. The reason and context of this variability is discussed later in this report.

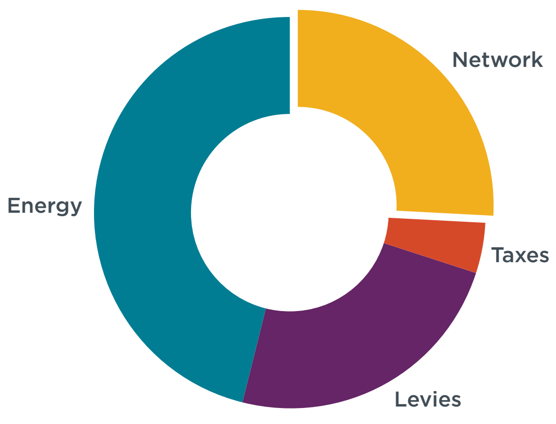

Figure 8. Average European network costs as part of electricity bill for small industrial consumers, data as of 2015. Figure from Kolokathis, C., Hogan, M., & Jahn, A. (2018). Cleaner, smarter, cheaper: Network tariff design for a smart future. p.3. Regulatory Assistance Project. https://www.raponline.org/knowledge-center/cleaner-smarter-cheaper-network-tariff-design-for-a-smart-future/

13 To shift to cleaner resources for transportation, taxation and levies need to be reformed to allow fair treatment of resources, limiting the implicit subsidies currently given to fossil fuels and fossil energy. Graf, A. & Lenck, T. (2019). CO_2-oriented energy pricing: Lessons from the German debate for the EU's smart sector-integration strategy [Presentation]. Agora Energiewende. https://www.agora-energiewende.de/fileadmin2/Projekte/2020/VAs_sonstige/2020-04_Webinar-Reihe/2020-04-16_CO2-oriented_energy_pricing_AG_TL/Presentation_Graf_Lenck_Agora-Webinar_16042020.pdf

14 Eurostat defines small industrial customers as those whose annual consumption ranges from 20 MWh to 500 MWh per year.

15 REF-E, Mercados & indra. (2015). *Study on tariff design for distribution systems. Final Report*. p. 115. https://ec.europa.eu/energy/sites/ener/files/documents/20150313%20Tariff%20report%20fina_revREF-E.PDF

The cost for electricity purchased by the logistics depot for general consumption and charging its trucks is based on the commercial electricity tariff charged by the energy supplier. If that tariff is time varying or dynamic, it will change over the course of the day, depending on the spot market price on the electricity wholesale market.[16] As a result, the price reflects, in different degrees of granularity, how much cheap energy is available on the grid for a given period. These price signals offer incentives to customers to exercise their flexibility, for example, by shifting the timing of EV charging, to minimise cost. This kind of optimisation of charging that benefits both the grid and the consumer is referred to as smart charging.[17]

In Figure 9 below, we show an illustrative load curve for a depot, based on the standard commercial customer load profile in Germany. We used this to calculate the electricity and network charges of the depot itself, as well as the cost of the depot with charging the trucks. In a second step, we then look at the additional costs for charging the trucks.

In the absence of real data provided by operators, the depot's estimated consumption is modelled on a typical commercial customer's load curve. For this representative estimate, we assumed a load profile with relatively even consumption. This is a conservative estimate, as less homogenous demand leads to even higher costs and, hence, also higher cost-savings potential. The lowest load occurs in the early morning hours, and the highest at noon, closely followed by the early evening. We assume that the depot itself has an annual consumption rate of about 100,000 kWh and almost 2,800 kWh consumption on a working day.

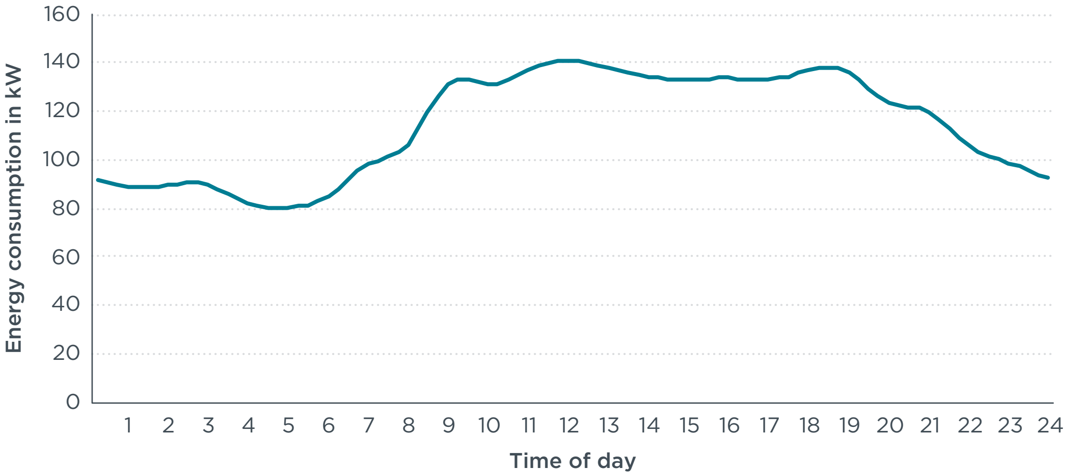

Figure 9. Depot load curve modelled on standard commercial customer load profile in Germany.

Although the fleet energy demand scenarios modelled in this study are not specific to a given country, it was necessary to select a reference country to model the electricity and network costs for a typical depot's consumption. As our case study data was modelled based on information from transport operators in Germany, the electricity price calculations are based on the German electricity spot market, i.e., the prices on the wholesale market for energy (Figure 10). At the wholesale market level, these prices are similar to those in other European countries, so they can be considered to

16 Following national implementation of 2019 European electricity market reforms, suppliers are required to offer dynamic electricity price contracts for customers who request them and have a smart meter installed. European Parliament and the Council of the European Union. Directive 2019/944/EU of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast). Article 11. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944&from=EN

17 Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C., & Jahn, A. (2019). *Start with smart: Promising practices for integrating electric vehicles into the grid.* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/start-with-smart-promising-practices-integrating-electric-vehicles-grid/

be within a representative range.[18] Wholesale market prices reflect most transparently the cost of electricity production, in hourly variations throughout the day, as day-ahead prices on workdays in 2019. They provide an approximation of the logistics operators' optimisation potential with regard to power prices, assuming the price would be passed on to them by their supplier, based on a dynamic price contract. Based on these assumptions, the typical depot's consumption would incur 34,000 euros in electricity costs.[19] Throughout this report, electricity costs are calculated based on wholesale market prices to ensure comparability.

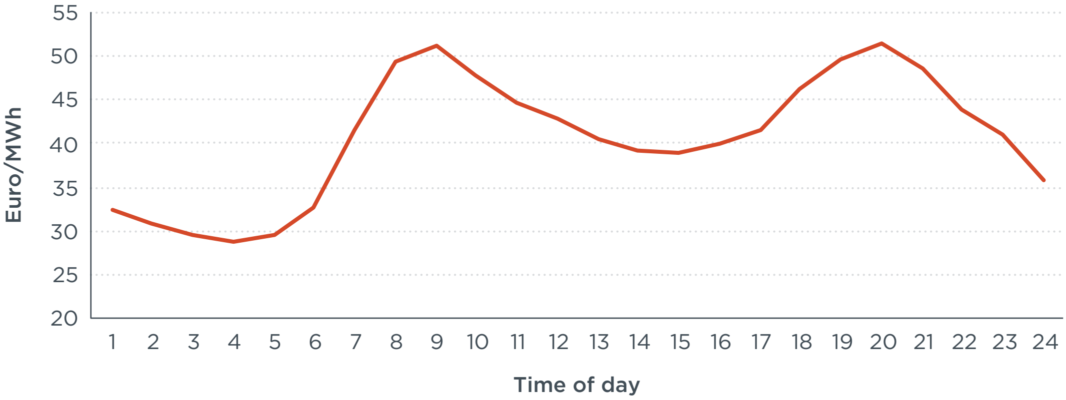

Figure 10. Average workday day-ahead spot market price in Germany, 2019. Calculation by Regulatory Assistance Project, based on EPEX Spot data. https://www.epexspot.com/en/market-data

Network charges are the fees paid by electricity consumers to cover the costs of power lines, transformers and network services. They form a significant part of consumers' bills. Unlike the electricity cost component of the bill, network costs are determined by national energy regulators, who regulate transmission and distribution companies as natural monopolies. These agencies are usually accountable to a Member State's energy ministry and therefore are subject to national and European legislation. Across the EU, network costs have been increasing over the last few years. This trend can be expected to continue, especially at the distribution network level, as networks accommodate new decentralised activities such as electric vehicle charging and distributed generation. In 2015, charges for electricity accounted for approximately one-quarter of small industrial consumers' electricity bills, as shown in Figure 8 above. For the typical depot considered in our study, 2019 network charges would range between 18,300 and 24,700 euros, or 35%-42% of the total bill (see Table 2). This represents a slightly higher share of the total electricity bill, compared to the energy costs, than the European average in Figure 8. All costs are summarised in Table 2 below.

The way regulators currently design network charges in many European countries can be a barrier to optimising EV charging, in particular for fast charging with its higher capacity and voltage levels.[20] Depending on the Member State, network charges often combine several elements: a fixed charge that does not vary with the amount of electricity consumed, a capacity-based (kW) charge that depends on the size of a consumer's connection to the network or the consumer's peak demand across a predetermined period, and a volumetric (kWh) component based on the user's consumption. The share of capacity-based charges tends to be substantial for

18 Market Observatory for Energy of the European Commission. (2020). *Quarterly report on European electricity markets*, *13*(1), for example Figure 33. https://ec.europa.eu/energy/sites/ener/files/qr_electricity_q1_2020.pdf

19 Compared to other European Member States, Germany has one of the highest average power bills due to taxes and levies. However, costs for electricity consumption and network use are based on wholesale prices and regulated tariffs and are very similar to other Member States. They are, therefore, still considered representative of a typical cost range.

20 Jahn, A. (2020, 9 March). E-Mobilität braucht Reform der Netzentgelte [E-mobility needs a reform of network tariffs]. *Tagesspiegel Background*. https://background.tagesspiegel.de/energie-klima/e-mobilitaet-braucht-reform-der-netzentgelte?

commercial and small industrial consumers. Both the fact that network charges are predominantly based on peak demand and the fact that these charges tend to be more relevant for commercial and industrial consumers imply high costs for charging e-trucks.

For our calculations, we selected network costs from Germany as a reference, including locational information on depots within specific grid areas from the cases underpinning this study. Germany's network fee structure is representative of the cost structure logistics depot operators would face in many European Member States to the degree that its largest component is based on the customer's peak capacity consumed over the billing period. Network costs do vary strongly by grid area and tend to be higher in less densely populated areas.[21] As a consequence, the geographical characteristics of the grid areas in which logistics depots are located impact total charging costs. We accounted for these variations in the study by basing our estimates on two different grid areas in the country that illustrate a likely range of costs for operators. All other aspects being equal, costs for other depot locations are likely to fall within this range, with the exception that extreme rural areas could be more expensive. Network costs are thus expressed in a cost range of relevant scale.[22]

Figure 11 summarises the load curves resulting from the two scenarios for 10 trucks.

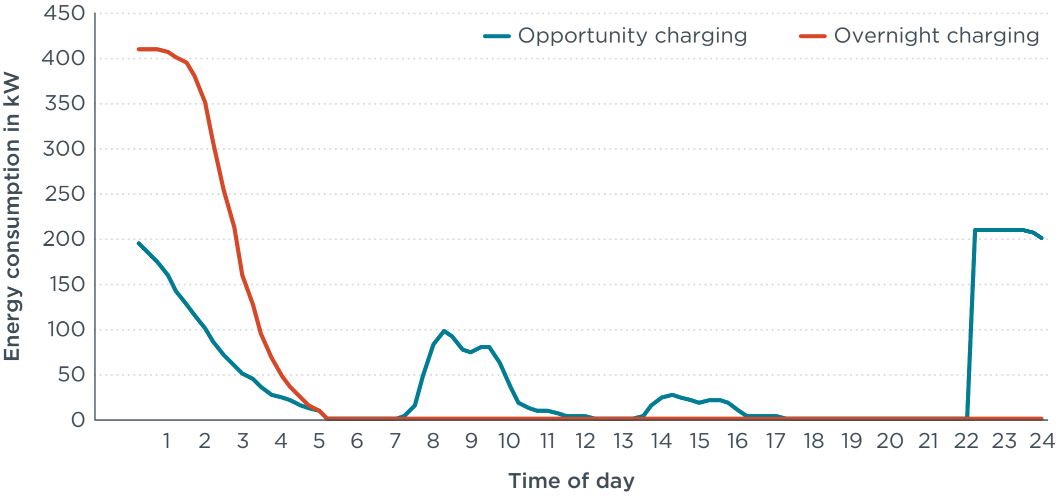

Figure 11. Summary of load curves from two scenarios.

Table 2 shows the costs logistics operators pay for the electricity consumed and for delivery of electricity for the depot only, as well as truck charging in the two scenarios for 10 trucks. The results for a larger fleet of 20 trucks are discussed separately below.

21 This variation spreads across European countries and ranges from the fees of over 800 operators in Germany, including many small municipal operators, to France where one grid operator retains a quasi-monopoly over 99% of the grid. A Member-State-specific cost simulation would be necessary to support this finding, but this exceeds the scope of this report.

22 An annual fixed fee of a few hundred euros in additional network costs is incurred for metering and measuring. Since this fee does not vary with consumption, it is not considered in the calculations.

Table 2. Modelling and calculation results for 10 trucks, separated by demand and charging mode, electricity and network costs, in euro and volumetric

Costs	Electricity charges (Euros)	Network charges (Euros)	Total (Euros)	Total (Ct/kWh)
Depot only	34,000	18,300 – 24,700	52,300 – 58,700	5.3 – 5.9
Depot + opportunity charging* - Scen.1	46,500	34,000 – 40,000	80,500 – 86,500	5.8 – 6.2
Depot + overnight charging* - Scen.2	44,800	49,800 – 50,200	94,600 – 95,000	6.7 – 6.8

*Electricity consumption varies slightly due to charging mode

In the following, we compare costs for each charging scenario in detail. When charging 10 electric trucks overnight with opportunity charging during the day (scenario 1, Figure 12), a logistics depot faces total costs of 80,500 to 86,500 euros per year for power consumption, network tariffs, and depot and truck charging. In this scenario, the network costs operators would pay for depot and opportunity charging increases to 42%-46% of the total costs versus 35%-42% for depot charging only.

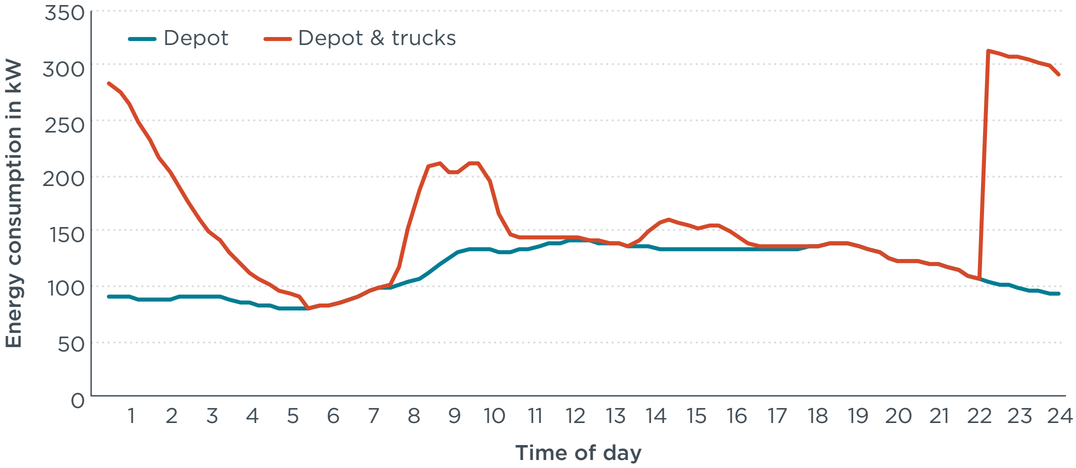

Figure 12. Load curve of depot and trucks for overnight charging with opportunity charging during the day (scenario 1)

Our analysis found that the more expensive option entailed operators charging trucks only overnight, with charging starting at midnight, and without opportunity charging during the day (scenario 2). The depot's load curve in this charging scenario is illustrated in Figure 13. The total costs for depots adds up to 95,000 euros per year for a 10-truck fleet.

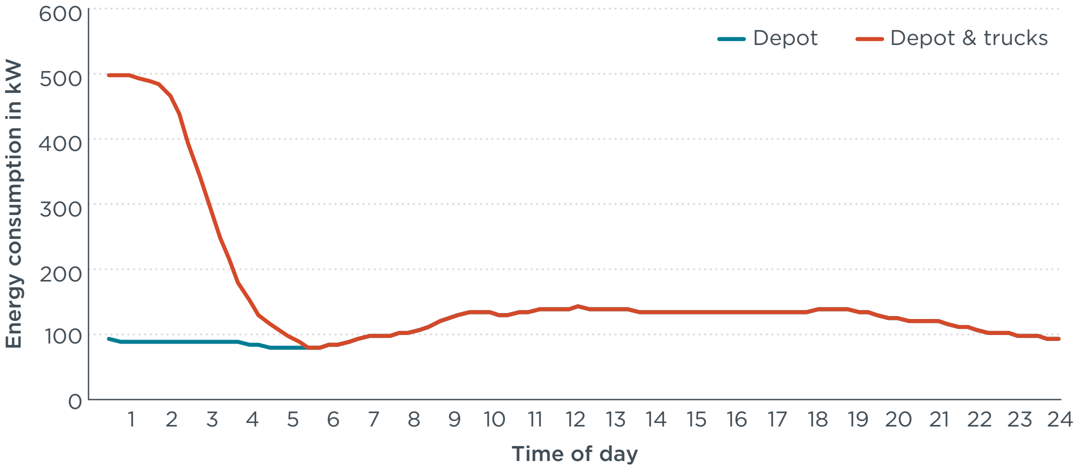

Figure 13. Load curve of depot and trucks for overnight charging only (scenario 2).

Again, network costs emerge as the highest share of the costs at 53%, or about 50,000 euros for charging 10 trucks overnight only.

Electricity costs in an overnight-charging-only scenario are slightly lower, as power prices are cheaper during the night than during the day (Figure 10). At 10,800 euros per year, the electricity costs for charging trucks only (without the depot's use, for comparison see Table 2) represent a mere 11% of the total cost in this scenario. However, potential savings from lower wholesale power prices only represent part of the depot's electricity bill. The savings can be negated by other, higher bill components. As a consequence, depot operators can only identify real saving options if they examine the results of the combined network fees and electricity prices.

In comparing the two charging scenarios, the total cost to operators for the depot and charging trucks varies from about 80,000-86,000 euros for overnight charging and opportunity charging, and around 95,000 euros for higher-capacity (i.e., 43 kW vs. 22 kW) overnight charging only. These cost differences can be explained by the way network costs are designed. The fee depots need to pay for peak demand contributes significantly to the network costs and, consequently, to the depot's total electricity bill. This can be seen when comparing the load curves in Figure 12 and 13. Operators combining overnight with opportunity charging during the day (Figure 12) reach a peak just over 300 kW. Overnight charging only creates a 500 kW peak if all of the trucks start to charge at midnight. The resulting network costs are a combination of the depot's consumption and truck charging which creates a higher aggregate peak. Smart charging strategies depots can deploy to flatten this type of consumption peak are discussed later in this report.

If we compare the total costs for both scenarios, logistic **depots can save up to 15,000 euros in this particular use case by extending the trucks' charging time overnight at lower capacity and allowing for opportunity charging during the day**. In the case of charging 20 trucks, as discussed below in Table 3, the savings amount to almost 30,000 euros. **This total cost comparison finds that the charging strategy including opportunity charging during the day with overnight charging at lower capacity (scenario 1) is more cost-efficient overall than overnight charging only at higher capacity (scenario 2).** This may seem counterintuitive, as overnight charging generally remains the advisable option, but is explained by analysis of the main cost drivers below.

FACTORS DRIVING CHARGING COSTS

Charging at lower capacity at the depot can reduce costs

By combining overnight with opportunity charging (scenario 1), trucks can charge at a lower capacity (22 kW) at night. When charging overnight only (scenario 2), the trucks charge at a higher capacity (43 kW) than in scenario 1 to be able to reach a full charge by the next day. This charging behaviour causes a higher peak in the depot's overall load curve which, in turn, increases cost (see Figures 12 and 13). The current static design of network tariffs results in high costs for consumers such as depots and does not encourage using the grid at cheaper, off-peak times. This is further explained by the third cost driver described below. Time-varying network tariffs better reflect the actual cost of grid use and thus incentivise smart charging behaviour. Smart charging strategies for trucks are discussed in detail below.

LONGER PERIOD FOR CHARGING ALLOWS FOR BETTER OPTIMISATION AND COST SAVINGS

A comparison between scenarios also shows that it pays off to start charging earlier, as it allows for a longer charging period at lower capacity (22 kW). As a consequence, trucks charging in parallel created a lower peak overall, incurring lower network costs for the depot. By extending the charging period by only two hours compared to scenario 1 and using the energy already gained through shorter opportunity charging intervals during the day, operators manage to make better use of the flexibility in the trucks' schedules and their ability to provide grid services (i.e., demand response). This implies that the overall number of hours the trucks spend charging at lower capacity is decisive for overall costs. It also highlights that charging at a lower capacity is more cost-efficient if the charging period is sufficiently long. Based on these insights, it should be noted that truck charging doesn't necessarily require higher capacity charging in all cases.

NETWORK COSTS ARE THE LARGEST COST DRIVER FOR A TYPICAL DEPOT'S TOTAL COST

A central finding of this study is that cheaper energy prices are not necessarily a reliable basis for cost-optimisation. If a logistics operator decides to raise capacity to charge vehicles more quickly during a period when energy prices are lower, there is a risk of cancelling out the price savings by incurring higher network costs. Network costs account for 42% to 53% of overall charging costs for logistics depots that electrify their fleets in both scenarios. As such, they make up the more relevant share of power bills compared to the bills of the average small industrial consumer (Figure 8). As stated earlier, the main reason for this high percentage is tariff design, which can undermine savings gained. Today's annual network demand fees, as designed in most European countries, do not reflect utilisation of the grid or the peaks in demand. In other words, they do not reflect a consumer's individual contribution to the overall network peak or enable a fair allocation of costs based on usage.

In Germany, the reference for our case study, and in many other countries, network tariffs are designed to reflect peak demand. They are mainly based on the highest amount of power that a customer, such as a depot that also charges trucks, draws from the grid during the year. This means that a logistics depot pays network fees based on peak demand, even if this peak occurs very rarely and regardless of whether the local network is under stress at the time of peak. This is likely to be true, with some degree of variation, for all European countries where capacity-based network fee design prevails. In these countries, network charges are likely to be the largest cost driver for truck charging at depots because they are linked to peaks in demand and not actual consumption. This finding is supported by the fact that electricity prices at the wholesale market level, that could account for variation in total cost, are essentially harmonised across Europe.[23] However, detailed comparative analysis across European Member States would be needed to corroborate findings for more depots and use cases.

The calculations from scenario 2 for 10 trucks illustrate this point. The calculations show that the cost for electricity could be reduced to 11% of the total costs with overnight charging only. These savings for the depot, however, are outweighed by the higher network costs that result when the trucks are charged over fewer hours, thus creating higher peaks in demand. This outcome explains why dedicated overnight charging only, despite lower energy prices, is not necessarily the cheaper option. It also suggests that if network fees better signalled actual grid conditions and varied accordingly, the results of this scenario would likely be more favourable.

The cost for charging a fleet of 20 electric trucks indicates that network costs remain the highest cost driver in both charging scenarios. Charging a 20-truck fleet overnight only, starting at midnight (scenario 2) without opportunity charging during the day, is the more expensive option ranging up to 141,300 for depot consumption and truck charging combined. In an overnight-charging-only scenario, where electricity costs only represent 15% of the total cost for a 20-truck fleet, potential savings in electricity costs based on spot market prices are also negated by the higher network costs. Of the total cost, network costs dominate as highest cost factor at 75%, or 86,000 euros

Our calculations, as shown in Table 3, also uncovered interesting implications for logistics operators seeking to optimise their trucks charging with regard to a depot's overall consumption: The larger the electric truck fleet, the higher the overall charging demand and, therefore, the less impact a depot's consumption has on the overall cost calculation. **This implies that while it may be relatively easy to optimise a smaller electric truck fleet around the depot's consumption, larger electric truck fleets require comprehensive load management solutions to optimise the fleet's consumption.**

Table 3. Cost comparison of 10 versus 20 trucks within one distribution network.
*Differences are based on modelling results.

	Electricity charges (Euros)	Network charges (Euros)	Total (Euros)	Total (Ct/kWh)
Depot only	34,000	18,300	52,300	5.3
10 Trucks				
Depot & opportunity charging*	46,500	34,010	80,500	5.8
Depot & overnight charging*	44,720	50,222	95,000	6.8
20 Trucks				
Depot & opportunity charging*	59,090	53,641	112,731	6.3
Depot & overnight charging*	55,049	86,256	141,304	7.9

Findings from this section highlight that the results of a cost analysis are specific to the use cases. Should the overall consumption of a depot change or if network costs are reformed, we recommend that logistics depots consider adjusting their charging optimisation strategies. It's also important to note that our scenarios worked with average hourly prices that vary considerably from day to day. Preliminary conclusions can be drawn, however, from the analysis of how to optimise electric truck charging at depots. These are discussed in more detail in the next section, preceded by a brief discussion of the European context of our findings.

23 Market Observatory for Energy of the European Commission, 2020 (Figure 33).

EUROPEAN CONTEXT

This study's general findings regarding energy demand from electric truck fleets, cost drivers for charging and cost optimisation strategies for logistics operators are representative for most European Member States. Exact cost estimates will differ from the use cases studied, as will the electricity and network costs for a typical depot. But the assumed power prices and their variations, as well as the excessive costs created by capacity-based network charges, can be found in several European Member States. Europe-wide comparative research on tariff design and the related factors that enable customer flexibility finds that "network tariff [...] design is one of the main barriers limiting the use of flexibility services, severely limiting business cases and hampering their development."[24] Corroborative evidence can be found from operators of public electric (passenger) vehicle charging points who are facing market barriers resulting from high network costs. In Slovakia, Poland and Spain, for example, operators of fast charging points report high costs from network charges based on a charging point's peak capacity (for example, 50 kW, 100 kW, or 150 kW). This is due to the lack of time-varying tariff design that does not take into account that the numbers of vehicles charging will initially be low.[25] It is likely that this cost barrier will increase when charging trucks, which use higher capacities, thus driving cost.

In recognition of these challenges, Denmark's grid operators will introduce a time-of-use network tariff starting with the 2020 winter season. This tariff applies a higher network price to the most congested hours on the grid, which are 5:00 p.m. to 8:00 p.m. from October to April. All private and commercial customers will be subject to this rate, sending a price signal for them to shift their consumption away from these hours.[26]

Strategies for "smart truck charging"

This section starts by introducing the concept of "smart," or optimised, charging of electric trucks at depots and then explores optimisation strategies based on the two charging scenarios.

Truck charging can be optimised by aligning the depot's overall consumption with periods when cheaper energy is available. This is usually the case during the nighttime hours. If cheaper renewable energy is available during the day, however, it can also be favourable to charge trucks, for example between noon and 2:00 p.m., to take advantage of local solar energy. This will become even more beneficial as more renewable energy is integrated into the grid. In the rare cases when network prices reflect periods of available capacity or congestion on the network, these can give additional price signals to consumers to direct their consumption to the hours with excess grid capacity. Peaks in the distribution network, to which the truck depots are connected (see Figure 7), usually occur in Central Europe, for example, in the afternoon in the winter between 5:00 p.m. and 8:00 p.m. This period, therefore, should generally

24 Pinto-Bello, A. (2019). *The smartEn map: Network tariffs and taxes.* smarten Smart Energy Europe. p. 10. https://smarten.eu/the-smarten-map-network-tariffs-and-taxes-2019/

25 Hildermeier, J. (2020). *Building a market for EV charging infrastructure: A clear path for policymakers and planners.* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/building-market-for-ev-charging-infrastructure/; and, for Poland, Polish Electromobility Association. (2020). Konsultacje Białej Księgi Elektromobilności [The White Paper for E-mobility]. https://pspa.com.pl/2020/informacja/konsultacje-bialej-ksiegi-elektromobilnosci/

26 Radius. (2019). *Effekt af tidsdifferentierede elnet-tariffer* [Effect of time-varying electricity tariffs] [Presentation]. https://radiuselnet.dk/wp-content/uploads/Effekt-af-tidsdifferentierede-elnet-tariffer.pdf

be avoided. Ideally, both electricity and network prices would reflect actual costs to give a strong price signal to consumers for smarter consumption.

The concept of "smart" or optimised truck charging is illustrated below in Figure 14. The calculation is based on the reference depot's load curve, with illustrative truck charging values. To be able to model the actual charging optimisation potential for a specific truck fleet at a specific depot, more variables need to be taken into account, including the trucks' schedules and routes, as well as the depot's actual consumption and load curve.[27]

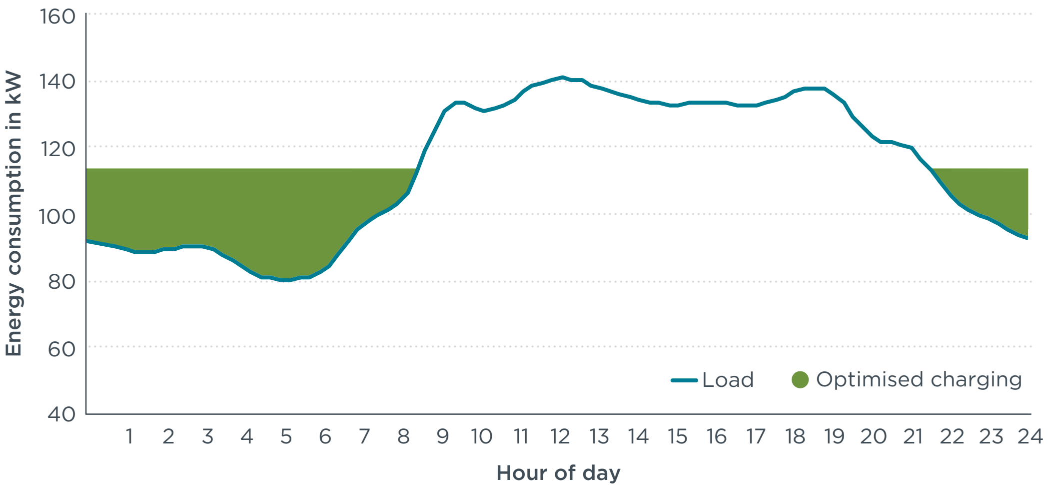

Figure 14. Illustration of smart truck charging at the depot.

Combining smart truck charging with the cost analysis from the previous section confirms a key lesson for beneficial integration of electric vehicles into the grid: **Using the existing infrastructure more effectively means lowering costs per unit. To optimise overall power system costs—and to generate savings for consumers—customers must receive effective price signals from networks and power markets to be able to integrate their demand beneficially into the power system.** Since network cost optimisation is more relevant for commercial customers, such as operators of e-trucks, network pricing needs to be reformed. Ideally, today's network tariffs, which are mainly based on peak demand, would be replaced to the greatest extent possible by time-varying rates that reflect the customer's actual electricity consumption and conditions on the power system.

To sum up, **logistics operators can optimise cost of charging e-trucks in different ways**:

» Opportunity charging is a valuable option to control additional cost. As long as an e-truck is not being driven, it can be connected to the power system to optimise the depot's electricity bills. This is also true for charging at lower capacity levels. In principle, the higher the charging capacity at the depot—for example, at 43 kW instead of 22 kW—the higher the potential to optimise total operational costs. With more flexibility, operators can increase savings by charging more during periods with lower prices. This includes delaying charging for some of the trucks in the fleet to adjust to network costs or fluctuations in power prices. This savings potential could not be realised in our scenario, however, because high network costs cancelled out the savings from electricity prices.

27 A specific depot's load curves can differ from the standard load curve illustrated here, depending on the depot's activity. For example, a supermarket depot will have additional consumption from refrigeration, which will offer additional flexibilities that could be used for grid flexibility services. These need to be studied, in addition to fleet charging, when optimising the depot's overall consumption.

» Faster charging at night, when electricity prices are lower, is not always the best solution. For total cost optimisation, investment into higher or faster charging needs to be evaluated against the long-term saving options from operations. It is possible, for example that charging at lower power over longer periods is more beneficial overall and thus cheaper.

» The actual power demand and load shape of the depot itself is highly relevant for the depot's total electricity bill. It may vary considerably from the conservative, typical commercial consumer's load curve assumed as a reference case for this study.

» In particular for smaller e-truck fleets, operators need to adjust the charging with the depot's overall consumption. The larger the truck fleet, the less impact the depot's consumption is likely to have. Load management systems can optimise charging automatically for larger truck fleets.

» A depot's geographic location is also key in determining the magnitude of network costs. Factoring in network connection capacities when planning the site—particularly identifying locations where grid capacity is abundant—can help operators to control costs.

Further options for optimal integration of e-truck charging at the depot that were not explored in this study are:

» Additional on-site **storage**: By adding on-site storage to the depot, possibly from batteries from secondhand electric vehicles, the logistics operator can gain independence from both peak energy and network tariffs.

» On-site electricity **generation**: Logistic depots can be equipped with solar panels to support cheap energy production for local use. Using and storing self-generated electricity in turn reduces dependency and costs of electricity markets and networks.

» **Vehicle to grid services**: One logistics company informing this study started working with an aggregator to optimise consumption and seek additional revenue by offering on electricity spot markets the excess energy produced by electric vehicles at the depot. For this option, on-site storage and supply investments increase both the flexibility and the benefits.

More comparative research on electric truck charging opportunities, costs and framework conditions is needed across European Member States to corroborate these indicative findings.[28] This includes implications for a harmonised European market for electric logistics operation, in particular in border regions, as well as implications for a Europe-wide network of supportive roadside and destination charging networks.

28 A comprehensive analysis of charging demand for electric logistics in the Amsterdam area can be found here: Groen, M., Verweij, K., Vos, G., Otten, M., Tol, E., Wagter, H., de Goffau, W., Nering Bogel, W., Schoo, R., Ploos van Amstel, W., Balm, S., van den Hoed, R., van den Engel, A., Kindt, M., Kin, B., Nesterova, N. & Quak, H. (2019). *Charging infrastructure for electric vehicles in city logistics.* Buck Consultants International, CE Delft, Connekt, Districon, HvA, Paneia, & TNO. https://www.cedelft.eu/en/publications/2356/charging-infrastructure-for-electric-vehicles-in-city-logistics. An analysis for truck charging infrastructure needed across the Netherlands can be found here: Noordijk, R., Refa, N., van Rookhuizen, J. (2020). Truckers komen op stroom. De ontwikkeling van batterij-elektrische trucks in (inter)nationale logistiek in Nederland t/m 2035. https://www.elaad.nl/uploads/files/20Q3_Elaad_Outlook_E-trucks_internationale_logistiek.pdf

CONCLUSIONS AND POLICY RECOMMENDATIONS

This section summarises the main conclusions and policy recommendations for logistics operators seeking to electrify electric truck fleets at depots. **The key question for logistics operators is how to harmonise their operations schedule with the opportunities inherent to an electric fleet. In other words, how can they time electric vehicle charging to take advantage of lower prices and excess renewable energy on the grid.**

Beyond raising awareness and increasing the knowledge of transport operators, we need joint efforts in the areas of power and transport policy, as well as in charging infrastructure build-out and urban planning. These types of collaborations can help ensure that electric trucks are charged in a cost-efficient manner that also benefits the power system. Additional policies that were not addressed in this report are needed to place these strategies within the larger context of electrifying logistics and freight to decarbonise the European transport sector. These are discussed below as future areas of study.

Recommendations for transport operators converting to an electric fleet:

» **Optimising truck charging is vital for success.** It's important to calculate both the costs for electricity (energy prices) and its delivery (network costs), in addition to the depot's consumption, taxes and levies.

» **Charging trucks overnight at the depot is the preferred option.** Fleet operators may find, however, that there are cost benefits in opportunity charging during the day. Shifting charging by only a few hours can make a significant difference in cost.

» **Faster charging is not a guarantee for cost reduction.** Operators should consider that charging at lower capacity may be cheaper if the charging period is sufficiently long, as they can benefit from lower network costs.

» **Optimisation strategies are likely to change with fleet size.** It may be relatively easy to optimise a smaller electric truck fleet around the depot's consumption. The larger the electric truck fleet, however, the more important it becomes to seek comprehensive load management solutions to optimise the fleet's consumption.

» **Siting a depot where there is existing power infrastructure saves money.** Further comparative studies could help transport operators explore how existing capacities or local renewable energy production can be used, either in close proximity or on-site.

» **Collaboration is key.** Logistics operators can seek collaboration with grid operators and e-mobility service providers to test fleet electrification and study their specific grid integration costs.[29] Energy suppliers, municipalities and other concerned entities can help to facilitate procedures and information for logistics operators seeking to electrify.

Smart pricing for electricity and network use is crucial to creating a conducive environment for cost-efficient, grid-optimal electrification of urban logistics, and electric road transport more broadly. The more prices reflect actual cost, the more incentives there are for consumers such as transport operators to integrate their electric vehicles and other flexible resources into the grid in a way that is beneficial for all. Previous studies have shown how these smarter rates can reduce costs for consumers and the system as a whole, thus lowering the costs of the transition to cleaner transport and energy at the same time.[30]

29 Projects underway are, for example, Reiner Lemoine Institut. (n.d.). Netz_eLOG: Intelligente Netzintegration der elektrifizierten Logistik (inkl. Deutsche Post DHL) [Netz_eLOG: Smart integration of electric logistics (incl. Deutsche Post DHL)]. https://reiner-lemoine-institut.de/intelligente-netzintegration-e-mobilitaet/

30 Hildermeier et al., 2019.

Recent electricity market reforms[31] support this development. The Clean Energy for All Europeans legislative package[32] requires Member States to establish a well-functioning, open and competitive electricity market. Part of these reforms requires energy suppliers to offer consumers dynamic electricity prices for the energy component of their bill. These electricity prices, however, represent only part of the electricity bill (see Figure 8). As we have shown, network charges represent the larger part of the bill for small industrial consumers in particular. To fully enable cost-reflective pricing and incentivise smart charging behaviour, national regulators should set ambitions high when implementing the reforms. They should mandate, for example, that network companies implement time-varying network tariffs for controllable loads such as electric vehicles.[33] Our findings illustrate that the desired smart charging effects require peak prices based more on electricity and less on capacity. The findings of this report have confirmed that under the current capacity-based network tariff design prevalent in many European Member States, transport operators pay network fees based on peak demand even if this peak occurs very rarely and regardless of whether the local network is under stress. It's important to redesign network tariffs in a way that reflects the actual cost of delivering electricity, for example through the use of time-varying rates. Under these cost-reflective tariffs, electric fleets will be able to charge at lower cost and at times that are beneficial for the grid—which also helps to integrate and use variable renewable energy resources. The introduction of time-varying network tariffs will also allow other consumers to optimise their flexible electricity consumption, for example for electric heating, with wider benefits for society.

Recommendations for power sector regulation:

» **Network tariff reform is crucial.** Capacity-based network charges are a barrier to optimising EV charging. Studying the charging costs for electrifying truck fleets has shown that network charges, in particular capacity-based charges, are a stronger cost driver than energy prices and a barrier to optimising EV charging.

» **Time-varying network charges can help advance the decarbonisation of transport**. Electricity market regulators across EU Member States can accelerate the electrification of heavy-duty vehicles, and clean transport more broadly, by introducing time-varying, volumetric network fees that reflect actual conditions on the power network. Grid operators can support this process locally, for example, by introducing pilots to gather experience on the grid impacts and customer acceptance of time-varying tariffs.

» **Flexible delivery times for electric heavy-duty vehicles can support fleet electrification.** Local authorities can help accelerate the electrification of fleets by eliminating restrictions on time of delivery. These regulations were originally designed to protect inhabitants from the noise and air pollution from diesel trucks and, as such, do not necessarily apply to deliveries made by electric trucks.

Depot charging, as studied in this report, only covers a part of the charging solutions required for electrifying freight to reduce emissions from transport. Additional destination charging, at delivery points, depots or centres with concentrated freight activity for example, and roadside charging infrastructure will be needed to electrify larger parts of the freight sector beyond urban and regional logistics.[34] This study's findings on charging optimisation and charging costs can provide general guidance for planning further charging infrastructure for electric heavy-duty transport.

31 More detailed recommendations on how energy market reforms can support transportation electrification in Hildermeier et. al, 2019, chapter 3.

32 European Commission. (2019). *Clean Energy for All Europeans package.* https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en

33 Hildermeier et al., 2019, chapter 4.

34 Mathieu, 2020.

Policy recommendations for build-out of charging infrastructure:

» **Integrated planning of transport and power infrastructure cannot wait.** When planning charging infrastructure for electric heavy-duty vehicles, the costs for grid integration should be considered and optimised from the start.

» **Member States can drive an essential charging network.** It would be most effective if the ongoing review of the European legislative framework for vehicle charging, the Alternative Fuels Infrastructure Directive, required Member States to accelerate charging options for electric heavy-duty vehicles at depots, destination centres and public sites.

» **The Alternative Fuels Infrastructure Directive can prepare all levels of government for electric heavy-duty transport.** This directive is the perfect vehicle for providing guidance and tools for grid-integrated planning for heavy-duty vehicle electrification jointly with Member States, regions and cities.

» **Users want transparent and comparable pricing for charging services for all electric vehicles.** Recommendations for the revised Alternative Fuels Infrastructure Directive will need to align with Member States' ambitious implementation of electricity market reforms. This alignment can facilitate the introduction of cost-reflective electricity prices and, in particular, network pricing, as explained above.

» **Transitional solutions are needed for public fast charging of electric heavy-duty vehicles.** Service providers are likely to face the same cost barriers that operators of electric vehicle charging points already face today. Until the charging network ramps up, infrastructure operators face prohibitively high network charges that affect the viability of their charging stations.

Electrification of heavy-duty vehicles is key to decarbonising the transport sector and can help the EU to be climate neutral by 2050. The electrification of logistics is an important first step and is already possible today. This study identifies cost-optimisation strategies that logistics operators can apply to smart truck charging at depots. We found that the cost for electricity delivery, the network costs, are the highest cost driver and need reform if we are to accelerate the electrification of freight. Depot charging is only part of a more comprehensive heavy-duty electrification and charging strategy in the future that includes grid-integrated planning of charging at freight centres. This includes destination charging of e-trucks at hubs and urban nodes with high freight activity from different logistics companies, as well as public charging for electric trucks. These much-needed changes can be addressed in the forthcoming European legislative framework for electric vehicle charging, as well as in forthcoming pan-European transport strategies such as the Smart and Sustainable Mobility Strategy.[35] More research is needed to support logistics operators across Europe in estimating costs and preparing strategies to electrify and charge their fleets. This could include refining analytical tools to understand the energy demand of electric fleets and comparing cost-optimisation strategies and use cases from different EU Member States. Joint policy action on the electrification of heavy-duty vehicles is crucial to advance the clean transport and clean energy transitions, and to maximise benefits for consumers, the grid and the environment.

35 The Smart and Sustainable Mobility Strategy is currently in consultation. European Commission. (2020). *Smart and Sustainable Mobility Strategy*. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12438-Sustainable-and-Smart-Mobility-Strategy/public-consultation

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