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ELECTRIFYING LAST-MILE DELIVERY

A total cost of ownership comparison of battery-electric and diesel trucks in Europe

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EXECUTIVE SUMMARY

Last-mile delivery trucks, such as parcel delivery vehicles, represent one of the most significant heavy-duty vehicle segments by sales volume in Europe, as vehicles with a gross weight between 3.5 and 7 tonnes recorded an 11% market share in 2020. The electronic commerce industry has witnessed 15% growth over the last couple of years, and this growth is expected to be sustained. As a result, last-mile delivery trucks are a vital segment of the transport sector to decarbonize. Given their low daily driving ranges of less than 100 km and predictable schedules, they are promising candidates for electrification.

This study quantifies the total cost of ownership (TCO) of last-mile delivery battery-electric trucks (BETs) and compares it to existing diesel truck fleets. The study also provides policy recommendations to overcome the differential cost between battery-electric trucks and their diesel counterparts. The geographic scope of the study covers six major European cities: Berlin, Paris, Rome, London, Warsaw, and Amsterdam.

The study presents comprehensive TCO modeling considering the different cost components fleet operators encounter during ownership, such as purchase costs, detailed energy costs, including grid costs of battery-electric truck fleets, maintenance costs, taxes, and financing costs. The study's time frame extends until 2030, and the TCO is quantified assuming a five-year holding period, representing the first-user ownership period.

We arrive at the following main findings:

» Battery-electric trucks for last-mile delivery can reach TCO parity with their diesel counterparts today in most of the European cities considered in this study with the purchase premiums currently available. Without these premiums, they would not reach economic viability relative to diesel trucks until the second half of the decade as shown in Figure ES1.

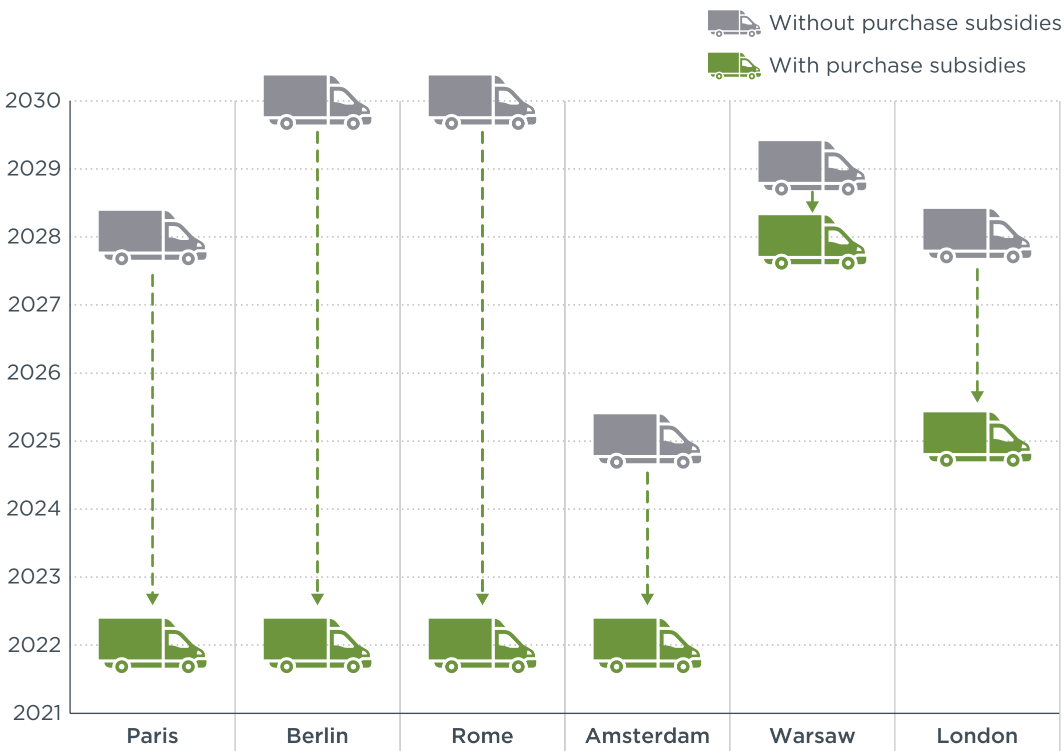

Figure ES1. The year battery-electric trucks achieve total cost of ownership parity relative to diesel trucks with and without purchase subsidies.

» Adjusting the battery size to a truck's daily mileage and route-level energy needs can help to reduce the truck's purchase price gap relative to its diesel counterpart. The truck retail price is a primary driver of the higher TCO of battery-electric trucks relative to diesel trucks. While oversized batteries provide more flexibilities to overcome scheduling disruptions during operation, this results in a high purchase price.

» Battery-electric powertrains are more energy efficient which results in lower energy consumption per km than diesel trucks. This makes their TCO less sensitive to charging costs variation than diesel trucks' sensitivity to the increase in diesel fuel price. Thus, the time in which battery-electric and diesel trucks reach TCO parity is more sensitive to variation in diesel fuel prices than electricity prices as shown in Figure ES2.

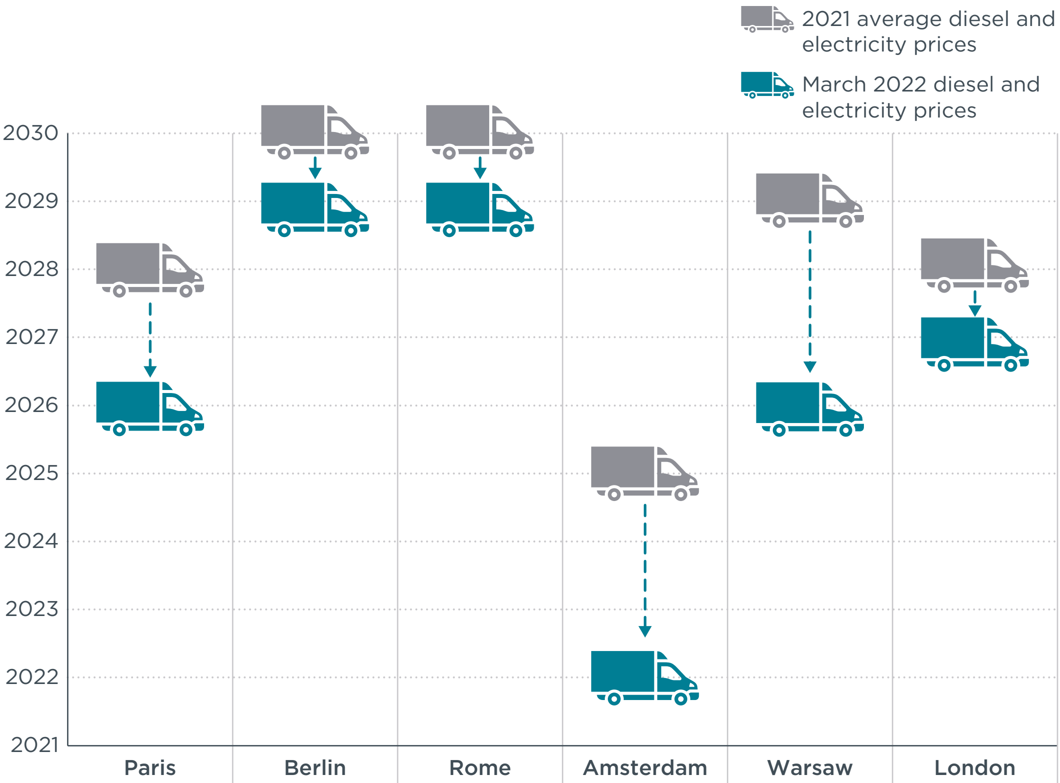

Figure ES2. The year battery-electric trucks achieve total cost of ownership parity relative to diesel trucks considering March 2022 diesel (50-70% increase relative to 2021) and electricity prices (100% increase relative to 2021).

Based on the main findings in this analysis, we recommend a set of policy measures to help overcome the TCO gap between battery-electric and diesel trucks and stimulate the early market uptake of last-mile delivery battery-electric trucks:

» **Implement a bonus-malus tax scheme to finance purchase incentives for zero-emission trucks**. Purchase incentives can help overcome the TCO gap between battery-electric last-mile delivery trucks and their diesel counterparts. The incentives can be financed by introducing a bonus-malus tax scheme that would impose an additional tax on the registration of new diesel trucks based on the truck's CO_2 emissions. The tax could, in turn, be used to fund the purchase incentive for battery-electric trucks. The bonus-malus tax scheme would ideally be budget-neutral and should be updated annually, taking into consideration the actual TCO gap between battery-electric and diesel trucks.

» **Impose emissions charges on all diesel vehicles entering low- and zero-emission zones**. An emissions charge in the range of €2/day to €4/day for six days a week per diesel-powered heavy-duty vehicle can reduce the TCO gap, allowing battery-electric trucks to reach TCO parity before mid-decade.

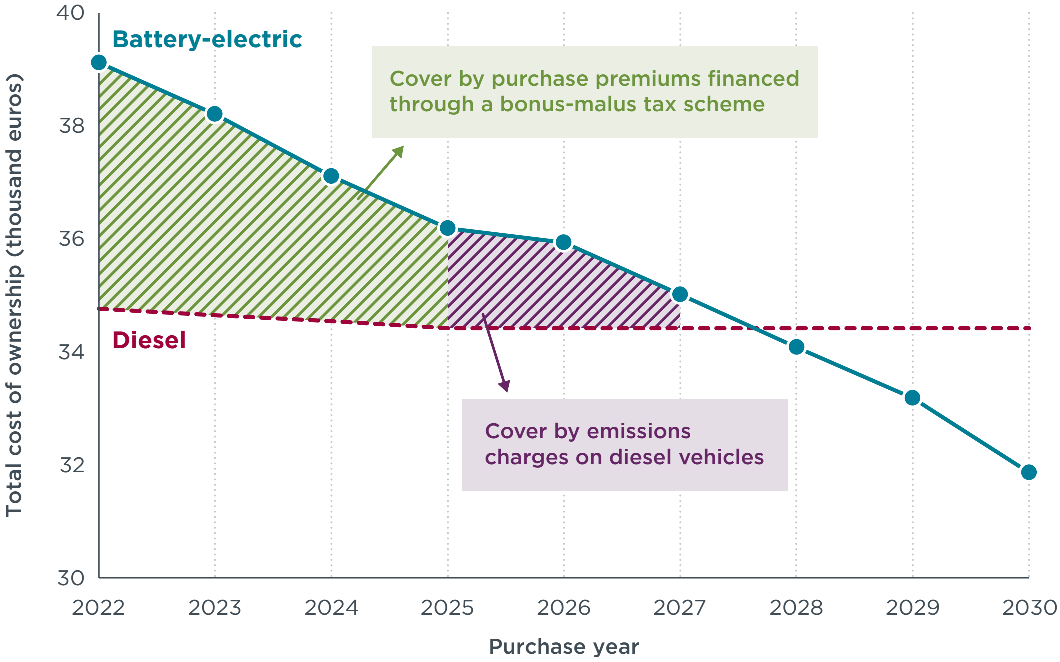

Figure ES3. The total cost of ownership of battery-electric and diesel last-mile delivery trucks estimated over five years of ownership (case of Paris, France).

» **Encourage charging infrastructure deployment at urban logistics depots and ensure the equipment is smart**. In the European Energy Performance of Buildings Directive currently under revision, policy makers should include requirements for equipping new and renovated depots with charging points for commercial vehicle charging. Requirements to set up smart charging infrastructure at commercial depots with public access should also be included into the Alternative Fuel Infrastructure Regulation currently under revision. In addition, grid integration of the charging equipment in depots needs to be addressed in local urban planning, for example as part of the European New Urban Mobility Framework.

» **Require grid operators to set time-varying network tariffs that consider available grid capacity**. Network costs are a significant driver of charging costs for urban depots and are often caused by tariff design that doesn't reflect the actual state of the grid. Introducing time-varying network tariffs, that change based on rising and falling electricity demand on the grid, will help battery-electric truck fleet operators optimize their fleet charging strategies and minimize the related costs.

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INTRODUCTION

Decarbonization of the heavy-duty vehicle (HDV) segment in Europe is crucial to curb greenhouse gas (GHG) and pollutant emissions from the transport sector. Heavy-duty vehicles were responsible for almost 20% of the European transport sector's GHG emissions in 2019 (European Environment Agency, 2020). In addition, road freight is the fastest growing source of GHG emissions of all road transport segments, and is responsible for close to 80% of the global increase in diesel fuel demand since the year 2000 (International Transportation Forum, 2018).

Regulatory efforts to reduce the carbon footprint of HDVs are still nascent and under continuous revision. The first European regulation addressing CO_2 emissions from HDVs was introduced in 2019, requiring truck manufacturers to reduce their fleet emissions by 15% in 2025 and 30% in 2030, relative to 2020 (European Commission, 2019). In addition to efficiency improvements in diesel vehicles, this can be achieved by increasing sales of zero-emission HDVs such as battery-electric and fuel cell vehicle technologies.

Fortunately, sales of electric trucks have been rising over the past several years. More than 1,300 zero-emission trucks were registered in Europe in 2020, compared to fewer than 400 registrations in 2018, with the vast majority being battery-electric trucks (Basma & Rodriguez, 2021). This increase was primarily driven by light- and medium-duty last-mile delivery trucks and heavy vans, with gross vehicle weights (GVW) ranging between 3.5 tonnes and 7.5 tonnes.

Light- and medium-duty trucks are one of the most significant segments by volume, representing more than 11% of HDV market share in 2020 (Basma & Rodriguez, 2021). Although this truck segment is currently not responsible for the largest share of CO_2 emissions, their large sales volume in Europe and the tremendous growth in the electronic commerce industry worldwide of almost 15% over the past year make last-mile delivery trucks an essential segment to decarbonize (Mueed, 2021).

Last-mile delivery trucks are a promising application for electrification given their low daily mileages and the opportunity to recharge throughout the day, either during loading and unloading at depots or at delivery destinations if the truck is parked long enough near a charging station. This is primarily the case for trucks delivering to dense residential areas. However, it is still unclear how battery-electric last-mile delivery trucks compare to their diesel counterparts from an economic perspective.

Moreover, the large-scale deployment of electric last-mile delivery trucks raises questions about how this additional charging demand can be integrated into local power grids and what this will cost. This requires detailed knowledge about factors that drive grid integration costs for electric truck fleets, including costs for electricity and the electricity networks used, taxes and levies, and costs for grid connection or upgrades, if applicable (Hildermeier et al., 2020). It is critical to provide fleet operators, industry stakeholders, regulators, and policy makers on a local, national, and European scale with information about how these cost factors can be optimized (Oeliger et al., 2020). Full transparency on energy pricing and resulting costs enables consumers to achieve benefits through smart charging, i.e., charging when the costs for electricity and grid use are lowest, without compromising their mobility needs (Hildermeier et al., 2019). With this in mind, we have thoroughly investigated the various costs in this comprehensive TCO analysis.

This study quantifies the total cost of ownership (TCO) of last-mile delivery battery-electric trucks and compares it to their diesel counterparts, focusing on their charging cost. The analysis is conducted for six European cities: Berlin, Germany; Paris, France; Rome, Italy; London, United Kingdom; Warsaw, Poland; and

Amsterdam, the Netherlands, which represent more than 95% of zero-emission truck sales in Europe[1] between 2016 and 2020 (Basma & Rodriguez, 2021). We also conduct a detailed TCO analysis, focusing on the capital and operational expenses, including location-specific data for energy prices and network fees, taxes, and levies. Based on the cost comparison, the study concludes with policy recommendations to help overcome the technological and economic challenges facing the electrification of last-mile delivery trucks.

1 This includes EU27 + Switzerland, Norway, and the United Kingdom.

USE CASE DEFINITION

This TCO analysis of battery-electric last-mile delivery trucks and vans in several European cities examines parcel delivery vehicles with a gross vehicle weight ranging between 3.5 and 7.5 tonnes.

The analysis considers two representative vehicles with similar technical specifications: a large diesel cargo van, the Ford Transit 350E, and its battery-electric equivalent, StreetScooter WORK XL (Figure 1), which is based on the same chassis. The Ford Transit is one of the most popular last-mile delivery vehicles in Europe, with more than 2,600 units of its different variants being sold since 2016, mainly in Germany, France, and the United Kingdom, representing more than 13% of the market share for this vehicle group.[2] The StreetScooter WORK XL is the highest selling electric vehicle in this segment, with more than 250 units sold in Germany in 2020 (Basma & Rodriguez, 2021). Table 1 summarizes the technical specifications of both vehicles. The energy efficiency of both trucks, based on values reported by the manufacturers, is also presented in Table 1. It is assumed that there will be no energy efficiency improvements between 2020 and 2030, as this vehicle group is not regulated by the European Union's HDV CO_2 standards.

Figure 1. Deutsche Post DHL StreetScooter WORK XL electric truck model.

Table 1. Summary of vehicles' technical specifications.

	Diesel delivery truck [a)]	Battery-electric delivery truck [b)]
Axle configuration	4x2	4x2
Gross vehicle weight (kg)	4,490	4,050
Unladen weight (kg)	2,482	2,775
Maximum payload (kg)	2,008	1,275
Powertrain rated power (kW)	114	90
Transmission	6-speed manual gearbox	Single speed + differential
Engine size (Liters)	2.2	-
Battery size (kWh)	-	76 kWh
Energy efficiency	9.5 l/100 km (0.95 kWh/km)	0.3 – 0.4 kWh/km
CO_2 emissions [c)]	250 g/km	0 g/km

[a)] Data based on (Ford, 2016)
[b)] Data based on (StreetScooter, 2020; Wattev2buy, 2019)
[c)] Calculated considering 2,640 g of CO_2 per liter of diesel fuel

2 Content supplied by IHS Markit Global S.à.r.l.; Copyright © IHS Markit Global S.à.r.l., 2021. All rights reserved.

The main characteristics of the vehicle use case are defined as follows:

- Vehicles operate for 12 hours a day, from 6:00 a.m. to 6:00 p.m.
- Vehicles return to their respective depots by 6:00 p.m., where charging takes place within the next 12 hours (6:00 p.m. to 6:00 a.m.), as shown in Figure 2.
- Based on the vehicles' technical specifications, charging uses AC 11 kW or AC 22 kW chargers.
- The fleet is composed of 23 vehicles that share the same depot.
- The average vehicle travels 40 to 60 km per day and consumes 0.3 to 0.4 kWh/km, which adds up to an average of 5,000 kWh of annual electricity consumption over 300 days per year.
- Vehicles are not recharged during the day due to operational constraints, such as a lack of charging availability at loading and unloading locations. In addition, drivers' breaks during the day are very short, which eliminates the possibility of daytime charging.

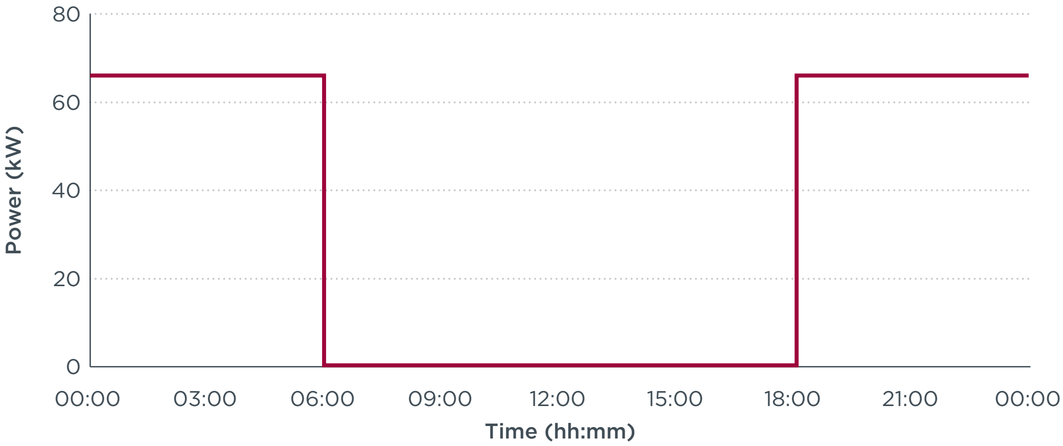

Figure 2. Fleet charging load.

METHODS AND DATA

This section explains the methodology used to quantify the TCO of battery-electric and diesel last-mile delivery trucks operating in six European cities. The analysis is split into two parts: (1) fixed expenses and (2) operational expenses. The methodology is adapted from a previous ICCT study on the TCO of battery-electric tractor-trailers in Europe (Basma et al., 2021). Figure 3 summarizes the method's global framework as detailed in the upcoming sections.

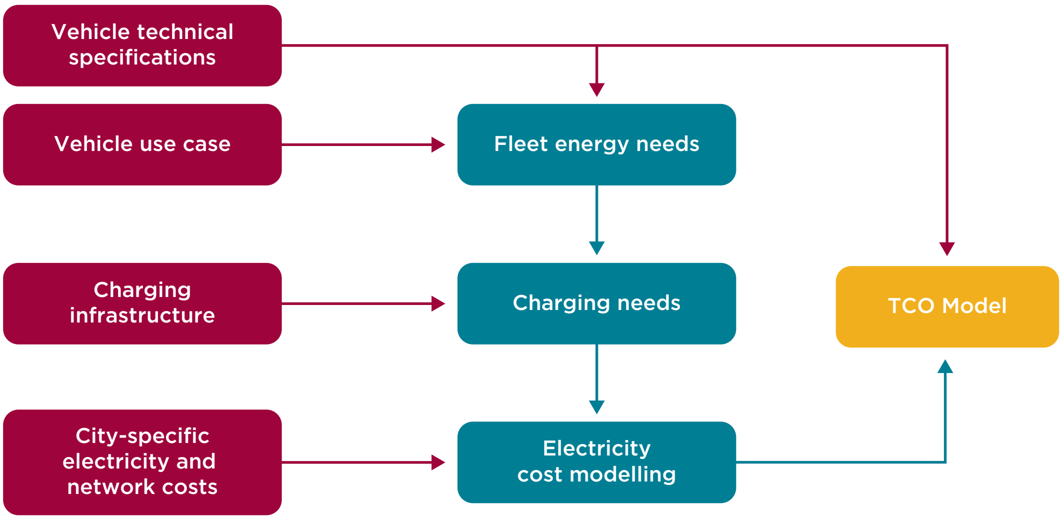

Figure 3. Total cost of ownership method framework.

FIXED EXPENSES

Fixed expenses are all expenses independent of the vehicle mileage during operation, which includes the purchase price of the trucks, registration and ownership taxes, and any other financial costs incurred, such as interest on loans to finance the purchase of the trucks.

Retail price

The retail price of the battery-electric vehicle between 2022 and 2030 is estimated through a bottom-up approach based on a detailed vehicle component cost analysis. Table 2 summarizes the battery-electric vehicle cost components and the estimated total vehicle retail price in 2022, 2025, and 2030.

Table 2. Battery-electric truck retail price breakdown in 2022, 2025, and 2030.

Cost component	2022	2025	2030
Battery	€9,272	€6,840	€3,952
Powertrain	€3,405	€3,081	€2,730
Chassis and assembly	€23,995	€23,995	€23,995
Indirect costs	€14,962	€12,074	€8,283
Total retail price	€51,634	€45,990	€38,960

The battery direct manufacturing cost is considered to be $135/kWh in 2022,[3] a figure that will decrease to $100/kWh in 2025 and $58/kWh in 2030, according to Bloomberg New Energy Finance's latest Lithium-ion battery price survey report (BNEF, 2021). Other component costs such as the electric machine, transmission, power electronics, thermal management, on-board charger, and all other powertrain-related components

3 Cost data expressed in USD are converted to EUR using a conversion factor of EUR 1 = 1.11 USD.

are estimated to have a direct manufacturing cost of €3,405 in 2022. According to Mulholland (2022), this will decrease to €2,730 by 2030 due to reduced electric drive costs. The truck chassis and assembly costs are calibrated to reflect the actual 2022 price of the vehicle. Indirect costs are also considered, such as profit markups, research and development, marketing, overhead, and distribution. These costs are captured by multiplying the estimated direct manufacturing costs by an indirect cost multiplier adapted from (U.S. EPA & U.S. DOT, 2016). This is estimated to be 1.425 in 2020 and will decrease linearly to reach 1.27 by 2030.

The presented bottom-up approach used to estimate the retail price of the battery-electric truck is calibrated against the StreetScooter WORK Box L model, a vehicle similar to the StreetScooter WORK XL but with a smaller 40 kWh battery pack, with a reported retail price of €45,450 excluding VAT (Bundesamt für Wirtschaft und Ausfuhrkontrolle, 2022).

The reported diesel Ford Transit cargo van retail price excluding VAT is around €33,000 (Ford, 2022). This price is assumed to remain constant between 2022 and 2030.[4]

Figure 4 presents the retail price evolution of the battery-electric and diesel vehicles between 2022 and 2030, excluding VAT. The retail price gap exceeds €19,000 in 2022, which will be reduced to almost €13,000 in 2025 and less than €6,000 by 2030. This is driven by the reduction in battery cost and indirect costs, as shown in the detailed retail price breakdown in Figure 5.

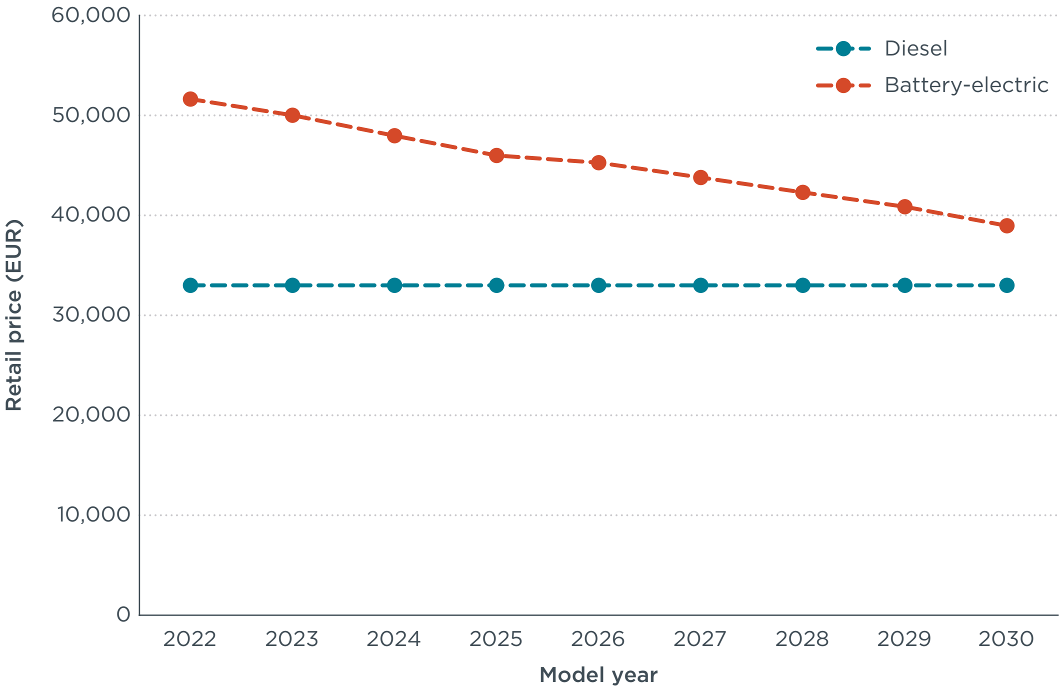

Figure 4. Retail price evolution of last-mile parcel delivery diesel and battery-electric trucks.

4 The reported cost is in 2022 USD and a currency conversion factor of EUR 1 = USD 1.11 is considered for 2022 cost data.

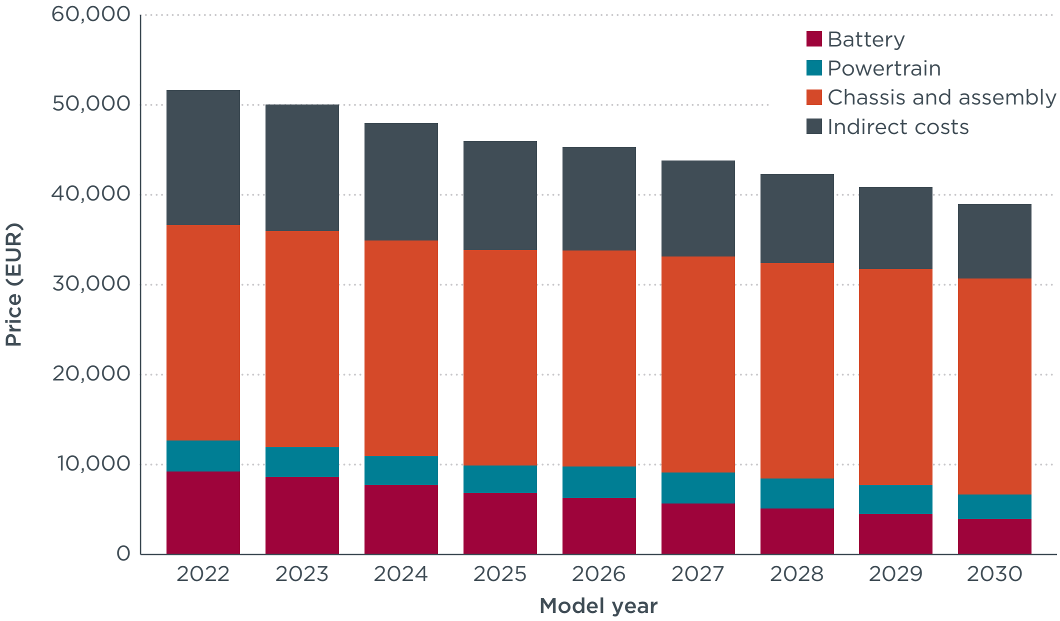

Figure 5. Battery-electric truck retail price breakdown as function of model year.

Infrastructure costs

The depot underlying our use case is equipped with ten chargers with a 22-kW power rating to serve the fleet of 23 vehicles through an on-site dynamic load management system. The vehicle charging time could range between 1 and 3 hours, depending on whether the charging power is restricted due to constraints in the depot's maximum power capacity. The infrastructure capital and operational expenses (CAPEX and OPEX) are informed by the recently published impact assessment study of the revision to the proposal for the Alternative Fuels Infrastructure Regulations in Europe (AFIR) (European Commission, 2021b). The total infrastructure CAPEX and OPEX are calculated and amortized considering the chargers' service life and the number of vehicles utilizing the chargers at the depot. Table 3 summarizes the main assumptions and calculation methods for the charging infrastructure costs.

Table 3. Summary of main assumptions and calculation methods for charging infrastructure costs.

ID	Parameter	2022	2030	Calculation method
A	Number of chargers	10	10	-
B	Charger power (kW)	22	22	-
C	Charger hardware cost (€)	3,110	2,598	-
D	Charger installation cost (€)	2,844	2,376	-
E	Charger availability	95%	95%	-
F	Total hardware cost (€)	31,100	25,979	C x A
G	Total installation cost (€)	28,440	23,761	D x A
H	CAPEX (€)	62,517	52,227	(F + G) x (1+1-E)
I	OPEX share of CAPEX	1.2%	1.2%	-
J	OPEX (€/year)	750	627	H x I
K	Internal rate of return	9.5%	9.5%	-
L	Service life (years)	15	15	-
M	CAPEX annual payment (€/year)	7.986	6,672	$H \times K \times (1 + K)^L / [(1 + K)^L - 1]$
N	Total annual expenses (€)	8,736	7,298	M + J
O	Number of vehicles	23	23	-
P	Amortized cost per vehicle (€/Year)	380	317	N / O

Finance, residual value, and taxes

The focus of this study is to quantify the TCO from a first-user perspective, thus the analysis period is set at five years, representing the average time a first owner uses a new delivery truck. The truck's purchase is financed through a loan that will be paid in equal installments by the operator of the truck over the considered analysis period at a 2% interest rate at the beginning of each year.

The truck residual value is estimated after five years based on its remaining service life. Second-hand prices for the two vehicles studied are already available on commercial online platforms. While those prices are likely representative for the diesel truck, they might not reflect the actual depreciation of the electric truck, as no data are shared regarding the battery state of health and the remaining warranty period. For this purpose, this study utilizes an analytical approach previously presented in (Mao et al., 2021) and (Basma et al., 2021). As defined in the use case, the vehicles travel an average of 50 km each day for 300 days a year, resulting in 15,000 km in annual mileage. Over five years of operation, the vehicles travel 75,000 km. As shown in Figure 6, the residual value of the diesel truck is estimated to be 53% of its original value after five years of operation, assuming a vehicle lifetime of 240,000 km for urban delivery large vans (Lee et al., 2013).

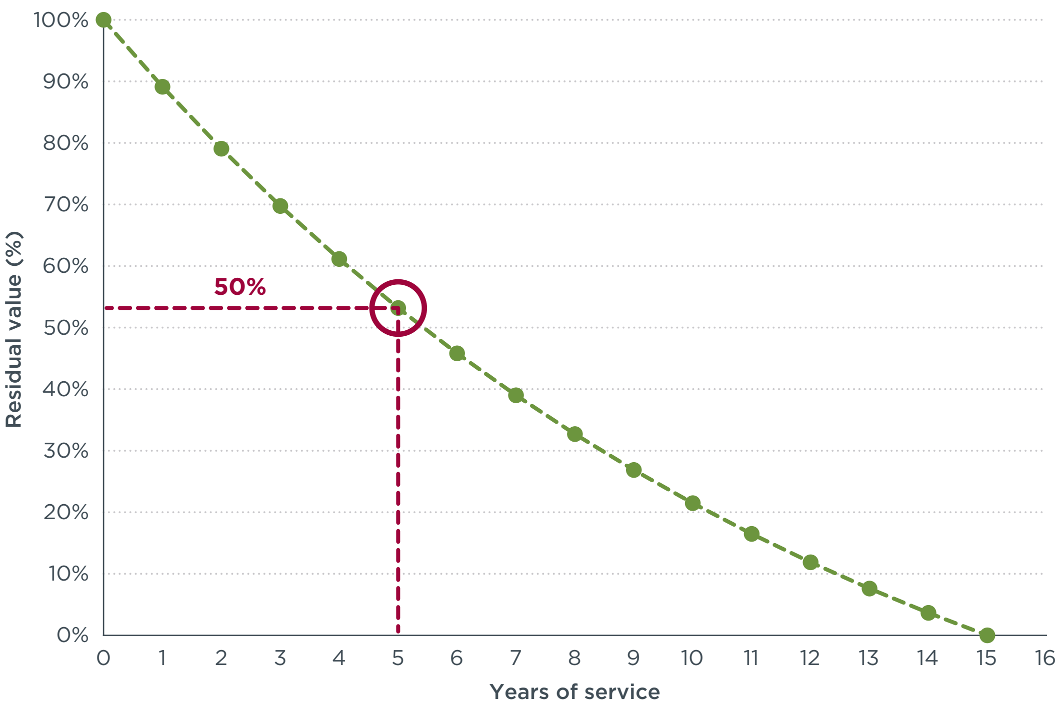

Figure 6. Vehicle depreciation curve over its service life.

Regarding the battery-electric truck residual value, the battery residual value is estimated separately and considered to be 15% of its original value after five years of operation if there is no need for battery replacement during this period (Burke & Fulton, 2019; Burke & Sinha, 2020). The residual value of the other truck components is considered to be similar to the diesel truck at 53%. Table 4 summarizes the vehicles financial costs and residual value.

Table 4. Summary of vehicle finance costs and residual value.

Finance	Analysis period	5 years
	Interest rate	2%
	Discount rate	9.5%
Residual value	Diesel truck	53%
	Electric truck (excluding battery)	53%
	Battery	15%

Two types of taxes are considered: vehicle ownership taxes and vehicle registration taxes, as shown in Table 5. Ownership taxes are paid annually, while registration tax is a one-time charge. Data for France, Italy, and Poland are based on (ACEA - European Automobile Manufacturers' Association, 2021). Data for Germany are based on (BDF, 2021), data for the United Kingdom are based on (Driver and vehicle licensing agency, 2020), and data for the Netherlands are based on (Belastingdienst, 2022a).

Table 5. Vehicle registration and ownership taxes in European countries of interest in this study.

Country	Registration (€)		Ownership (€/year)	
	Diesel	Electric	Diesel	Electric
Germany	0	0	285	285
France	454	262	0	0
Italy	386	386	200	200
Netherlands	0	0	320	0
Poland	0	0	370	370
United Kingdom	0	0	200	200

OPERATIONAL EXPENSES

Operational expenses are costs directly related to the vehicle kilometers traveled, including charging, diesel fuel, and maintenance costs.

Charging cost

This section identifies in detail all grid-related costs for charging electric trucks at the depot, assuming the described use case. Grid-related costs are often difficult to estimate but can be significant (Hildermeier et al., 2020). The price components are power prices (energy component), network prices (network component), and taxes and levies. To understand the charging costs at the various depots, we calculated the costs for charging the truck fleets based on the charging patterns defined in the use case and the depot's overall consumption.

Table 6 summarizes the charging costs for depots calculated explicitly for each of the six cities, and Figure 7 shows the charging cost breakdown by component. VAT has been deducted from the charging costs, as it is assumed that VAT can be refunded for fleet operators, similar to the diesel fuel VAT. The analysis reveals that a depot's charging costs vary between 8 and 21 ct/kWh in the cities studied. The following sections explain results by price component, starting with power prices.

Table 6. City-specific charging costs for the depot defined in this use case.

City	Power prices incl. margin ¢/kWh	Network prices ¢/kWh	Taxes and levies ¢/kWh	VAT ¢/kWh	Charging costs ¢/kWh	Charging costs without VAT ¢/kWh
Berlin	6.5	1.7	9.6	3.4	21.2	17.8
Amsterdam	6.7	1.6	2.4	2.2	12.9	10.7
Warsaw	7.1	0.6	0.3	0.4	8.4	8
Rome	5	0.8	9.5	3.5	19.2	15.7
Paris	6.9	2.8	3.2	2.6	15.5	12.9
London	8.4	7.3	1.3	3.4	20.3	16.9

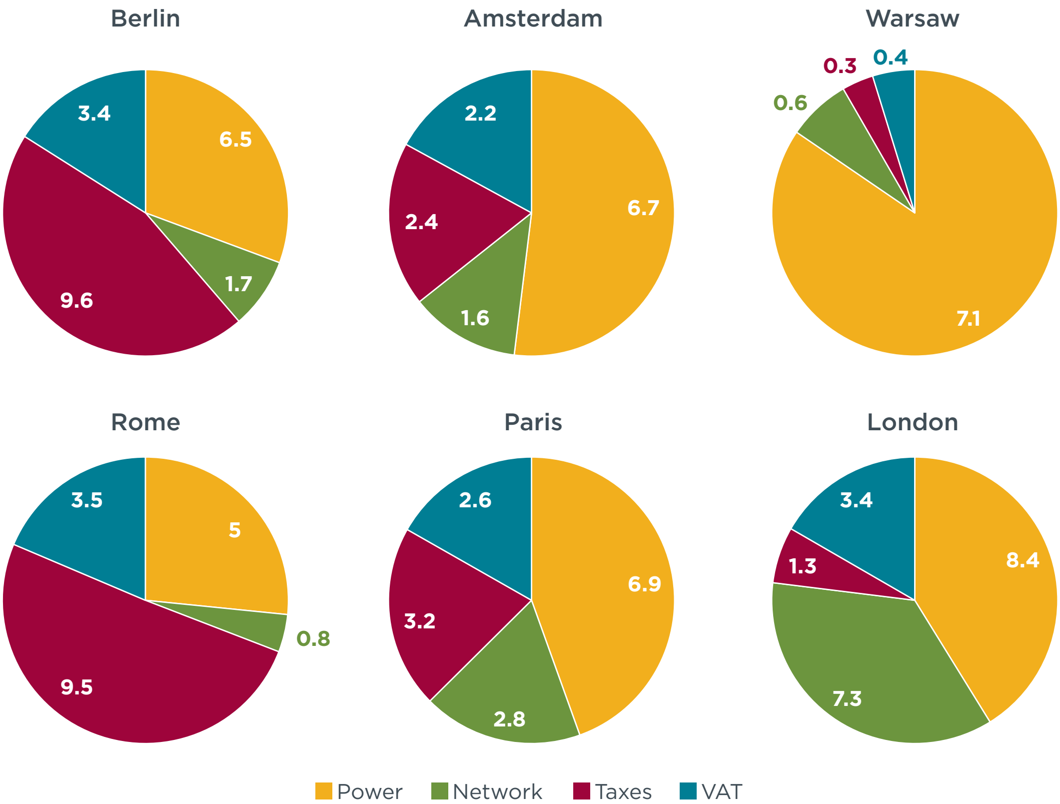

Figure 7. Charging costs breakdown per city (¢/kWh).

Power prices

Power prices are estimated based on the wholesale market as the average hourly day-ahead price for the first half of 2021 (January–June) in the six respective countries (Agora Energiewend, 2022; ENTSO-E, 2022). A steep increase in energy prices occurred in 2021 and, given the current energy crisis, their development is very uncertain. At the time of drafting this report, as illustrated in Figure 8, power prices in the first half of 2021 reflect a middle ground between previously low average prices and higher prices in early 2022. The total charging costs of electric truck fleets will therefore vary strongly with future power prices.[5]

5 The study has not factored in possible savings through credits from the use of renewable electricity in electric transport. These credits are allowed through a crediting mechanism in the Netherlands, Germany, and France, and are under discussion for inclusion in European legislation as part of the Renewable Energy Directive (RED) recast. Two ways of accounting for electricity from renewables are possible: direct line savings through a renewable source (e.g., solar panel on a logistics depot's roof) or savings based on the CO_2 emissions from the electricity grid mix. Savings can only be accounted for if the charging of EVs is separately metered, which is not the case in our example.

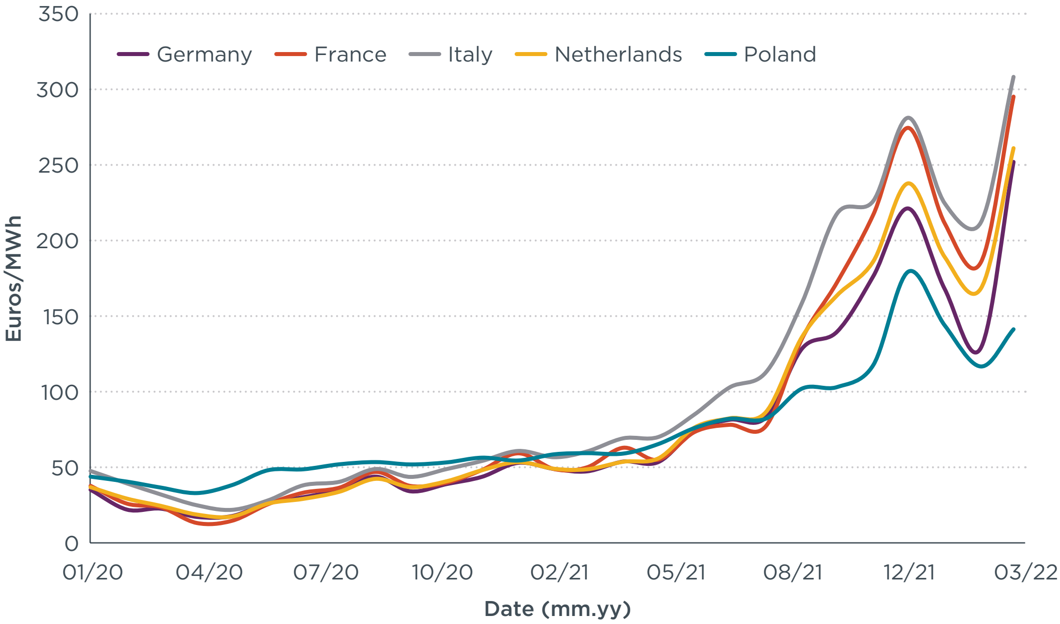

Figure 8. Power prices between 2018 and 2022 for Germany, the Netherlands, Poland, Italy, France. Data obtained from Ember (2022).

Most of the variation in charging costs across cities in the six European countries is explained by the differences in network prices set by local grid operators and taxes and levies defined nationally and locally. These components are discussed in the following sections.

Network prices

Network costs are defined as the price of delivering electricity to the connection point, which in our case is the logistics depot. The network costs vary depending on the depot's power demand and how it is distributed during the day within the depot's overall installed grid capacity (see load curve in Figure 2). The applicable network tariffs depend on the depot's location in a specific grid area and on how the local distribution grid operator sets these rates. These tariffs can vary significantly between grid areas and cities.

For this analysis, network costs were calculated individually per location for an assumed logistics depot operating a fleet of battery-electric trucks. Based on applicable tariffs in the first half of 2021 in the six cities' grid areas and considering the charging load and the depot operation load, network costs were estimated for each location. Figure 9 provides an overview of how network costs are calculated:

- » This study identifies the applicable grid areas and network tariffs for all six locations. Sources are tabulated in Table A7 in the Appendix.
- » Based on the depot's overall consumption, it is classified into the appropriate network tariff consumer category.
- » Costs for the depots are determined by matching the truck fleet's load curve with the tariff structure. If the tariff comprises different time bands depending on when the electricity is consumed (time-of-use tariff), charges will fluctuate according to peak and off-peak hours over the day.

Figure 9. Framework for calculating network costs for urban depots.

The design of the applicable network tariffs also varies from one location to another. Most network tariffs in Europe are based on the annual peak demand capacity in kW and the volumetric electricity charges in kWh. High demand charges based on capacity can present a barrier to integrating distributed, flexible demand such as for electric vehicle charging (Hildermeier et al., 2019). Inversely, including time-varying elements into network tariffs encourages consumers to shift consumption to cheaper hours. This allows for better grid utilization, creating benefits for electricity consumers (Burger et al., 2022).

London's network, for example, illustrates how charging costs can vary depending on how tariffs are designed, which allows fleet operators to optimize EV charging using their flexibility (smart charging). London's distribution network operator added a time-of-use component for network use in its tariff, as shown in Figure 10. The fleet considered in this study is assumed to charge overnight, starting at 18:00. In the case of London, the first hour of the fleet's charging period (18:00 to 19:00) coincides with the high peak time band of London's applicable network charge, which is at almost 7 p/kWh. Because the network tariff for London applies a high-cost time band until 19:00, the first hour of charging the fleet in a London depot is about four times higher than those in other cities (see Table 6). This illustrates that information about network tariffs and costs is crucial and will encourage operators to shift the fleet's charging to after 19:00 if flexibility allows.

For electric delivery trucks and larger fleets with higher mileage, charging costs are likely to become a more significant part of the fleet's overall TCO. As a result, optimizing charging will become even more critical.

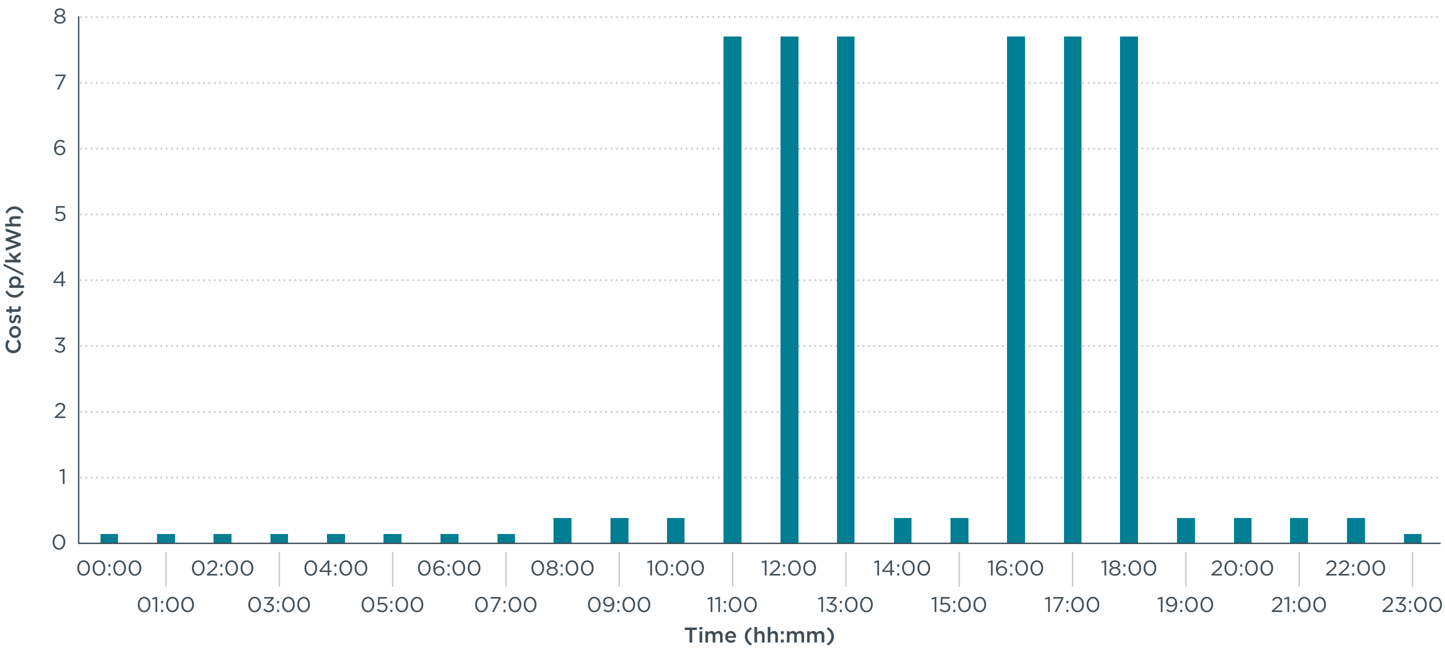

Figure 10. Volumetric time-of-use charges in London. Source: (UK Power Networks, 2022).

Taxes and levies

Taxes and levies considered in the study include electricity taxes, federal and local taxes if applicable, environment-related levies, and other country-specific charges reflecting the period of analysis in the first half of 2021. These are summarized in Table 7. It should be noted that these taxes and levies are still evolving. For example, the German green electricity levy will be significantly reduced in 2022 to 3.7 ct/kWh, reducing the gap in charging costs between Berlin and other depot locations (undesminsterium fuer Wirtschaft und Energie, 2022).

Table 7. Summary of taxes and levies per city.

City	Taxes and Levies	ct/kwh
Berlin [a]	Green electricity levy (EEG Umlage)	6.5
	Electricity tax	2.05
	Other charges	1.09
	Total	**9.64**
Paris [b]	Federal tax (Contribution au Service Public d'Electricité – CSPE)	2.25
	Local tax (Taxes sur la Consommation Finale d'Electricité – TCFE)	0.96
	Total	3.21
London [c]	Climate charge levy	0.87
	Carbon tax	0.37
	Total	**1.24**
Amsterdam [d]	Power tax	0.13
	Climate levy	2.25
	Total	**2.38**
Warsaw [e]	Capacity levy	0.4
	Total	**0.4**
Rome [f]	Energy efficiency, renewable, and nuclear energy levy	9.5
	Total	**9.5**

[a] (Bundesnetzagentur, 2021)
[b] (French-property, 2021)
[c] (UK Government, 2022)
[d] (Belastingdienst, 2022b)
[e] (Innogy Stoen Operator, 2021)
[f] (Autorità di Regolazione per Energia Reti e Ambiente, 2018).

Grid upgrade costs

Grid upgrades can add high costs to a depot's overall charging costs, but upgrades are not considered for the use case at hand because the fleet's charging needs stay within the depot's overall capacity. More specifically, the logistics depot is connected to a mid-voltage grid (530 KW) and its peak consumption of 150 KW falls between 6 a.m. and 8 a.m., which does not overlap with charging time of the truck fleet. Their 12-hour parking time provides enough flexibility to charge the entire fleet overnight. Even if all trucks were charged at the same time as the depot's peak consumption peak, the maximum additional load would be 66 KW (as three trucks at most can charge at the same time), which remains within the depot's installed capacity.

However, if trucks can't only be charged overnight, or if the fleet size increases and its overall charging needs exceed the depot's installed capacity, a depot will need to upgrade its grid connection to a higher capacity, which implies high additional annual costs. Therefore, it is essential for depot owners to consider and optimize the costs of grid integration when planning charging infrastructure for heavy-duty electric vehicles, as electric truck fleets are likely to grow. In addition to grid-integrated planning, time-varying energy and network prices help fleet operators to optimize fleet charging. Based on price signals, which can be tied in real-time to the energy spot market, the speed and timing of charging can be adapted to the low power price periods and/or periods of abundant renewables production (Burger et al, 2022). Such smart charging strategies for battery-electric trucks can provide significant cost savings for fleet operators of up to 15,000 euros annually, or about 10%-15% of total energy costs, including charging for an operator of a ten truck electric fleet (Hildermeier et al., 2020). More importantly, optimizing consumption on site at the depot through smart charging can ensure that the total depot power demand during charging will not exceed the overall installed capacity of the depot, avoiding costs for grid upgrades.

Diesel prices

Table 8 shows the average diesel prices in 2021 across the European countries studied, collected from (DKV, 2021). VAT is deducted from the fuel prices as it can be refunded for fleet operators. Also, some excise duties can be reimbursed to fleet operators, according to (Vialtis, 2021).

Table 8. Summary of diesel prices (€/liter) in European countries of interest in 2021.

Country	Gross price (€/liter)	VAT rate	VAT (€/liter)	Excise duty refund in 2021 (€/liter)	Net price with tax refunds (€/liter)
Germany	1.38	19 %	0.22	0	1.16
France	1.46	20 %	0.24	0.16	1.06
Italy	1.52	22 %	0.27	0.21	1.03
Netherlands	1.54	21 %	0.27	0	1.27
Poland	1.17	23 %	0.21	0	0.95
United Kingdom	1.61	20 %	0.27	0	1.34

Maintenance costs

The diesel vehicle's average maintenance cost over its lifetime is considered to be €11/100 km, while the battery-electric vehicles maintenance cost is estimated to be €7.5/100 km (Burnham, 2020), which is approximately 32% less than that of the diesel vehicle.

RESULTS AND DISCUSSION

KEY FINDINGS

In this analysis, the TCO of the battery-electric last-mile delivery truck is compared to that of its diesel counterpart under two scenarios:

» A scenario where no purchase premiums are considered to reflect the actual technology costs.

» A scenario where the currently applied purchase incentives are considered in each city to reflect the current costs encountered by fleet operators. These purchase incentives are summarized in Table 9.

Table 9. Summary of purchase incentives offered for battery-electric trucks in the cities of interest in this study.

City	Purchase incentives
Berlin [a)]	80% of price difference to diesel truck capped at €100,000
Paris [b)]	40% of the vehicle acquisition cost capped at €50,000
Rome [c)]	€14,000 fixed premium
Amsterdam [d)]	20% of the vehicle acquisition cost capped at €40,000
Warsaw [e)]	30% of price difference to diesel truck capped at €33,333
London [f)]	€7,000 fixed premium

[a)] (Bundesamt für Güterverkehr, 2022)
[b)] (République Française, 2021)
[c)] (Ministero delle infrastrutture e della mobilità sostenibil, 2021)
[d)] (Gemeente Amsterdam, 2021). As of May 2022, the national subsidy scheme will come into place providing different incentives as detailed in (Ministerie van infrastructuur en waterstaat, 2021). The Netherlands also offers Environmental Investment Allowance (MIA) and the Random Depreciation of Environmental Investments (Vamil) that reduce the taxable profit of entrepreneurs investing in technologies considered in the Environmental List (Rijksbureau voor Ondernemend Nederland, 2022).
[e)] (Ministerstwo Energii, (2019)
[f)] (Department for Transport, (2020)

Figure 11 shows the TCO of both truck technologies as a function of the truck purchase year over the first five years of ownership in each of the cities. In general, the TCO of the battery-electric truck declines with time, driven by the reduction in the truck retail price. For the scenario where no purchase premiums are considered, the battery-electric truck specified for this analysis will achieve TCO parity by the end of the decade in most of the cities considered in this study, except for Amsterdam, where parity is achieved by 2028 due to a combination of high diesel prices and low electricity prices relative to other cities. The retail price of the battery-electric truck is significantly higher than that of the diesel truck, almost €19,000 higher in 2022 and €6,000 higher in 2030, as presented earlier in Figure 4. This is the main reason behind the battery-electric truck's higher TCO. In addition, the low daily mileage in our use case reduces the benefits of operating a more efficient electric powertrain with lower operating costs.

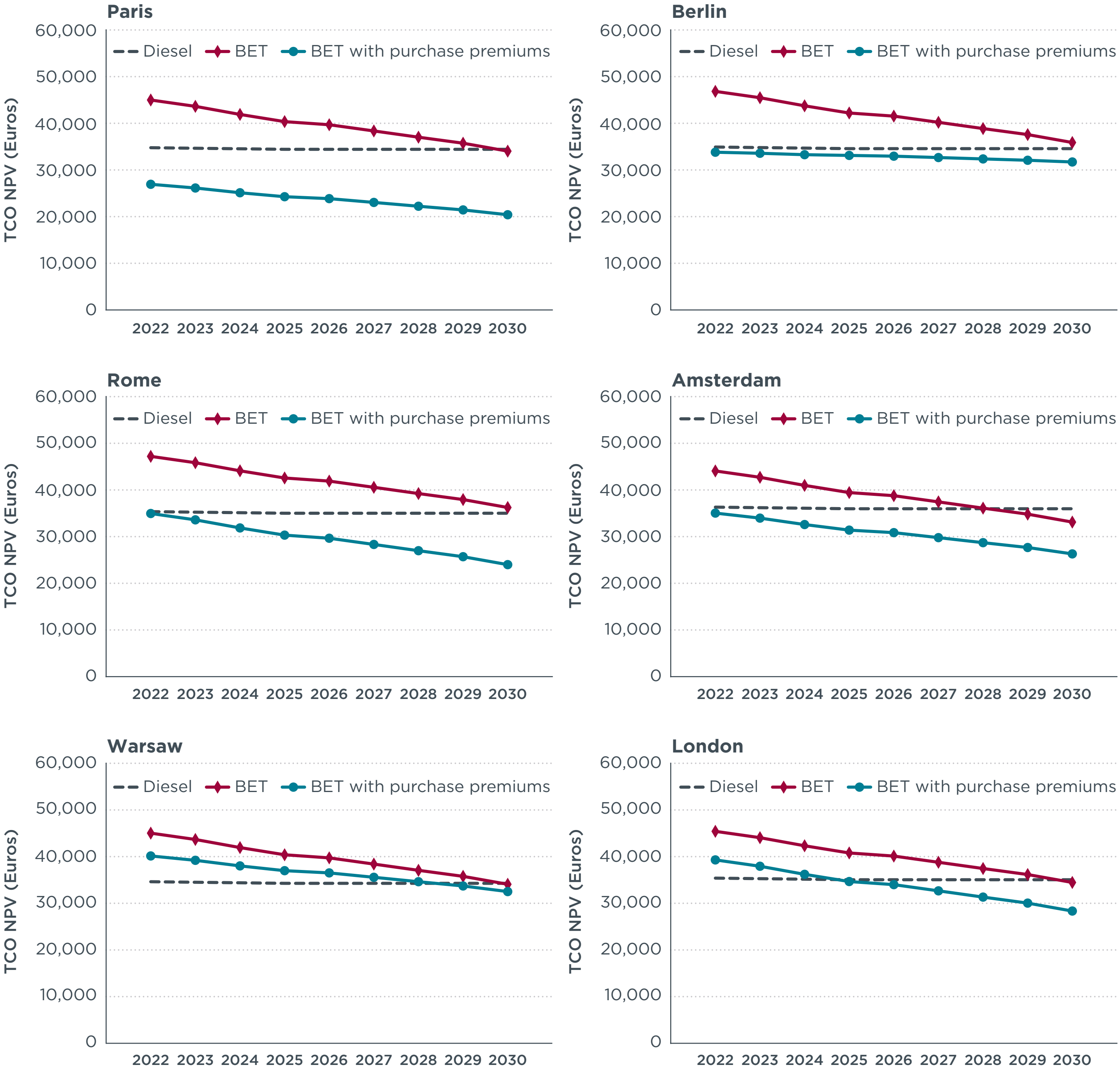

Figure 11. Total cost of ownership net present value (TCO NPV) of battery-electric trucks (BETs) and diesel trucks for different model years from the first ownership perspective (5 years) between 2022 and 2030.

To better understand this TCO behavior, Figure 12 presents a detailed TCO breakdown for both truck technologies focusing on trucks purchased in 2022, 2025, and 2030. Although electricity costs in each city are 30% to 60% lower than the diesel fuel costs, the fact that last-mile urban delivery trucks do not travel for long mileages during their lifetime reduces the impact of the lower operating costs of battery-electric trucks. As a result, fleet operators cannot compensate for their high initial investment in purchasing battery-electric trucks and installing the necessary charging infrastructure with lower operational costs.

Figure 12. Total cost of ownership (TCO) breakdown of diesel and battery-electric trucks for purchase years 2022, 2025, and 2030 across cities of interest in this study.

Considering the currently offered purchase incentives in each city, which are assumed to remain in place until 2030, batter-electric trucks start to achieve a better TCO than diesel trucks as of 2022 in Paris, Berlin, Rome, and Amsterdam. The TCO parity of battery-electric trucks operating in Warsaw and London is delayed to 2028 and 2025, respectively, due to lower offered purchase incentives. Table 10 summarizes these findings.

Table 10. Year when total cost of ownership (TCO) parity is achieved between the battery-electric truck and the diesel truck.

City	Paris	Berlin	Rome	Amsterdam	Warsaw	London
TCO parity year without premiums	2030	2030	2030	2028	2030	2030
TCO parity year with premiums	2022	2022	2022	2022	2028	2025

The structure and amount of purchase incentives are different across the cities considered in this study. In the case of Rome and London, purchase incentives are defined as a fixed amount in Euros, regardless of the actual vehicle price and category. Incentives offered in Paris and Amsterdam are defined as a percentage of the vehicle acquisition cost, capped at a specific limit. In this case, effectively, the higher the vehicle acquisition cost, the higher the subsidy. In Berlin and Warsaw, incentives cover a percentage of the cost difference between an electric vehicle and its diesel equivalent. The latter approach provides subsidies to level the retail price of battery-electric and diesel trucks, assuming proper premiums caps. In addition, such an approach will result in lower premiums when the price of a battery-electric truck becomes comparable to that of a diesel truck until both trucks' retail prices converge, and thus purchase premiums are phased out.

IMPACT OF PROPER BATTERY SIZING ON ELECTRIC TRUCKS' TOTAL COST OF OWNERSHIP

Batteries are a significant cost component of electric trucks. Proper battery sizing helps to reduce the truck retail price and TCO, in addition to generating payload and volume capacity gains. Batteries should be sized depending on the truck use case, taking into consideration the daily driving range, energy efficiency, and available charging infrastructure. In the use case presented in this study, electric trucks are equipped with 76 kWh batteries, enough to cover more than 150 km of daily driving range on a single charge. However, those trucks travel for 50 km daily on average, meaning the battery is significantly oversized. This section examines the impact an adjusted battery size would have on the TCO parity considering the use case needs. The TCO analysis is conducted for a battery size of 35 kWh, enough to cover at least 85 km of driving range with an 85% usable battery state of charge window. Electric vans operating in last-mile delivery applications, such as the Volkswagen eCrafter, MAN TGE, and Mercedes-Benz eSprinter are already equipped with such battery size.

Table 11 shows the impact of proper battery sizing on the TCO parity year without purchase incentives. A significant reduction in the TCO parity year is witnessed for all cities, making battery-electric trucks economically feasible to operate by the second half of the decade, thanks to a reduction in the electric truck battery price and, consequently, the truck retail price.

Table 11. Impact of proper battery sizing on the total cost of ownership parity year between battery electric and diesel trucks without purchase incentives.

City	Paris	Berlin	Rome	Amsterdam	Warsaw	London
TCO parity year with current battery size (76 kWh)	2030	2030	2030	2028	2030	2030
TCO parity year with proper battery size (35 kWh)	2028	2030	2030	2025	2028	2028

Truck batteries can potentially offer additional revenues for fleet operators through smart charging. Batteries of parked trucks that are connected to the charging station can be aggregated at the depot, by fleet operators or third parties, and used to provide demand response services. Demand response allows battery charging speed and capacity to be adjusted, as with smart charging. In addition, aggregated vehicle batteries can discharge power to the grid, thus providing “flexibility services,” for which the operator is financially rewarded. These additional services from bi-directional or “vehicle-to-grid” charging (providing power to and drawing power from the grid) can help stabilize the grid by providing energy services. These services may be in response to temporary spikes in electricity demand, may participate at different levels in the power market, or absorb excess renewable energy. While still at the pilot stage across Europe—for an overview, see (European Commission, 2022)—the savings that can be earned vary significantly depending on regulatory framework conditions, such as the degree of dynamic tariffication, taxation, rules for participation in local energy markets, and the like.

IMPACT OF IMPOSING EMISSION CHARGES ON DIESEL VEHICLES ENTERING LOW- AND ZERO-EMISSION ZONES

European cities are implementing low- and zero-emission zones in city centers to enhance air quality. There are more than 250 low-emission zones in Europe with different stringencies regarding which vehicles can enter these zones, depending on their emissions classification (Urban Access Regulations, 2022). In addition, a handful of zero-emission zones have been enacted or announced. Amsterdam will upgrade its low-emission zone to a zero-emission area covering the entire city by 2030. London has two zero-emission zones, in Islington and Hackney, and Paris will upgrade its low-emission zone to a zero-emission zone as of 2030 (Cui et al., 2021). While low- and zero-emission zones ban vehicles that do not meet specific emission standards from entering the zones, there are other cases where non-compliant vehicles are assessed a daily charge to access those zones, such as in London and Oxford (Cui et al., 2021). This analysis considers the latter approach, as it is more conducive to estimating the policy impact on the TCO of diesel and electric delivery vehicles.

To assess the impact of such policy intervention on the TCO parity between both truck technologies, a hypothetical charge ranging from €2/day to €6/day is considered, as summarized in Table 12. It is assumed that the trucks will pay a fixed daily fee regardless of the number of entries per day. It is also assumed that trucks will enter these zones six days a week for 52 weeks a year. In all the cities considered in this study, a charge of €2/day to €4/day could significantly reduce the TCO gap between BET and diesel trucks, allowing TCO parity before mid-decade.

Table 12. The impact of imposing an emissions tax on diesel vehicles entering low- and zero-emission zones on the year total cost of ownership parity is achieved between battery electric and diesel trucks.

City	Paris	Berlin	Rome	Amsterdam	Warsaw	London
TCO parity year without policy interventions (35 kWh battery)	2028	2030	2030	2025	2028	2028
2 €/day	2024	2027	2027	2022	2025	2024
4 €/day	2022	2024	2023	2022	2022	2022
6 €/day	2022	2022	2022	2022	2022	2022

USE OF A BONUS-MALUS POLICY MEASURE TO FINANCE BATTERY-ELECTRIC TRUCKS PURCHASE INCENTIVES

While purchase premiums for battery-electric trucks are pivotal in the early market phase, such policy measures are not fiscally sustainable and are funded mainly from taxpayer money. Several countries have tackled this issue for passenger vehicles by introducing a bonus-malus tax scheme based on the “polluter-pays” principle (Wappelhorst et al., 2018). The idea of such a tax scheme is to finance the incentives provided for zero- and low-emission vehicles by imposing high registration taxes on vehicles with higher levels of CO_2 emissions, as is the case in France, or to increase the annual ownership taxes for polluting vehicles for a specific period, such as in Sweden. The former approach is adopted in this study for illustration purposes.

The amount of purchase incentives (bonus) for battery-electric trucks is determined based on the five-year TCO gap relative to their equivalent diesel trucks in each country. On the other hand, the taxes (malus) imposed on diesel trucks are dependent on their level of CO_2 emissions and the total number of battery-electric and diesel trucks registrations each year. The taxes imposed on diesel trucks are designed to balance the total incentives provided for the purchase of battery-electric trucks.

Similar to the currently implemented bonus-malus tax schemes for passenger vehicles in France (Wappelhorst et al., 2018), we propose the system presented in Figure 13. The figure shows the proposed bonus-malus tax amount as a function of the trucks’ CO_2 emissions for model years 2022 and 2025 in Germany under several scenarios for market share of battery-electric truck registrations. Only Germany-specific results are presented in this section for brevity, while results for other countries are summarized in the Appendix in Table A1 to Table A6.

For battey-electric trucks registered in 2022, a bonus of €6,058 would suffice to cover the five-year TCO gap relative to diesel trucks. This bonus would result in an additional tax on newly registered diesel vehicles in the same year, depending on the truck’s CO_2 emissions and the share of battery-electric trucks. This additional tax increases progressively as the truck’s CO_2 emissions increase, until it converts to a constant tax beyond a certain CO_2 emissions level. This threshold is considered to be 250g CO_2/km, representing the average CO_2 emissions of diesel trucks with gross vehicle weight between 3.5 tonnes and 7 tonnes in Europe. If these taxes are to balance the total incentives provided for all new battery-electric trucks registered in the same year, the maximum tax to be paid for newly registered diesel vehicles ranges between €673 and €2,596 when the share of BETs is between 10% and 30% of new registrations in 2022. This structure considers two factors: (1) a higher share of battery-electric trucks results in a higher total incentives budget, and (2) a higher battery-electric truck share, implying a lower diesel truck share, would increase the tax paid per newly registered diesel truck.

For battery-electric trucks purchased and registered in 2025, as shown in the bottom panel of Figure 13, the level of incentive provided for a battery-electric truck is €3,462, which is lower than the incentives needed for vehicles purchased in 2022 due to the lower TCO gap. Despite this lower incentive per battery-electric truck, the tax that should be paid by newly registered diesel trucks is higher, reaching a maximum of approximately €8,000 if battery-electric trucks represent 70% of the market.

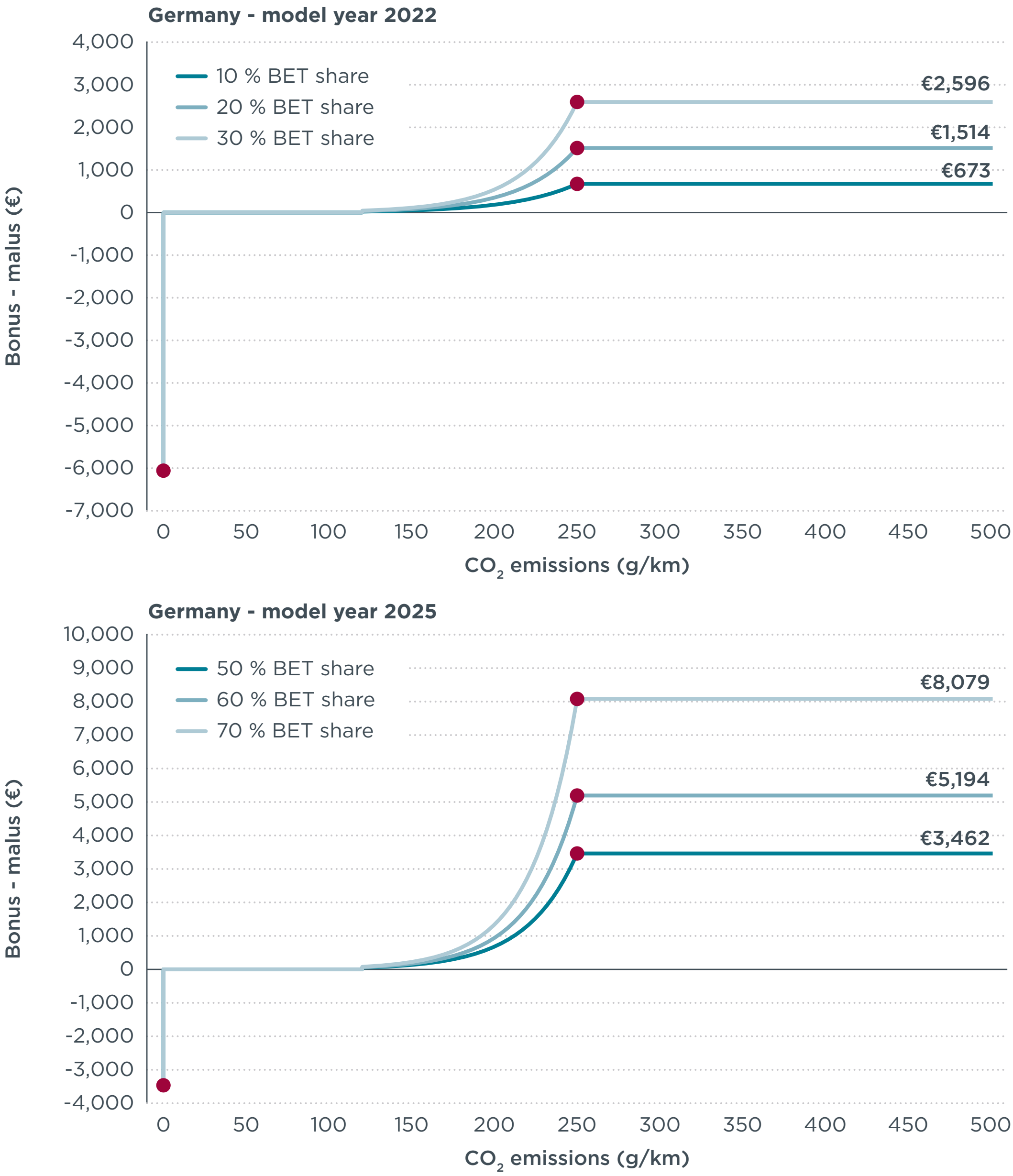

Figure 13. Bonus-malus tax amount as a function of truck CO_2 emissions based on the five-year total cost of ownership gap.

Trucks operating in other countries and cities would be subject to different bonus-malus amounts as the TCO gap between battery electric and diesel trucks is driven by location-specific costs such as diesel fuel, electricity, and taxes. Data for the six considered cities are summarized Table A1 to Table A6 in the appendix.

SENSITIVITY ANALYSIS

IMPACT OF FUEL AND ELECTRICITY PRICES

The diesel fuel and electricity prices considered in this analysis are representative of the period between January and June 2021. With the staggering increase in both diesel and electricity prices in Europe during the second half of 2021 and the first quarter of 2022, it is critical to assess the impact of such an increase on the TCO of both truck technologies.

This study includes a sensitivity analysis around diesel fuel and electricity prices in each city increasing by 0% to 100% relative to the baseline presented earlier in the *Charging cost* and *Diesel prices* sections. Figure 14 shows the year battery-electric and diesel trucks reach TCO parity under different diesel fuel and electricity prices. These prices play a significant role in the year battery-electric trucks achieve TCO parity with diesel trucks. In the case of Berlin, parity can be achieved in 2023 in a case where diesel fuel prices are doubled (100% increase relative to 2021) and electricity prices increase less than 20% above the relatively high 2021 costs. On the other hand, TCO parity might not be achieved during this decade at all if electricity prices double and diesel fuel prices do not record a significant increase of above 50% relative to 2021. In the case of Paris and Amsterdam, any combination of electricity and diesel fuel prices would still result in a positive business model for battery-electric trucks during this decade.

Reflecting on the prices recorded by the end of March 2022 in Europe, the gross price of diesel fuel witnessed a 50%–70% increase relative to 2021 prices (DKV, 2021), while the wholesale electricity prices doubled (Ember-Climate, 2022). Under such a scenario, TCO parity is achieved one to three years earlier in all cities studied, illustrating that TCO has a higher sensitivity to diesel fuel prices than electricity prices. This is related to the energy efficiency of the trucks, because battery electric trucks consume less energy per km, making them less sensitive to an increase in electricity prices compared to diesel trucks' sensitivity to the increased diesel fuel prices.

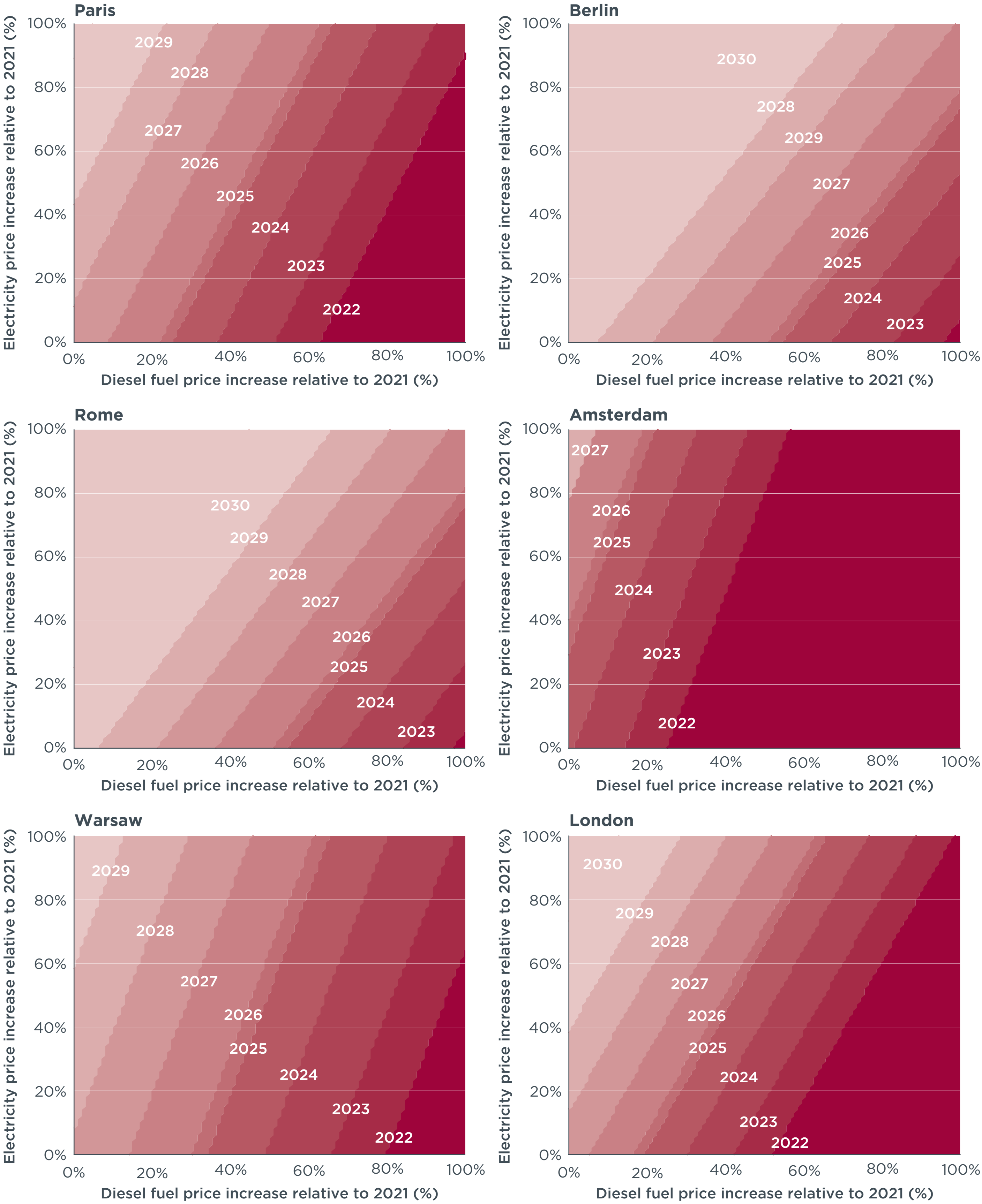

Figure 14. Year battery-electric and diesel trucks reach total cost of ownership parity under different diesel fuel and electricity prices.

IMPACT OF DRIVING RANGE

The case study in this analysis is representative of an urban parcel delivery truck with low annual vehicle kilometers traveled (AVKT) of around 15,000 km. Other last-mile delivery applications may operate over significantly higher mileages. This section examines the impact of the AVKT on the TCO parity year between battery-electric and diesel trucks. The AVKT is considered to vary between 15,000 and 60,000 km (Molliere, 2022).

Table 13 shows the year battery-electric and diesel trucks with various AVKT reach TCO parity. As shown, battery-electric and diesel trucks achieve TCO parity earlier with higher AVKT. Two factors explain this behavior: (1) battery-electric trucks are more energy-efficient, and (2) require less maintenance. Thus, BETs' maintenance and fuel costs are less sensitive to increasing AVKT than their diesel counterparts. Figure 15 shows the TCO breakdown for both trucks in Paris in 2022 and 2025, highlighting the sensitivity of diesel trucks' fuel and maintenance costs to the increase in AVKT. Although bigger batteries are needed with higher AVKT, as more kilometers are traveled by a battery-electric truck, the higher truck net cost is outweighed by the lower fuel and maintenance costs.

Table 13. Battery electric and diesel trucks' TCO parity year at different annual vehicle kilometers traveled (AVKT).

AVKT (km)	Berlin	Paris	Rome	Amsterdam	Warsaw	London
15,000	2030	2028	2030	2025	2028	2028
20,000	2029	2027	2029	2024	2027	2027
25,000	2028	2025	2028	2023	2026	2025
30,000	2028	2025	2028	2022	2025	2024
35,000	2027	2024	2027	2022	2025	2024
40,000	2027	2024	2027	2022	2024	2024
45,000	2027	2024	2027	2022	2024	2023
50,000	2026	2023	2026	2022	2024	2023
55,000	2026	2023	2026	2022	2023	2023
60,000	2026	2023	2025	2022	2023	2022

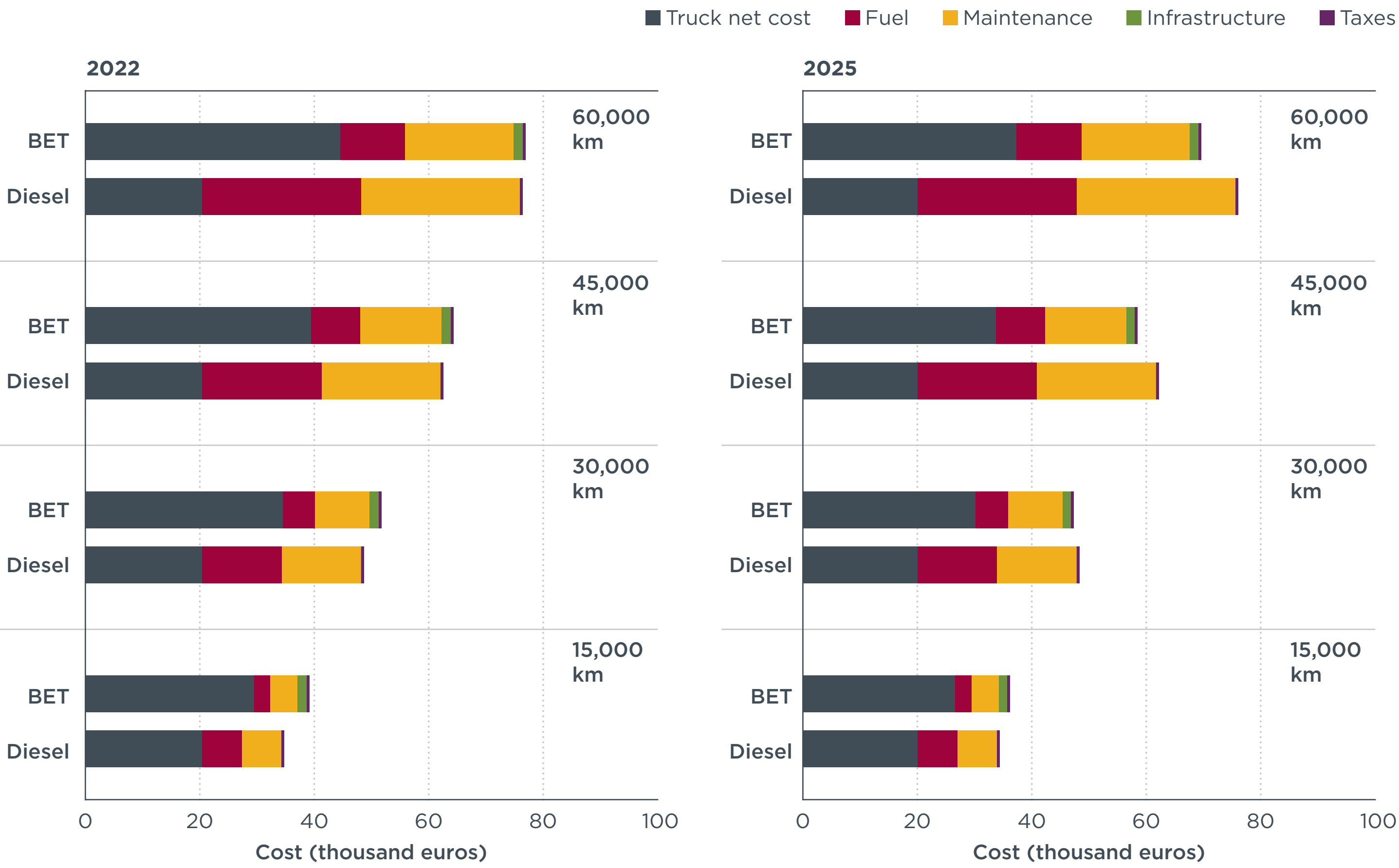

Figure 15. Total cost of ownership breakdown for truck purchase years 2022 and 2025 for different annual vehicle kilometers traveled (Case of Paris).

CONCLUSIONS AND POLICY RECOMMENDATIONS

Last-mile delivery trucks represent a significant share of the HDV sales volume in Europe. The remarkable growth in the e-commerce industry worldwide makes them a significant segment to decarbonize. Given their low annual mileage and predictable schedules, these delivery trucks are a promising application for electrification with regard to technical feasibility. However, fleet operators are concerned about the economic viability of battery-electric last-mile delivery trucks. This study tackles this issue by comprehensively assessing the total cost of ownership (TCO) of these trucks, comparing their economic performance to their diesel counterparts under typical use cases. The scope of the study covers six European capitals, Berlin, Paris, London, Amsterdam, Warsaw, and Rome. We have arrived at the following key findings:

- **Last-mile delivery battery-electric trucks are economically viable today, given the currently available purchase premiums**. Last-mile delivery battery-electric trucks can achieve TCO parity with diesel trucks as early as 2022 in Paris, Berlin, Rome, and Amsterdam. Battery-electric trucks operating in London and Warsaw will reach TCO parity by 2025 and 2028, respectively, due to the low purchase premiums provided. Without the current purchase premiums, battery-electric trucks will achieve a positive business case relative to diesel trucks in most European cities by the end of the decade.
- **Proper battery sizing is essential to overcome the economic challenges of battery-electric last-mile delivery trucks**. As the truck purchase price is a large component of the TCO of battery-electric trucks, sizing the battery properly helps to reduce the total costs. Oversized batteries provide additional driving range that can overcome scheduling disruptions, but this comes at the expense of a high purchase price for the truck.
- **Charging costs are essential to consider** when designing a policy framework to set the best conditions for electrifying fleets. The energy costs of battery-electric fleets will become more relevant with growing fleet size and as a proportion of overall TCO as the retail prices for electric delivery trucks come down.
- **Smart charging of electric trucks is crucial to reduce costs for the depot or fleet owner.** Smart charging requires charging management technology and time-varying energy and network pricing, indicating when cheap (renewable) energy is available and when there is free capacity on the grids. The use of smart charging can reduce overall system costs and avoid costly upgrades of a depot's grid connection.
- **The time in which battery-electric and diesel trucks reach TCO parity is more sensitive to variation in diesel fuel prices than electricity prices**. The higher energy efficiency of battery-electric powertrains results in less energy consumption per km than diesel trucks. This makes their TCO less sensitive to charging costs variation than diesel trucks' sensitivity to the increase in diesel fuel prices.

In addition, we assess the impact of several policy measures on the TCO of battery-electric and diesel trucks and recommend the following:

- **Implement a national bonus-malus tax scheme to finance purchase incentives for zero-emission trucks and limit the duration of these incentives depending on the TCO gap with diesel trucks**. Purchase incentives are proven to be a key lever for the economic viability of battery-electric last-mile delivery trucks. However, they are not fiscally sustainable. A bonus-malus tax scheme can help finance these incentives by imposing an additional tax on the registration of new diesel trucks determined from the truck's CO_2 emissions. The bonus and malus amounts should be reviewed annually based on the actual TCO difference between both truck technologies and the expected technology market share each year.

» **Impose emission charges on all diesel vehicles entering low- and zero-emission zones in city centers**. Cities implementing a hypothetical emissions charge between 2€/day and 4€/day per vehicle in low- and zero-emission zones can capture some of the environmental externalities of diesel trucks by increasing their operation costs. Such measures can reduce the TCO gap between battery-electric and diesel trucks, helping them to achieve cost parity before 2025 without any additional purchase premiums.

» **Encourage charging infrastructure deployment at urban logistics depots and ensure the equipment is smart**. This will facilitate the uptake of battery-electric trucks in logistics fleets and, in parallel, accelerate the deployment of smart technology and services to charge them, avoiding costs for users and the system. This requires addressing the integration of the charging equipment into the grid as part of local urban planning, for example as part of the European New Urban Mobility Framework (European Commission, 2021a). In addition, policy makers should include requirements for equipping new and renovated depots with charging points for commercial vehicle charging in the European Energy Performance of Buildings Directive currently under revision. Requirements to install charging infrastructure at commercial depots with public access should also be included into the Alternative Fuel Infrastructure Regulation under revision.

» **Energy regulators in Member States should require grid operators to set time-varying network tariffs.** Reformed network tariffs should reflect the actual state of the grid based on the varying electricity demand during the day. This, in turn, would send price signals to customers such as logistics depots to adjust their fleet charging in the most cost-effective way. EU Member States can accelerate this process by ambitiously implementing the Energy Market Reforms.

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APPENDIX

Table A1. Bonus-malus tax scheme in Germany: Maximum fee to be paid by newly registered diesel trucks with CO_2 emissions above 250 g CO_2/km.

Fee (€)		Battery-electric trucks registration share (%)								
Year	Bonus (€)	10%	20%	30%	40%	50%	60%	70%	80%	90%
2022	6,058	673	1,515	2,596	4,039	6,058	9,088	14,136	24,234	54,526
2023	5,259	584	1,315	2,254	3,506	5,259	7,888	12,271	21,035	47,329
2024	4,272	475	1,068	1,831	2,848	4,272	6,408	9,968	17,088	38,449
2025	3,463	385	866	1,484	2,309	3,463	5,194	8,080	13,851	31,166
2026	3,217	357	804	1,379	2,145	3,217	4,826	7,507	12,868	28,954
2027	2,297	255	574	985	1,532	2,297	3,446	5,360	9,189	20,675
2028	1,363	151	341	584	908	1,363	2,044	3,179	5,450	12,264
2029	465	52	116	199	310	465	698	1,086	1,861	4,188
2030	Policy phase-out									

Table A2. Bonus-malus tax scheme in France: Maximum fee to be paid by newly registered diesel trucks with CO_2 emissions above 250 g CO_2/km.

Fee (€)		Battery-electric trucks registration share (%)								
Year	Bonus (€)	10%	20%	30%	40%	50%	60%	70%	80%	90%
2022	4,356	484	1,089	1,867	2,904	4,356	6,533	10,163	17,422	39,200
2023	3,556	395	889	1,524	2,371	3,556	5,334	8,297	14,224	32,004
2024	2,569	285	642	1,101	1,713	2,569	3,854	5,995	10,277	23,124
2025	1,760	196	440	754	1,173	1,760	2,640	4,107	7,040	15,840
2026	1,514	168	379	649	1,010	1,514	2,271	3,533	6,057	13,628
2027	594	66	149	255	396	594	892	1,387	2,378	5,350
2028	Policy phase-out									
2029										
2030										

Table A3. Bonus-malus tax scheme in Italy: Maximum fee to be paid by newly registered diesel trucks with CO_2 emissions above 250 g CO_2/km.

Fee (€)		Battery-electric trucks registration share (%)								
Year	Bonus (€)	10%	20%	30%	40%	50%	60%	70%	80%	90%
2022	5,973	664	1,493	2,560	3,982	5,973	8,960	13,938	23,893	53,760
2023	5,174	575	1,293	2,217	3,449	5,174	7,760	12,072	20,695	46,563
2024	4,187	465	1,047	1,794	2,791	4,187	6,280	9,770	16,748	37,683
2025	3,378	375	844	1,448	2,252	3,378	5,067	7,881	13,511	30,399
2026	3,132	348	783	1,342	2,088	3,132	4,698	7,308	12,528	28,188
2027	2,212	246	553	948	1,475	2,212	3,318	5,162	8,849	19,909
2028	1,277	142	319	547	852	1,277	1,916	2,981	5,110	11,497
2029	380	42	95	163	253	380	570	887	1,521	3,422
2030	Policy phase-out									

Table A4. Bonus-malus tax scheme in the Netherlands: Maximum fee to be paid by newly registered diesel trucks with CO_2 emissions above 250 g CO_2/km.

Fee (€)		Battery-electric trucks registration share (%)								
Year	Bonus (€)	10%	20%	30%	40%	50%	60%	70%	80%	90%
2022	1,888	210	472	809	1,258	1,888	2,831	4,404	7,550	16,988
2023	1,088	121	272	466	725	1,088	1,632	2,539	4,352	9,791
2024	101	11	25	43	68	101	152	236	405	911
2025	Policy phase-out									
2026										
2027										
2028										
2029										
2030										

Table A5. Bonus-malus tax scheme in Poland: Maximum fee to be paid by newly registered diesel trucks with CO_2 emissions above 250 g CO_2/km.

Fee (€)		Battery-electric trucks registration share (%)								
Year	Bonus (€)	10%	20%	30%	40%	50%	60%	70%	80%	90%
2022	4,542	505	1,136	1,947	3,028	4,542	6,813	10,599	18,169	40,881
2023	3,743	416	936	1,604	2,495	3,743	5,614	8,733	14,971	33,684
2024	2,756	306	689	1,181	1,837	2,756	4,134	6,431	11,024	24,804
2025	1,947	216	487	834	1,298	1,947	2,920	4,542	7,787	17,520
2026	1,701	189	425	729	1,134	1,701	2,551	3,969	6,804	15,309
2027	781	87	195	335	521	781	1,172	1,823	3,125	7,030
2028	Policy phase-out									
2029										
2030										

Table A6. Bonus-malus tax scheme in the United Kingdom: Maximum fee to be paid by newly registered diesel trucks with CO_2 emissions above 250 g CO_2/km.

Fee (€)		Battery-electric trucks registration share (%)								
Year	Bonus (€)	10%	20%	30%	40%	50%	60%	70%	80%	90%
2022	4,160	462	1,040	1,783	2,773	4,160	6,240	9,707	16,640	37,441
2023	3,360	373	840	1,440	2,240	3,360	5,041	7,841	13,442	30,244
2024	2,374	264	593	1,017	1,583	2,374	3,561	5,539	9,495	21,364
2025	1,565	174	391	671	1,043	1,565	2,347	3,651	6,258	14,081
2026	1,319	147	330	565	879	1,319	1,978	3,077	5,275	11,869
2027	399	44	100	171	266	399	598	931	1,596	3,591
2028	Policy phase-out									
2029										
2030										

Table A7. Sources for network tariff data by city/distribution area.

City	Source
London	(UK Power Networks, 2022)
Berlin	(Stromnetz Berlin, 2021)
Warsaw	(Innogy Stoen Operator, 2021)
Amsterdam	(Liander, 2022)
Paris	(Commission de Regulation de L'Energie, 2021)
Rome	(Areti, 2022)

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