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ACCELERATING THE SHIFT TO SUSTAINABLE HEAVY-DUTY TRANSPORT: A COMPARISON OF THE TOTAL COST OF OWNERSHIP OF BATTERY-ELECTRIC TRUCKS WITH DIESEL TRUCKS

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Executive Summary

Europe has recognized heavy-duty transport as the next area of large-scale electrification to cut transport emissions and reach sustainability targets. Ambitious fleet emission thresholds demand truck manufacturers to increase their sales of zero-emission vehicles. With main application of trucks in the logistics industry with narrow margins, cost over lifetime is one of fleet owners' key requirements in their vehicle purchase decision. P3 has developed a comprehensive tool to evaluate the total cost of ownership (TCO) for heavy-duty trucks with internal combustion engine (ICE-HDT) and battery-electric heavy-duty trucks (e-HDT) in the German market. The result shows, that in both regional-haul and long-haul application, e-HDT are already today capable to achieve cost advantages under realistic conditions. However, daily routes of 500 km+ are not yet unrestrictedly feasible due to technical constraints and the lack of a comprehensive public fast charging network and can only be realized in a hub-to-hub use case.

Keywords: Heavy Duty Electric Vehicles & Buses; Trends & Forecasting of E-Mobility; Business Models for Vehicle Sales; Modelling & Simulation; Environmental Impact

1 Introduction

Today, the German truck market is largely dominated by established players. Big manufacturers have not been jeopardized in the last years due to their solid performance with the diesel powertrain.

With electrification of trucks gaining momentum, manufacturers are now facing new challenges – not only technology-wise, but also with an increasingly multifaceted competitive landscape with aspiring US companies like Tesla, and emerging contenders from the East, for instance the Chinese electric mobility giant BYD, competing for market share.

Meeting customer requirements is becoming even more important for manufacturers to retain relevance in the market and drive sales numbers. The high cost-sensitivity of the logistics industry as the main customer group in the truck industry dictates the minimization of operational expenses as a decisive argument for vehicle acquisition. Today more than ever, battery technology is on the verge of replacing diesel drives. Whether this will extend to the heavy-duty sector crucially depends on financial attractiveness. The cost comparison of ICE-HDT and e-HDT evaluates whether e-HDT have the potential to disrupt the German truck market and take the lead in the transition towards sustainable road freight transportation.

2 Methodology and base assumptions

To enable a substantiated evaluation on the TCO of e-HDT compared to ICE-HDT, P3 has developed a comprehensive calculation tool – which has been used to conduct the comparative analysis in this report.

2.1 Truck models in focus

P3's calculation tool catalogues the technical specifications of different reference truck models in a database for selection. As there are only minor differences in technical characteristics of truck models registered in the German market, this analysis takes an average of technical specifications among the most modern and common HDT models in compliance with highest emission standards. Table 1 displays the main specifications for the truck models under investigation.

Table 1: Vehicle specifications

	e-HDT	**ICE-HDT**
Body type	Semi-Truck	Semi-Truck
Model year	2024	2024
Date of acquisition	01/01/2025	01/01/2025
Net vehicle purchase price [EUR]	280,000	110,000
Gross vehicle weight [t]	42	40
Emission class	5	3
Gross battery size [kWh]	600	/
Power class [kW]	500-600	300-400
Electricity consumption [kWh/km]	1.3	/
Fuel consumption [l/km]	/	0.33

2.2 Input parameters for TCO calculation

The calculation tool divides total expenditures (TOTEX) into capital expenditures (CAPEX) and operational expenditures (OPEX). To draw an objective comparison between e-HDT and ICE-HDT, the configurations of the calculation tool were set to reflect reality as accurately as possible. Table 2 shows the consideration of main input parameters in the analysis of e-HDT to ICE-HDT.

Table 2: Input parameters

CAPEX		
Vehicle related	Vehicle leasing considering residual value	included
	Battery replacement within holding period	excluded
Charging infrastructure related	Depot charging infrastructure installation	included
OPEX		
Distance related	Fuel, ad-blue and electricity cost	included
	Highway tolls	included
	Lubricants and oil	included
	Tires	included
	Repair and service	included
	Charging losses	included
	Vehicle insurance	included
Time-related	Depot charging infrastructure operation	included
	Vehicle tax	included
	Driver cost	excluded
Revenue streams		
Vehicle related	Vehicle subsidies	excluded
Charging infrastructure related	Depot charging infrastructure subsidies	excluded
Time-related	Greenhouse gas quota	included

All input factors used in the calculation tool were corroborated by official sources including publications by truck manufacturers and independent research institutions. Forecasts on energy price trends and cost developments are based on P3 assumptions.

An essential assumption in the TCO calculation is the selection of leasing as prevalent acquisition form. This was chosen based on P3's market insights showing most commercial fleet owners being deterred from or not capable of affording the high purchase cost for e-HDT today. The higher acquisition costs for the e-HDT are reflected in a higher leasing rate.

Battery replacement costs are not included in the TCO calculation as battery lifespans are expected to exceed both the considered holding period and projected mileage. Manufacturer warranties of 6-8 years further justify this exclusion.

In contrast to the dense network of public diesel stations and private refueling options in Germany and abroad, there are only limited public charging options for e-HDT today. Coupled with the higher cost of electricity for on-route charging, it makes sense for fleet owners to install depot charging infrastructure. In principle, CAPEX can be reduced by installing charging stations below 150 kW per charging point which are sufficient for recharging the big truck battery overnight or even within long parking times. In the present calculation, the installation of a 200 kW station in the fleet owners depot is assumed to enable faster recharging. Besides charging hardware, CAPEX for depot charging infrastructure also include planning, installation and grid connection.

Driver costs are not included in the TCO as they are differing by company, are independent from drive type and carry the associated risk of distorting TCO results.

Due to the lack of nationwide subsidies for e-HDT in Germany since the 2024 cancellation of the KsNI-funding, subsidies for the truck are not considered in the TCO calculation. Although there are active subsidies for charging infrastructure available today, they will not be considered due to the lack of continuous availability and the limited size of funding pots.

Today, trading based on the greenhouse gas quota enables an upside revenue potential for e-HDT owners. In the future, a declining trend is assumed with increasing electrification in the market, thus having only small impact on the TCO calculation.

2.3 Scenario simulation

To consider the TCO effects depending on different use cases, two scenarios were set up.

“Regional-haul scenario”, representing the standard application of e-HDT in distribution transport around depot today (no last mile delivery in cities): daily route distance of 200-300 km, 100% charging in depot of fleet owner.

“Long-haul scenario”, representing the standard long-haul application of ICE-HDT today: daily route distance of 350-500 km, 50:50 split into depot and highway charging.

For the calculation of annual mileage, 50 weeks per year with 5 working days each are assumed as a typical shift system. The share of mileage on toll roads is generally set high due to the geographical proximity of most logistic depots to highways and main traffic axes.

Table 3: Main scenario assumptions

	Regional-haul Scenario	**Long-haul Scenario**
Mileage [km/a]	60,000	100,000
Mileage on toll roads	80%	90%
Holding period truck	6 years	
Lifetime charging infrastructure	8 years	
Charging behavior	100% depot (DC: 200 kW)	50% depot (DC: 200 kW) 50% highway (HPC: 400 kW)

Although HDT electrification is of relevance for most customers in the long-term, the analysis focuses specifically on the customer type with highest interest in e-HDT today: medium and large companies with 50+ HDT in their fleet and commitment to sustainability reporting (ESG) typically prioritize fleet charging and are used as a baseline in this analysis. The minimum requirements are eight charging points in their depots and daily route with on average 250 kilometers.

2.4 Cost forecast for diesel and electricity

Assumptions about the development of diesel and electricity costs are decisive factors for the TCO analysis. Based on the announcements of constant increases in the next years, P3 expects CO_2-taxes to drive up diesel prices in the future. Electricity prices on the other hand, set to be around 20 ct/kWh for medium-sized companies, are expected to remain stable over the next years due to the opposing effects of rising grid charges and falling costs for (renewable) electricity generation. Hence, the gap between diesel and electricity prices will increase (see Table 4).

Table 4: Cost forecast assumptions for diesel and electricity

	Net electricity prices [EUR/kWh]		Net diesel prices [EUR/l]
	Depot charging	**Public charging**	
2025	0.20	0.33	1.47
2026	0.20	0.33	1.48
2027	0.20	0.33	1.52
2028	0.20	0.33	1.56
2029	0.20	0.33	1.60
2030	0.20	0.33	1.64

Nevertheless, as sharp increases in energy prices during the Ukraine war have shown, both diesel and electricity can be subject to significant and hard-to-predict price fluctuations. Accordingly, a sensitivity analysis is made at the end of this paper, which elaborates upon the TCO effects of lowering/raising electricity and diesel costs.

3 Results

The direct comparison of TCO per km driven between ICE-HDT and e-HDT shows an advantageous result for e-HDT in both scenarios.

For the **regional-haul scenario**, a slight cost advantage of 5 ct/km is observed for the e-HDT. This is achieved through lower OPEX, which slightly outweighs the higher CAPEX for the vehicle and charging infrastructure.

For the **long-haul scenario**, a significant advantage of the e-HDT compared to its ICE-variant is visible, with the diesel truck being over 10% more expensive over the holding period. The substantial cost advantage of 13 ct/km of the e-HDT is mainly based on OPEX savings, including lower energy cost and toll benefits. However, the cost advantage of the e-HDT is contingent upon certain conditions.

1. Low electricity costs via industry tariffs, possibly complemented by decentral renewable production to keep charging cost at depot below diesel cost.
2. Adequate grid connection to enable installation of charging infrastructure at depot without big bureaucratic hurdles and long approval times.
3. HDT application within routes manageable for electric drives today. Average daily routing of >500 km/day is not (yet) sensibly feasible for e-HDT due to technical constraints.

3.1 Detailed cost breakdown

A closer examination reveals the origin of the e-HDT’s significant cost advantage.

Firstly, overall consumption makes up for substantial cost saving of the e-HDT with 17 ct/km in the long-haul scenario (regional-haul scenario: 27 ct/km). Due to the higher overall efficiency of the e-HDT of up to 95% compared to up to 45% of modern diesel engines, e-HDT require lower energy input per km driven.

Secondly, e-HDT can achieve significant savings in highway tolls of up to 24 ct/km in long-haul scenario (regional-haul scenario: 22 ct/km). Today, e-HDT are exempt from tolls until 31.12.2025 and are granted a significantly reduced toll rate of ≈ 25% from 2026 onwards. According to the coalition agreement of the newly formed German government, an extension of the toll exemption is planned beyond 2026, which would further improve the result in favour of the e-HDT. Furthermore, the increasing toll rates for ICE-HDT based on the ”polluter pays”-principle justify the assumption of a continued toll spread between e-HDT and ICE-HDT.

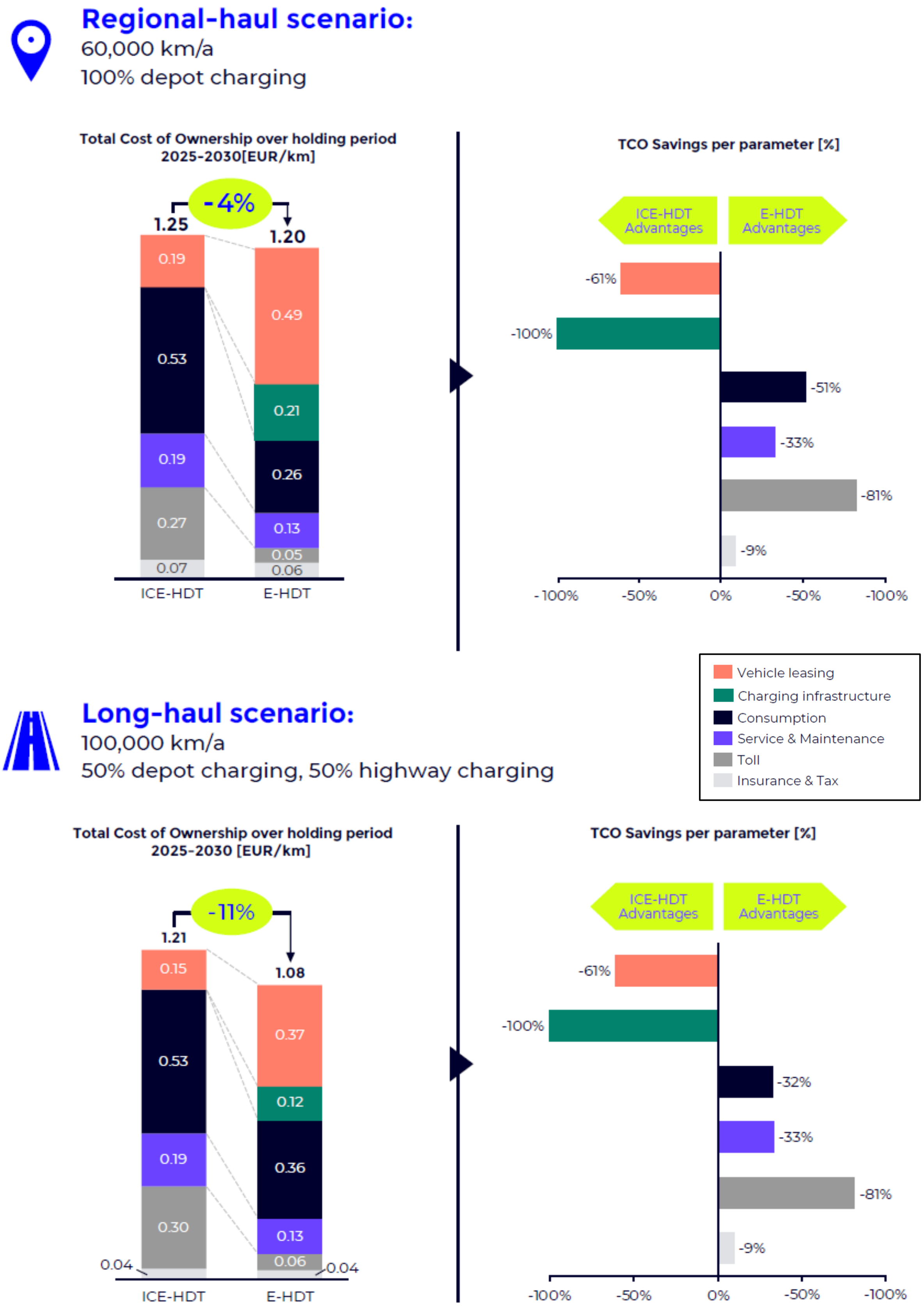

Figure 1: TCO over holding period and savings per parameter

Thirdly, cost advantages for e-HDT are found in repair and service: e-HDT incur lower spending on lubricants and maintenance due to fewer mechanical components, resulting in overall savings of approximately 6 ct/km compared to ICE-HDT. Tire costs show no discernible differences.

The fourth and final advantage for e-HDT are lower vehicle taxes. Although total exemption will no longer apply to electric vehicles registered after 2025, they are subject to only half the regular tax rate. However, when calculating annual tax payments for ICE-HDT, the cost amount to <1 ct/km and hence plays only a minor role in the overall assessment.

While e-HDT are advantageous in OPEX, the ICE-HDT brings cost advantages in two categories. Firstly, the omission of the acquisition and operation of charging infrastructure. Secondly, the acquisition or leasing cost for the HDT itself, with the vehicle purchase price of the e-HDT being more than double compared to the ICE-HDT.

3.2 Purchase vs. leasing

The 2.5 to 3 times higher acquisition costs associated with the purchase of an e-HDT compared to an ICE-HDT represent a major obstacle for many logistics companies. Leasing and rental models for vehicles and charging infrastructure can help to overcome this hurdle.

In case of operating leasing, there is no upfront purchase invest for truck and charging infrastructure as all payments are spread over the entire 6-year holding period. Comparing the cumulative costs for leasing ICE-HDT and e-HDT over the holding period, there is no point at which the ICE-HDT is more cost-effective, meaning the e-HDT remains advantageous throughout.

Comparing the purchase variant of ICE-HDT and e-HDT, the diesel variant shows an initial advantage of more than 230k EUR due to lower acquisition cost for truck and the omission of charging infrastructure. Nevertheless, the e-HDT catches up quickly with its significantly lower annual OPEX, ultimately achieving a cost advantage by the end of the fifth year in both scenarios (no discounting assumed).

The assumption of a prolonged holding period increases the economic attractiveness of the e-HDT, as the lower operating costs accumulate over a longer period. In addition, the influence of the residual value on the calculation is lower.

In summary, leasing an e-HDT can already be more financially viable than leasing its ICE-equivalent. When it comes to comparing e-HDT and ICE-HDT in purchase, cumulated costs deflect in favor of the e-HDT only at a late stage of the six-year holding period, which makes the result more vulnerable to changing assumptions in the calculation.

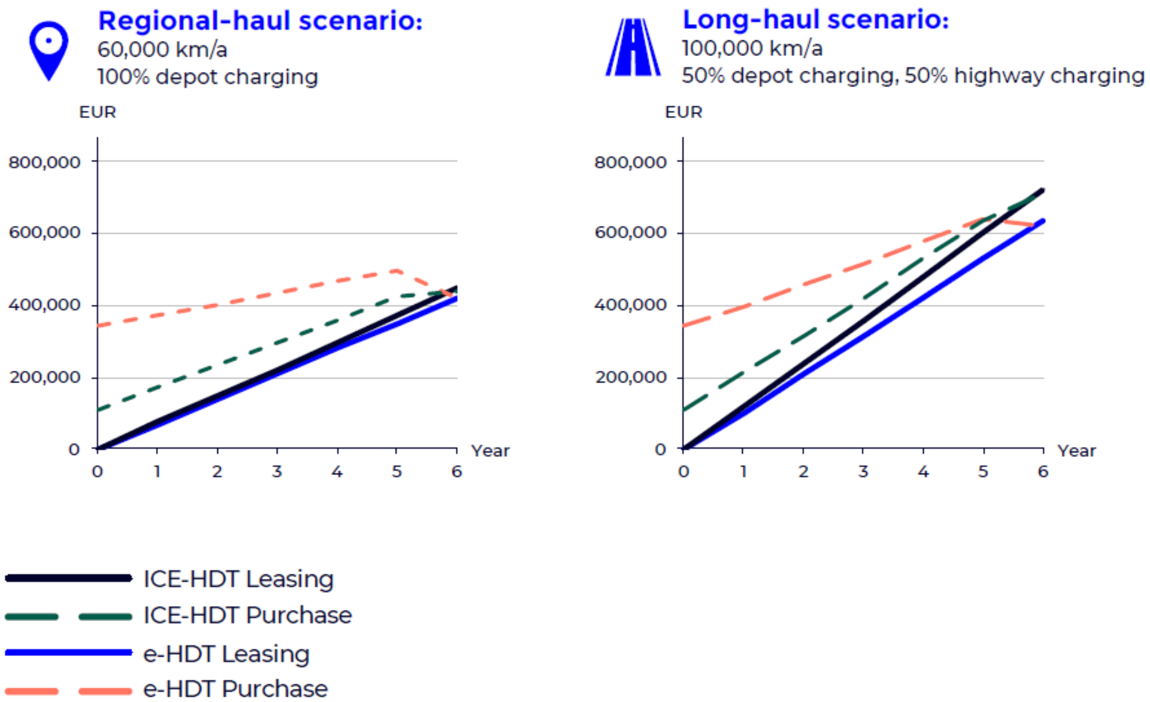

Figure 2: Cumulated cost for purchase vs. leasing over holding period

3.3 Sensitivity analysis

To illustrate the effects of variation in electricity and diesel prices as key influencing factors in both the long-haul and regional-haul scenario, a sensitivity analysis under existing assumptions is conducted.

In the regional-haul scenario, the tipping point towards advantageousness of e-HDT is already reached in the base case. Even when assuming increasing electricity prices up to 30%, the e-HDT can keep at least cost parity. A clear disadvantage of the e-HDT is only visible in the case of strongly decreasing diesel prices combined with increasing electricity prices, indicating a small actual risk.

In the long-haul scenario, the base case shows e-HDT having a strong cost advantage over ICE-HDT, which is maintained with most sensitivity adjustments. In the improbable cases of electricity prices increasing or diesel prices decreasing, e-HDT and ICE-HDT reach approximate parity. However, e-HDT only show a clear disadvantage in the most extreme cases when electricity prices rise significantly while diesel prices fall, indicating a low risk. Overall, e-HDT remain cost-effective in most scenarios for long-haul use.

Regional-haul scenario:
60,000 km/a
100% depot charging

Increase in electricity price ← **Electricity** → *Decrease in electricity price*

Diesel: *Increase in diesel price* ↑ / *Decrease in diesel price* ↓

Diesel \ Electricity	+30%	+15%	BASE CASE TCO in EUR/km e-HDT/ICE-HDT	-15%	-30%
+30%	Δ9%	Δ12%	Δ15% 1.20/1.41	Δ18%	Δ20%
+15%	Δ4%	Δ7%	Δ10% 1.20/1.33	Δ13%	Δ16%
BASE CASE TCO in EUR/km e-HDT/ICE-HDT	Δ-2% 1.27/1.25	Δ1% 1.23/1.25	Δ4% 1.20/1.25	Δ7% 1.16/1.25	Δ10% 1.12/1.25
-15%	Δ-9%	Δ-6%	Δ-2% 1.20/1.17	Δ1%	Δ4%
-30%	Δ-17%	Δ-13%	Δ-10% 1.20/1.09	Δ-6%	Δ-3%

Long-haul scenario:
100,000 km/a
50% depot charging, 50% highway charging

Increase in electricity price ← **Electricity** → *Decrease in electricity price*

Diesel: *Increase in diesel price* ↑ / *Decrease in diesel price* ↓

Diesel \ Electricity	+30%	+15%	BASE CASE TCO in EUR/km e-HDT/ICE-HDT	-15%	-30%
+30%	Δ13%	Δ17%	Δ21% 1.08/1.37	Δ25%	Δ29%
+15%	Δ8%	Δ12%	Δ16% 1.08/1.31	Δ20%	Δ25%
BASE CASE TCO in EUR/km e-HDT/ICE-HDT	Δ2% 0.97/1.21	Δ6% 1.01/1.21	Δ11% 1.08/1.21	Δ15% 1.15/1.21	Δ20% 1.19/1.21
-15%	Δ-5%	Δ0%	Δ4% 1.08/1.10	Δ9%	Δ14%
-30%	Δ-13%	Δ-8%	Δ-3% 1.08/1.05	Δ2%	Δ8%

- Clear TCO advantage of e-HDT (Δ>5%)
- Approx. parity of TCO between e-HDT vs. ICE-HDT (Δ±5%)
- Clear TCO disadvantage of e-HDT compared to ICE-HDT (Δ>5%)
- Δ Difference in TCO between e-HDT vs. ICE-HDT
- Trend scenario

Figure 3: Sensitivity analysis for electricity and diesel as key influencing factors

4 Excursus: Analysis of greenhouse gas emissions

In addition to the assessment of costs, P3's TCO tool also enables an ecological comparison by providing the CO_2 equivalents (CO_2-eq) emitted over the holding period of the respective truck. In a simplified assumption, the comparison covers only the CO_2-eq by operation of the truck and the production of the LFP (Lithium Iron Phosphate) battery in Europe. These two factors are considered due to their main impact on emissions of the selected drive types. To make a comprehensive statement on emitted CO_2-eq of e-HDT and ICE-HDT, a full lifecycle analysis must be performed.

The underlying rationale behind including the analysis of CO_2-eq is the Non-Financial Reporting Directive (NFRD), which requires more and more companies in the European Union to monitor their sustainability practices, starting with energy-intensive companies. Transparency is achieved by the publication of a non-financial report together with the annual management report on the company's ESG performance (Environmental, Social, Governance). The scope of the NFRD is gradually expanding to encompass all large and small publicly listed companies in the coming years.

By calculating with CO_2-eq as best practice in the industry, a unit of measurement is used to standardize the climate impact of different greenhouse gases: not only CO_2-emissions are considered, but also other greenhouse gases with even higher climate impact. Not surprisingly, the comparison of CO_2-eq for the operation of trucks over their holding period of six years strike out in favor of the e-HDT. Decreasing emission factors for electricity over time due to constantly increasing renewable energy production in Germany push the ecological dominance of the electric powertrain in truck operation compared to the diesel variant. Despite being often condemned as huge emission source, the production of the battery has only a minor impact on the e-HDT's CO_2-eq balance.

Considering both battery production and truck operation, the e-HDT can save more than 550 g CO_2-eq per km driven compared to the ICE-HDT, when calculating with the German electricity mix. This results in a cumulative 200 tons of CO_2-eq over the entire six-year usage period compared to the ICE-HDT in the regional-haul scenario, and even 350 t CO_2-eq for the long-haul scenario. The gap between e-HDT and ICE-HDT further widens when assuming a green electricity tariff, which is already available at minimally higher cost. In this case, companies can already reduce the emissions of their fleet operations to zero. The production of renewable electricity on site can further contribute to the improvement of companies' carbon footprints.

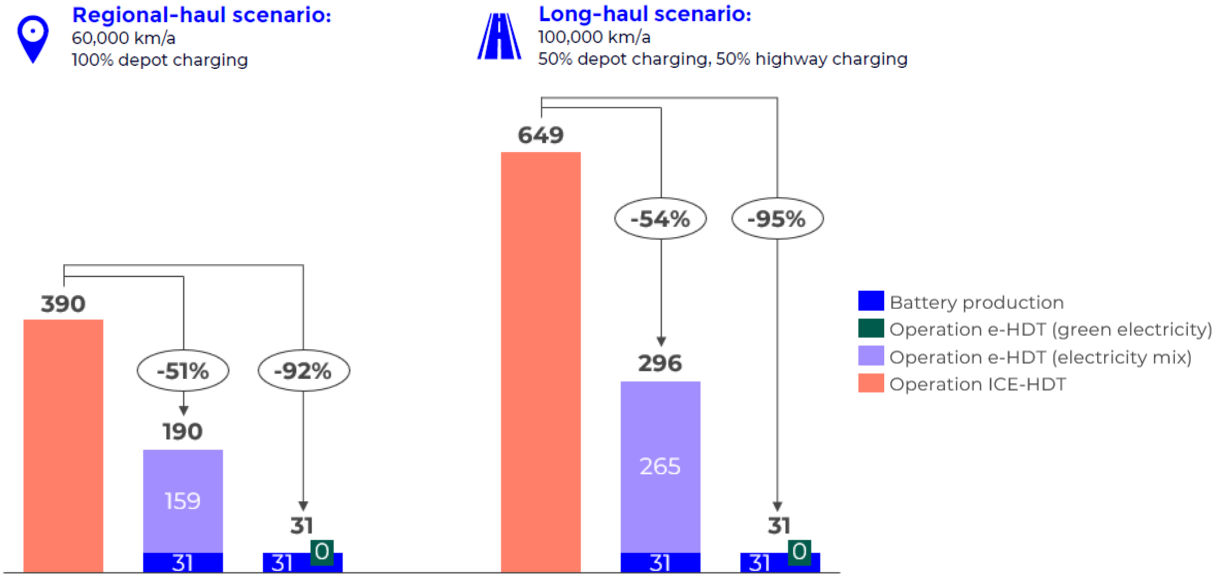

Figure 4: CO_2-eq for battery production and truck operation over holding period 2025-2030 [in t CO_2-eq]

5 Conclusion and outlook

Although lagging in today’s vehicle registrations, the transition to battery-electric heavy-duty trucks will gain more and more traction within the next years. This momentum can be attributed to the particularly high cost-sensitivity of the truck market, where operational expenses play a pivotal role in decision-making.

Market dynamics being heavily influenced by cost considerations coupled with the fierce competition among manufacturers provide fertile ground for disruptive innovations to gain traction swiftly. Now and in the future, energy-intensive sectors, such as logistic companies, must also give greater priority to environmental aspects – transitioning to an electric vehicle park provides high potential to reduce company greenhouse gas emissions.

Depending on the conditions at the operator's depot, there are already use cases today in which e-HDT financially outperform their ICE counterparts. As a result, e-HDT have become a viable alternative to ICE-HDT in terms of cost, with substantial savings per kilometer compensating for the higher acquisition cost for vehicle and charging infrastructure. Possible regulatory changes by the new government in Germany could further improve the result in favor of e-HDT.

As the scenarios of this whitepaper have shown, cost advantages for specific use cases already exist. However, many fleet owners remain hesitant due to the significant upfront investments. To overcome this barrier, a shift towards flexible acquisition models is essential. In particular, leasing of e-HDT has gained popularity and helps to accelerate market adoption.

Similarly, financing and rental options for charging infrastructure are increasingly sought after to spread costs over time. To meet market demands and lower entry barriers, manufacturers and solution providers must expand their offerings to include these flexible models. Alternatives such as subscription services or pay-per-use agreements could further enhance accessibility, enabling fleet operators to adapt more easily to market changes and technological advancements.

Beyond flexible acquisition models, the economic viability of e-HDT critically depends on consistently upholding low electricity prices at the depot. This requires a multifaceted approach that combines decentralized electricity production, strategic utilization of favorable electricity market prices, and implementation of intelligent charging systems. The goal is to create a smart energy ecosystem, where vehicle charging is seamlessly integrated into a comprehensive energy management strategy. This holistic approach not only enhances the cost-effectiveness of e-HDT but also contributes to the overall sustainability of fleet operations.

Whilst the two scenarios illustrated in this analysis have been chosen deliberately to represent standard use cases, they do not reflect the full spectrum of heavy-duty transport. Accordingly, it is crucial to highlight the importance of conducting individualized assessments. The operating procedures of the vehicle fleets and the special circumstances of each depot must be examined in detail to fully profit from fleet electrification.

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Presenter Biography

Alina Haller studied "Business Economics" and "Sustainable Mobilities" in Germany, Mexico and Denmark. Today, Alina Haller is Senior Consultant for E-Mobility and Charging Infrastructure at P3, a German technology consulting company. Within her work at P3, she focuses on strategy projects for all stakeholders in the e-mobility industry. In 2024, Alina Haller developed a calculation tool for the comparison of total cost of ownership of electric trucks in comparison to diesel trucks.