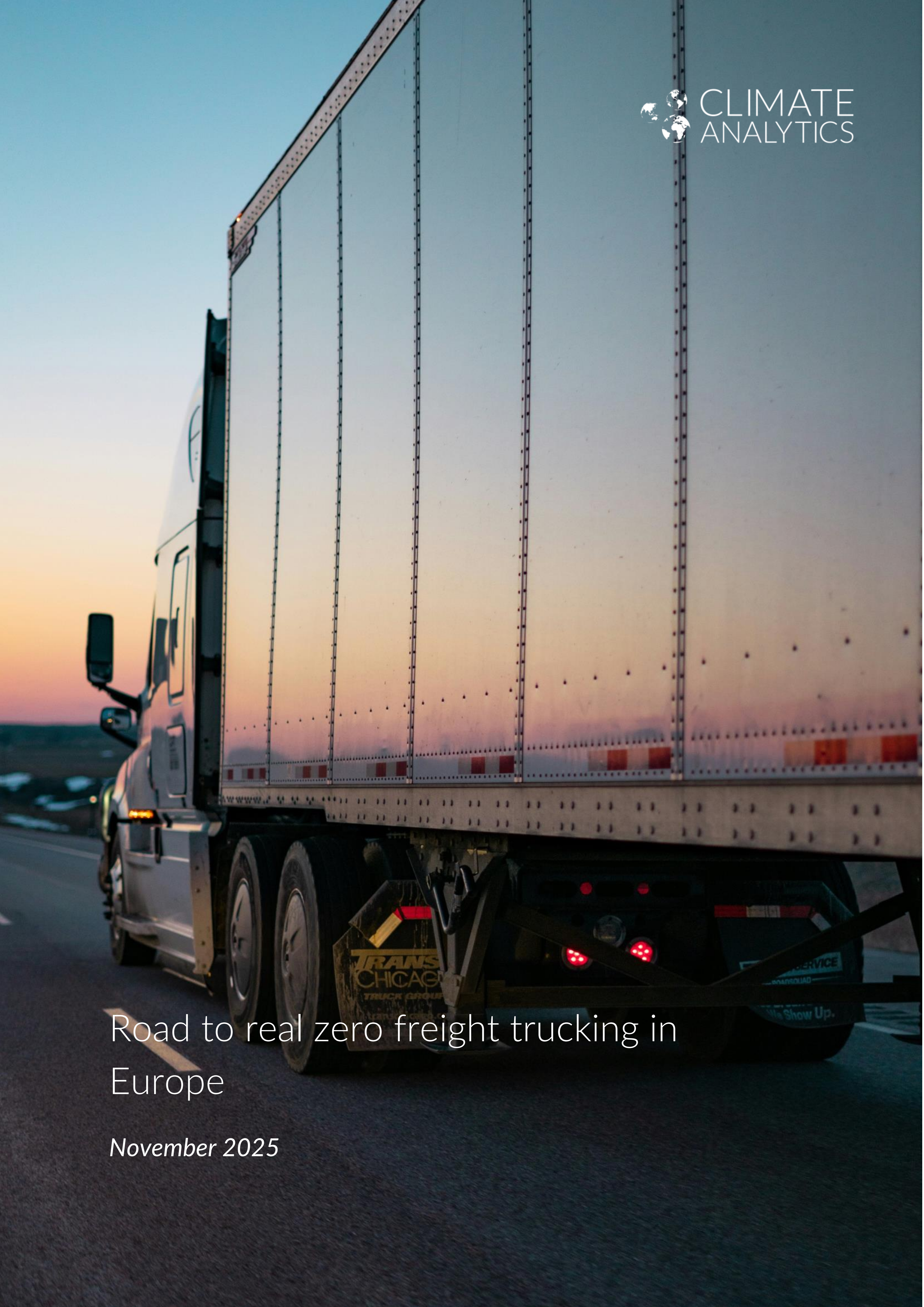

CLIMATE ANALYTICS

Road to real zero freight trucking in Europe

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About Climate Analytics

Climate Analytics is a global climate science and policy institute. Our mission is to deliver cutting-edge science, analysis and support to accelerate climate action and keep warming below 1.5°C.

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Summary

Achieving real zero emissions – defined as eliminating tailpipe emissions entirely by or before 2050 – is the most cost-effective and sustainable strategy for European road freight logistics companies. This report demonstrates that early adoption of battery electric trucks (BETs) is not only the best approach for decarbonisation but also delivers the greatest long-term financial savings.

Existing literature shows that from a total cost of ownership (TCO) perspective, cost parity of BETs with diesel trucks has been reached for urban and regional delivery trucks. For long-haul trucks, BETs are expected to reach TCO parity with diesel trucks between 2025 and 2026. In practice, logistics trucking companies typically operate a mix of routes, including urban, regional and long-haul segments. This report analyses the potential financial savings of pursuing a real zero emissions pathway compared to alternative, less ambitious strategies. However, to realize these benefits, companies must act quickly and accelerate their adoption of BETs within this decade.

The analysis compares different powertrain transition strategies, including Early Action (real zero), Business-as-Usual with a split powertrain mix, Current Action with full electrification, and Delayed Action towards full electrification. The findings show that transitioning to BETs under an Early Action strategy, aligned with real zero emission pathways, offers the lowest TCO across all emission profiles. To align with real zero pathways, companies would need to transition their fleet to a 68% BET share by 2030 and be fully electrified by 2045. By 2030, the TCO of BETs is projected to be 15% - 22% cheaper than diesel trucks. In contrast, other powertrain options, including fuel cell electric trucks (FCETs) and compressed natural gas (CNG) and liquified natural gas (LNG) vehicles, remain more expensive, with the latter projected to cost 36-46% more to operate than BETs by 2030.

The upfront cost of purchasing BETs are falling and by 2030, are expected to cost an average of 200,300 EUR, 34% lower than toda. By 2040, BET prices are projected to fall by 65%-75% relative to 2020 levels, making them significantly more cost-competitive than diesel or hydrogen alternatives. By 2050, logistics companies are projected to fully electrify their fleets, resulting in 100% emissions reductions.

The Early Action scenario, which aligns with the real zero emissions pathway, achieves significant emissions reductions early on. It represents companies that adopt BETs early and at scale, resulting in faster fleet electrification, lower TCO, and the deepest emissions reductions. By 2030, companies following this path would need to

have 68% of their fleet comprised of BETs, achieving 66% emission reductions compared to 2020 levels. By 2045, early acting companies achieve full decarbonisation. An Early Action approach delivers a 16% lower TCO compared to a Business-as-Usual approach in 2030. On the other hand, if companies delay achieving a real zero emissions pathway in five years with slower BET uptake, they can still achieve real zero by 2045, but face higher TCO costs. In 2030, TCO costs will be 7% higher compared to an Early Action approach. However, additional actions would be needed to cut the difference in carbon budget that will exist between a Delayed Action and an Early Action approach.

Companies following a Current Action or Business-as-Usual approach will rely on more expensive and polluting powertrains like diesel and CNG/LNG, which will become increasingly uneconomical under the road transport EU ETS II carbon pricing system. Even without the ETS II, this study shows it will still be more cost-effective for companies to rapidly shift to BETs rather than maintain their existing diesel truck fleets. These companies will also register higher emissions, with a Business-as-Usual scenario only achieving a 50% emissions reduction by 2050 compared to 2020 levels, far from the full reduction needed to meet EU climate targets.

Our analysis models the transition for a large trucking company operating 10,000 trucks across a mix of regional delivery, return-to-depot long-haul, and cross-border long-haul operations. While most trucking firms are small- or medium-sized enterprises, the largest operators will play a pivotal role in driving the sector's transition. Their greater resources enable them to adopt BETs early, helping to establish an affordable second-hand market that will make it easier for smaller companies to electrify their fleets.

The financial case for Early Action is further supported by the substantial savings that early adopters of BETs can expect. These savings will come from cheaper fuel costs, maintenance, compliance with road tolls and charges, and added savings from the EU ETS II which will increase the costs for diesel truck owners.

For instance, by 2030, large road freight logistics companies with fleets above 10,000 trucks and following the Early Action strategy could save between EUR 49 million and EUR 108 million annually in operational costs compared to slower adopters, without the added cost of the ETS II. By 2040, delayed transition could result in operating costs up to 4% higher compared to early adopters, underscoring the growing economic advantage of adopting BETs sooner rather than later.

For the first time, this report attempts to quantify what the added cost impact of the ETS II will mean for trucking companies. Companies relying on diesel trucks will face rising costs as carbon prices increase. In 2030, companies with a high share of diesel trucks could see their TCO increase by up to 7% under a high carbon price scenario, compared to only a 3% increase for early BET adopter companies with a real zero aligned BET share. In relative terms, BAU companies will pay an additional 4% under a high ETS II price, on top of the 16% TCO cost difference compared to early acting companies. In monetary terms, a BAU approach would cost a company an additional EUR 5 to 66 million annually in 2030, due to continued reliance on fossil fuel-powered trucks. By 2040, this cost gap becomes even more significant, with BAU companies facing up to 6-10% higher costs. In contrast, companies that adopt BETs early will experience minimal cost increases from the ETS II, ranging from 1%-2% in 2030. Beyond 2040, early BET adopters will not pay any ETS II premiums as their fleet will be fully electrified, making early adoption the most financially advantageous strategy.

Depot charging presents a practical solution for overcoming charging time constraints in long-haul operations. Depot charging allows trucks to recharge when they are not in use, taking advantage of off-peak electricity rates and minimising the impact on daily operations. This model works particularly well for return-to-depot operations, where trucks operate within a predictable range, allowing logistics companies to invest in private charging infrastructure at their depots. This approach reduces the need for public charging stations and mitigates the risk of congestion at high-power charging points.

Companies can implement operational strategies such as dynamic charging, where trucks power-up during mandatory driver rest periods, ensuring that idle time does not disrupt delivery schedules. Additionally, advancements in fast-charging infrastructure at strategic locations along highways can facilitate cross-border operations and inter-city freight movement. These charging stations, placed on key logistics corridors, can provide rapid refuelling opportunities for BETs, complementing depot charging infrastructure and enabling more flexible operations.

To support the transition to zero-emission freight trucking, the EU and member states need to implement several key policy changes, including:

- High-power charging infrastructure should be deployed along key logistics corridors, ensuring the availability of fast and reliable charging for BETs.
- Provide subsidies, grants or tax exemptions to enable logistics companies to overcome the high upfront costs of BETs – especially SME operators.

- Increase the number of megawatt charging systems (MCS), and encourage the development of private depot charging solutions through incentives or subsidies for fleet operators.
- Ensure that EU ETS II revenues are used to support SME truck operators through the update of BETs.
- Set strong BET mandates for larger companies through the Green Freight Initiative currently under development.
- Increase the stringency of CO_2 standards for new heavy-duty vehicles to at least a 65% reduction by 2030, coupled with mandates for BET sales for truck manufacturers.
- Send clear policy signals to vehicle manufacturers and logistics companies that fossil gas and biofuels are not suitable and represent costly lock-in investments into technologies that will not be compatible with achieving the EU's net-zero goals.

The EU must provide long-term policy certainty for logistics companies, particularly around emission reduction targets and the phase-out of internal combustion engine (ICE) trucks. Clear deadlines for the end of diesel truck sales and strong regulations on CO_2 emissions will give companies the confidence to make long-term investments in BETs and the required charging infrastructure.

The EU needs to ensure that production and supply of BETs in Europe can meet demand if logistics companies are to take an Early Action approach. If supply cannot be met, then logistics companies may have no choice but to slow their BET transition while simultaneously absorbing higher costs from keeping their diesel fleets operational. Additionally, the EU risks weakening the strategic importance of its vehicle manufacturing industry if BET production is not meeting domestic demand, as the resulting supply gap would likely be met by imports from third countries.

The early adoption of BETs leads to significant cost savings and emissions reductions, while companies that delay the transition risk being burdened with higher operating costs and missed opportunities for financial and environmental benefits. Early Action is therefore crucial to securing a competitive advantage, meeting EU climate targets, and ensuring long-term sustainability in the European freight sector.

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List of Acronyms

ACEA .... European Automobile Manufacturers' Association
AFIR .... Alternative Fuels Infrastructure Regulation
BET .... Battery electric truck
CCS .... Combined charging system
CNG .... Compressed natural gas
CO_2 .... Carbon dioxide
EAFO .... European Alternative Fuels Observatory
EEA .... European Environment Agency
EED .... Energy Efficiency Directive
ERS .... Electric road systems
ETC .... Energy Transitions Commission
ETS .... Emissions trading system
EU .... European Union
FCET .... Fuel cell electric truck
GHG .... Greenhouse gas(es)
HDV .... Heavy duty vehicle
HVO .... Hydro-treated vegetable oil
IAM .... Integrated assessment model
ICCT .... International Council on Clean Transportation
ICE .... Internal combustion engine
IEA .... International Energy Agency
LH .... Long-haul
LNG .... Liquefied natural gas
MPP .... Mission Possible Partnership
MS .... Member states
NOx .... Nitrogen oxides
OEM .... Original equipment manufacturer
PM .... Particulate matter
RD .... Regional delivery
RED III .... Renewable Energy Directive III
SME .... Small and medium-sized enterprises
TCO .... Total cost of ownership
TEN-T .... Trans-European Transport Network
TNO .... Netherlands Organisation for Applied Scientific Research
TTW .... Tank-to-wheel
UD .... Urban delivery
VECTO .... Vehicle energy consumption calculation Tool
WTT .... Well-to-tank
ZET .... Zero-emission truck

Introduction

The European heavy-duty vehicles (HDV) sector is pivotal to Europe's trade both within and outside the European Union. Trucks carry 75% of all EU freight over land (EEA, 2024b) with the remaining freight transported through inland waterways and rail (ACEA, 2025). Road freight transport accounted for 54% of total EU freight activity in 2022, reaching 1,866 billion tonne-kilometres, the highest level on record, and a 66% increase since 1995 (EEA, 2024a). It is projected to keep growing into the future with overall freight activity estimated to increase by 19% in 2025 and 30% in 2030 compared to a 2015 baseline (EEA, 2024a). This growth trend is reflected globally, with demand reaching 32.8 trillion tonne-kilometres in 2023 and projected to double by 2050 (World Economic Forum, 2024). The trade by road freight market is valued at €424 billion in 2023, comprising €294 billion in domestic operations (69%) and €130 billion in international transport (31%) (Transport Intelligence, 2024).

Despite representing only 4% of vehicles on the road (Monteforte et al., 2024), HDVs are responsible for a disproportionate 25% of road transport emissions in the EU (EEA, 2022; European Commission, 2023). Road transport accounted for 26% of the EU's GHG emissions in 2020 (ACEA, 2020), with HDVs alone contributing over 6% of the total (European Commission, 2024a). Trucks comprise 85% of emissions within the HDV category, with buses and coaches making up the remainder (EEA, 2022b). This disproportionate impact on emissions is compounded by the sector's projected growth (Mission Possible Partnership, 2022), and continued reliance on fossil fuels with over 95% of trucks being diesel-powered (Basma & Rodríguez, 2023a; World Economic Forum, 2024). Although the sector has achieved a notable 14% reduction in emission intensity from 2019 to 2024 through increased fuel efficiency and logistics optimisation, the majority of the remaining 5% of non-diesel trucks rely on biodiesel rather than zero-emission alternatives (Basma & Rodríguez, 2023a; World Economic Forum, 2024), highlighting the substantial gap that remains to achieve real zero emissions.

The EU has set its ambition of achieving net-zero emissions by 2050. It has also set a 2030 economy-wide emissions reduction target of 55% below 1990 levels. To achieve these goals, the EU needs to rapidly decarbonise its road sector. Its regulatory framework plays a crucial role in driving the transition of HDVs to zero-emission trucks. As part of the European Green Deal, the EU has adopted several regulations to support the uptake of "low"-emission trucks as well as their infrastructure.

Several policy drivers are accelerating this transition. The Eurovignette Directive (2022) and EU ETS II will impose CO_2 charges on trucks and carbon pricing on transport fuels, enhancing the competitiveness of BETs and fuel cell electric trucks (FCETs) compared to diesel vehicles. The EU ETS II (Directive (EU) 2023/959) extends carbon pricing to road transport fuels, increasing the cost of diesel and creating a financial incentive for logistics companies to switch to alternative fuels such as electricity or hydrogen (Transport & Environment, 2025a). The impact on fuel costs will directly impact diesel truck operators, with the magnitude of this impact determined by the carbon price under the ETS over time (Günther et al., 2025). The impact of EU ETS II on pushing the trucking sector toward BET adoption has not yet been studied. This report examines the potential additional costs for logistics companies operating diesel trucks compared with using BETs.

Charging infrastructure is a critical element in the uptake of zero emission BETs, but its limited availability has long represented a barrier. The EU is addressing infrastructure and fuel supply challenges through the Alternative Fuel Infrastructure Regulation (AFIR) (Regulation (EU) 2023/1804), which sets binding targets for the deployment of HDV charging stations and hydrogen refuelling infrastructure across the Trans-European Transport Network (TEN-T), as well as urban nodes, with phased targets between 2025 and 2030. The current build-out of BET charging infrastructure remains below what is required to support widespread trucking electrification by 2030 (Basma & Schmidt, 2025), suggesting that the pace of deployment may be too slow to meet industry needs.

BETs require rapid energy replenishment during mandatory rest periods to maintain operational schedules and carry payloads that demand substantial energy consumption making fast and ultra-fast charging infrastructure essential for commercial viability. These operational constraints of long-haul trucking, including driver-hour regulations and tight delivery schedules, make rapid charging within a 30-45 minute window suitable. This drives demand for higher-power charging infrastructure delivering at least 350kW power levels – fundamentally different from the chargers sufficient for depot-based or urban delivery applications (Transport & Environment, 2022b).

Several decarbonisation pathways are available for logistic road freight companies operating in the HDV sector. There is a strong case for the trucking sector to achieve real zero emissions – eliminating tailpipe emissions entirely by or before 2050 – if the world is to limit global temperature warming to 1.5°C. This is largely because net-zero emissions reduction pathways aren't really a possible option for the trucking sector in a scalable and sustainable manner. The only way the trucking sector can achieve net-zero emissions is through the use of biofuels or carbon offsetting.

- Biofuels face limits in scalability due to the limited availability of feedstocks and competition from other hard-to-abate sectors. Using crop-based feedstocks also raises sustainability concerns as it directly competes with food production and can exacerbate food insecurity (Liska et al., 2014; Transport & Environment, 2023a). Furthermore, depending on how feedstocks are produced, indirect land use changes (ILUC) can even increase the emission intensity of biofuels, making them more emissions-intensive rather than carbon neutral (Daioglou et al., 2020).
- Hydro-treated vegetable oil (HVO) biofuels could offer emission reductions compared to conventional diesel fuel, however they come with scalability and sustainability concerns. For example, it has recently been found that a quarter of the HVO consumed in Europe comes from palm-oil-derived feedstocks – making it directly linked to deforestation and competing with food supply in countries abroad (Transport & Environment, 2025b). Biofuel feedstocks are further limited by the availability and growing competition across other hard-to-abate sectors.
- Carbon offsetting has been found to be a highly ineffective way to cut emissions. It is estimated that only 16% of carbon offsetting projects are shown to result in additional emissions reductions (Probst et al., 2024). Carbon offsetting often does more harm than good by promoting misleading claims about carbon neutrality, as it allows companies to continue polluting while only appearing to mitigate their impact. Meanwhile, many carbon credit schemes lack quality, failing to represent real, additional, or permanent emissions reductions, which undermines their effectiveness as a climate solution. Offsetting one tonne of CO_2 emissions by purchasing a carbon credit that represents the avoidance, reduction, or removal of one tonne of CO_2 elsewhere is not always a valid or fair exchange, especially when credits represent temporary removals or preparatory actions rather than actual reductions (Frank, 2023). Rather than relying on offsets, companies should focus on cutting their own internal emissions, aiming for real zero reductions.

The argument then lies with making the economic case for companies to pursue a real zero transition pathway. This report reviews existing literature, coupled with quantitative fleet turnover and financial analysis to assess the cost competitiveness of real zero emission trucking pathways, demonstrating how the economics work out on a case-by-case basis.

This report investigates strategies that companies are employing today and model four different scenarios, all of which achieve zero emissions by 2050 (only one scenario represents real zero emissions). We start with an early action scenario to demonstrate what ambition is required to achieve real zero emissions. This is linked to the central real zero emission pathway derived from the IPCC Integrated Assessment Models (IAMs). We use a bespoke pathway from the REMIND model outlined in (Climate Analytics, Rescuing 1.5°C: new evidence on the highest possible ambition to deliver the Paris Agreement, which demonstrates that real zero emissions are achieved between 2045 and 2050. We then compare the real zero costs with the costs associated with a Business-as-Usual (BAU) scenario, a Current Action towards full electrification scenario, and a Delayed Action scenario.

The European road freight sector

The EU's truck freight sector is highly fragmented, with many operators of varying fleet sizes and service offerings. Germany hosts the largest truck fleet across some 35,000 logistics road freight companies (Mordor Intelligence, 2025). The majority of the truck operators (around 90%,) are small- and medium-sized enterprises, or SMEs (IRU, 2024). However, the largest operators play a significant role in this sector since they have the resources to be early adopters of zero-emission trucks, which will trickle down into a more affordable second-hand market for SMEs.

Heavy duty vehicle operation profiles

Truck activity is defined by three main mission profiles which specify operational patterns: urban delivery (UD), regional delivery (RD), and long-haul (LH), with additional classifications for construction and municipal uses. Trucks are categorised in EU regulation into VECTO[1] groups according to their axle configuration, operation and weight class. The truck groups assessed in this report cover the 4, 5, 9, 10 groups which are subject to CO_2 standards (Basma & Rodríguez, 2023c; Mulholland et al., 2023). This report focuses primarily on the long-haul segment from the VECTO groups that are currently covered by EU regulations (Appendix B - Table B1)

Regional heavy-duty trucks contribute 10% of HDV emissions and have some of the highest carbon intensity per tonne-kilometre (Mulholland et al., 2023). They make up 6% of new HDV sales, typically covering 300 km per day with predictable routes linking metropolitan distribution hubs (Basma & Rodríguez, 2023a), making them a key segment to transition to zero-emission trucks. Groups 4-RD and 9-RD dominate this segment, with 4-RD accounting for 10.3% of trucks, emitting 198 gCO_2/tkm, and 9-RD representing 4% with 111 gCO_2/tkm, reflecting improved efficiency in higher-axle configurations (Mulholland et al., 2023).

[1] The European VECTO (Vehicle Energy Consumption calculation Tool) system, designed to simulate fuel consumption and CO_2 emissions provides the technical foundation for HDV classification. It classifies HDVs by weight, body type, and axle configuration, and is the basis for regulatory compliance and technology assessment (Basma & Rodríguez, 2023c).

The long-haul segment, including 4-LH, 5-LH, 9-LH, and 10-LH, accounts for 90% of CO_2 emissions from the HDV fleet, with the 68% coming from 5-LH configuration alone in 2019 (ACEA, 2020). Long-haul operations represent 48% of new HDV sales (Basma & Rodríguez, 2023a). Emission efficiency varies across configurations: 5-LH (56 gCO_2/tkm), 10-LH (59 gCO_2/tkm), 9-LH (64 gCO_2/tkm), and 4-LH (102 gCO_2/tkm). The efficiency differences are attributed to the design advantages of tractor-trailer configurations (5-LH and 10-LH) over rigid trucks (4-LH and 9-LH). This report focuses on long-haul and regional delivery trucks, excluding VECTO categories below 4 and above 10 due to limited data availability.
Long-haul operations are stratified further, with half operating under 500 km daily in return-to-depot operations, a quarter in the 500-800 km range, and only 3% exceeding 800 km in cross-border operations with irregular routing (Basma & Rodríguez, 2023c). Each mission profile has distinct energy needs and infrastructure dependencies that influence the viability and implementation timelines of zero-emission technologies.

Defining zero emission trucking

Decarbonising the road freight sector requires several actions to take place simultaneously. The avoid-shift-improve (ASI) approach provides a framework for how to do this by first finding ways to avoid transport, then shifting to less carbon intensive transport modes (like maritime and rail), followed by improving fuel efficiency, such as switching to electric vehicles (Miklautsch & Woschank, 2022). Improving fuel efficiency translates to switching to different powertrains that drive the vehicle.

This report focuses on the improvement aspect for long-haul and regional delivery trucks. We assess the real zero emissions implications for tailpipe (tank-to-wheel) emissions only, as these represent the emissions that logistics companies are directly responsible for and can control through their operational decisions.

Across Europe, the prevalence of alternative fuel trucks (categories N2 and N3) has been expanding exponentially since 2008 with an average annual growth rate of 17% year on year. When broken down to the different powertrains, the largest growth has come from compressed natural gas (CNG), which makes up half of the alternative fuel truck sales and stock in recent years. Only in 2024 did BETs surpass CNG in alternative fuel truck sales. This shows that BETs are gaining ground, but worryingly, the market and industry's appetite for fossil gas trucks have resulted in a growing build-up of more fossil fuel trucks.

We consider only BETs and hydrogen FCETs to be compatible with a real zero transition because their tailpipe emissions are zero, while "low carbon" alternative fuels such as CNG and liquefied natural gas (LNG) still release GHG emissions. However, BETs and FCETs can achieve real zero emissions only when they are supplied by 100% renewable electricity and green hydrogen. Overall, BETs offer a clearer path to zero emissions, while FCETs present a more complicated picture, with their impact varying from 15% savings when hydrogen production is fossil driven to 89% GHG reductions when powered by green hydrogen (O'Connell et al., 2023). Fuel cell system manufacturing, hydrogen tank production, vehicle assembly, and maintenance, as well as upstream emissions from infrastructure for electrolytic hydrogen production, account for the remaining 11%.

As the electricity grid and hydrogen production are not yet fully decarbonised – and considering the current hydrogen supply in Europe is assumed to come from a mix of green and grey production sources – upstream emission intensity (i.e. well-to-tank) will remain high in the near-term, but will gradually fall toward 2050 (Basma & Rodríguez, 2023c). A real zero transition assumes that upstream electricity generation and hydrogen production will be fully decarbonised in line with 1.5°C compatible pathways. The real zero transition of renewable electricity and hydrogen must go hand-in-hand with end-use sectors such as transport. This report focuses only on the considerations to be taken by logistics road freight companies, rather than the full system change in the power and energy sectors.

In 2022, electricity and hydrogen production still resulted in high upstream GHG intensities – however, as renewables rapidly scale up, this intensity will fall below that of LNG and diesel production by 2050 (Basma & Rodríguez, 2023c). When considering the tank-to-wheel emissions (i.e. tailpipe emissions), diesel and LNG are significantly more GHG intensive, while battery electric and hydrogen drivetrains have no emissions. Over a vehicle's lifetime, the cumulative tank-to-wheel emissions account for the majority of a vehicle's emissions.

Industry perspectives – current commitments

As of 2024, only eight of the top 20 road freight companies have set carbon neutrality targets. While many companies see switching to electric trucks as a main driver to decarbonise their fleets, there are some companies looking to other alternative fuels. Worryingly, these include a growing stock of CNG, LNG and LPG trucks as outlined above (European Commission, 2024a), while other companies are increasingly switching to biofuels like HVO as a drop-in fuel which can be used in their existing internal combustion truck fleets (Transport Intelligence, 2024). This approach of maintaining investments in CNG, LNG, and biofuels like HVO while gradually adopting zero-emission trucks represents our BAU scenario – a mixed powertrain strategy that falls short of real zero emissions. Worryingly, several large truck logistic companies are currently relying on HVO as their approach to reduce their fleets emissions (see Appendix B - Table B4).

The largest European truck freight logistics companies are making some progress in transitioning to zero-emission technologies, particularly BETs, but they still have a long way to go to reach real zero ambition. Battery electric vehicles are becoming increasingly viable options for freight transport as the technology improves and charging infrastructure expands (Basma & Rodríguez, 2023c). Action to transition fleets is being taken by some of the largest logistics companies in Europe (see Appendix B - Table B4). Some firms have already introduced BETs into their fleets; others have placed orders for BETs while some are still exploring BET options. Comparatively few companies are heavily investing in hydrogen trucks. Some have committed significant resources to LNG and CNG for long-haul operations, but their continued use could become increasingly costly as stricter environmental regulations come into play (Transport Intelligence, 2024).

In a survey asking truck operators what actions they are taking to address climate change, the most common response (17.2% of respondents) said cutting carbon emissions, followed by reducing empty transportation mileage (16.8%) and investing in renewable energy options (15.7%) – however this also considered renewable diesel or switching to HVO fuels. Additionally, companies have indicated that they consider carbon offsetting and insetting as measures to cut their emissions (Transport Intelligence, 2024). These actions are concerning because they are not true emission cutting measures. Renewable diesel is not zero emission but rather has lower emission intensity compared to fossil diesel.

Approach

In the European context, techno-economic assessments on the viability of BETs compared against other fuel engine trucks has been studied extensively, namely by the International Council on Clean Transport (ICCT). We build on this research and further investigate the cost-competitiveness of three main truck fleet powertrain transition pathways likely to be available to road freight logistics companies. We provide company-level economic narratives demonstrating the total cost of ownership (TCO) that a typical road freight logistics company in Europe could face depending on its fleet decarbonisation strategy.

We explore whether companies striving to achieve real zero emissions by taking early action today stand to gain the most savings based on the total cost of ownership (i.e. vehicle retail price, maintenance, fuel, labour, insurance, and regulatory costs) over the next 25 years. We also highlight enablers, barriers, and opportunities for the green truck transition in Europe at both the company and EU policy-making levels, including changing infrastructure cost considerations. Based on this analysis, we provide a set of recommendations for both companies and policymakers.

A review of the existing literature was conducted to understand the most cost-effective powertrain for a real zero transition in the trucking sector. We also examined the financial implications from the perspective of a hypothetical company, analysing fleet composition, attitudes toward the transition, and how current strategies align with what is needed to achieve real zero emissions. This report provides:

- A literature analysis on the TCO of different truck types (i.e. urban, regional and long-haul) across different powertrains. It delves deeper into the different mission profiles of long-haul trucks (i.e. return-to-depot and cross-border operations). Lastly it compares how the up-front cost of BETs compares to other powertrains.
- A literature analysis on the challenges of charging infrastructure, the different options available to companies and the associated costs they may incur.
- A quantitative modelling component that builds a bottom-up age stock turnover model for mixed fleet operations (regional and long-haul trucks) to illustrate the fleet-wide financial costs and savings potential of different transition strategies. It uses the ICCT TCO factors from the literature analysis (Basma & Rodríguez, 2023a). The ICCT's BET TCO factors integrate charging infrastructure costs and utilization rate (public vs. depot) assumptions which are maintained in this report's quantitative modelling. The impact of the EU ETS II is integrated into the modelling by adjusting the TCO fuel costs of diesel fuel into the TCO factors to reflect the added costs calculated using Transport & Environment, 2025a and assumptions on future ETS II carbon prices from Günther et al., 2025.
- For the full details see the methodological note in Appendix A.

To evaluate the economic implications of different transition strategies across the segments, this analysis models four distinct pathways that road freight logistics companies can pursue.

- **Early Action approach towards full electrification** – aligning with real zero emission reduction pathways, using the sales and stock shares derived from the REMIND Integrated Assessment Model (Climate Analytics, forthcoming). This reflects companies that have already started investing in, or are planning a rapid transition to BETs. It envisages a majority electric fleet mix (some hydrogen is present to cover the cross-border segment), and reflects companies that have already made efforts to acquire BETs.
- **Business-as-Usual approach towards a split powertrain mix** – reflecting companies selecting different types of alternative fuel vehicles in line with the baseline HDV truck

sales shares published in the European Commission's revised HDV CO_2 standards impact assessment (European Commission, 2023) – which envisages continuation of LNG/CNG truck uptake with a growing demand for FCET trucks that will be as popular as BETs by 2050. This is not reflective of a real zero transition.

- **Current Action approach towards full electrification** of the fleet – this is based on existing low BET uptake levels and assumes the BET uptake is aligned with the HDV CO_2 standards regulation impact on the truck market as defined by Sen et al., 2025. This is not reflective of a real zero transition.
- **Delayed-Action approach towards full electrification** – this reflects companies currently with a low share of BETs but aligning to a five year delayed real zero pathway. It combines historic BET uptake rates with those from REMIND model real zero pathway. This reflects companies wanting to align with real zero pathways but that have been slow to start adopting BETs, reflecting historic rates.

The cost-competitiveness of real zero trucking

Literature analysis: total cost of ownership

The underlying concerns companies have had with switching to BETs are their higher costs, long charging times, range anxiety, and limited charging infrastructure. This section demonstrates that while these concerns may have had some validity, they are gradually being addressed through ongoing technological and infrastructure improvements.

TCO comparison across different powertrains

In Europe, long-haul BETs are set to achieve cost parity with diesel trucks by 2026 (for all truck operations) according to the ICCT. This is based on total cost of ownership (i.e. retail vehicle cost, fuel use, maintenance, insurance, and tolls). For BET and FCETs, the fuel cost TCO component also includes the cost of installing charging and hydrogen fuelling infrastructure. In the case of urban and regional delivery trucks, TCO parity with diesel trucks has already been achieved. By 2030, the TCO of BETs is projected to be 15-22% lower than diesel trucks, driven by declining costs and improving range, making BETs more attractive for logistics companies. Currently, BETs are already 15% cheaper to own and operate than bio-

CNG trucks, with the price gap expected to widen to 32% by 2030 (Basma & Rodríguez, 2023a).

Meanwhile, Transport Intelligence finds that the TCO of BETs in both regional and long-haul operations, cost-parity with diesel in European markets has already been achieved as early as 2023. Their analysis reveals that BETs cost €1.14/km compared to €1.18/km for diesel in regional operations, and €0.87/km versus €1.16/km for diesel in long-haul operations (Transport Intelligence, 2024). The cost advantage stems from lower fuel costs, with electricity at €0.20/km compared to €0.58/km for diesel, and reduced maintenance needs. In addition, zero emission vehicles benefit from reduction in road tolls through existing government incentives.

The economic case for real zero is further reinforced when assessing the total cost of ownership over the next decades. Both the ICCT (Basma & Rodríguez, 2023a) and the real zero pathway from REMIND EDGE-T model (Climate Analytics, forthcoming), show that the TCO of BETs in 2030 is significantly lower than any other fuel and powertrain (Figure 1, Table 1). This applies to the individual truck segments rather than a collective mixed fleet and operations.

Between 2023 and 2040, the cost of operating long-haul trucks BETs is expected to fall by 24% according to the ICCT study (Basma & Rodríguez, 2023a). The REMIND EDGE-T model expects that reduction to be 30% over the same period, for trucks larger than 18 tonnes. In contrast, fossil fuel ICE and gas engine trucks will see small reductions of only 5-8%.

In 2030, the TCO of alternative gas fuelled trucks will be 36% - 46% more expensive than BETs to own and operate, according to REMIND and ICCT. This means that current trends in the uptake of CNG and LNG trucks taken by some companies in Europe today will be a costlier path that will not sufficiently reduce the sector's emissions. These cost gaps are only expected to widen with time. Hydrogen fuel cell trucks are not expected to reach cost parity with BETs but they will reach TCO parity with diesel trucks by 2040 (Basma & Rodríguez, 2023a).

Across studies, the TCO for BETs and FCETs decreases in time, with BETs consistently shown to be the cheapest among all powertrain options.

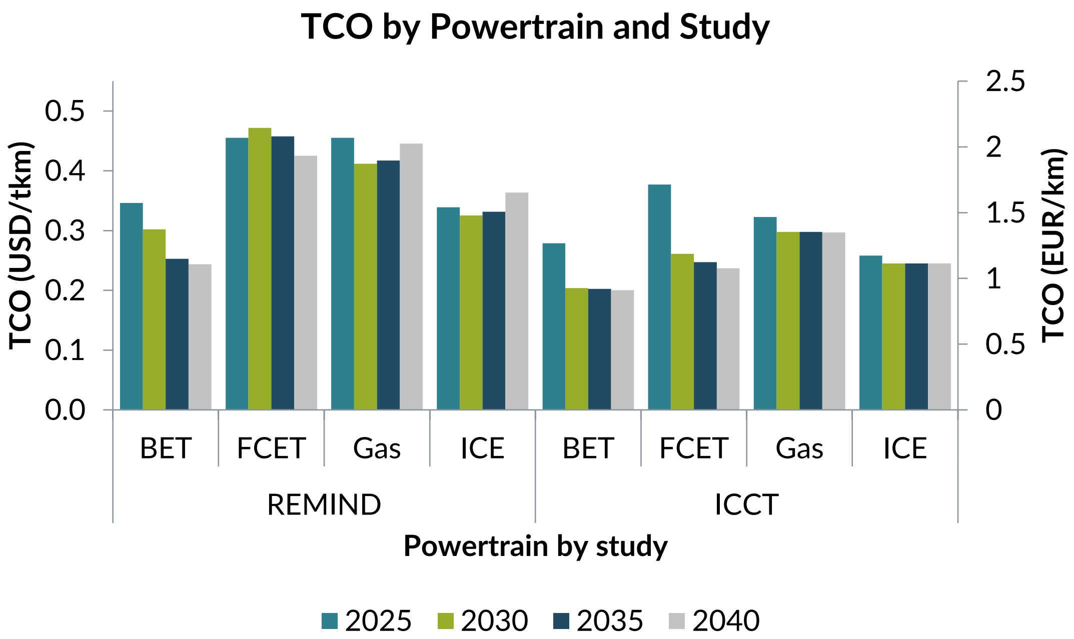


Figure 1: Comparison of TCO costs between different powertrains of long-haul truck segment across years. TCOs are also compared between the REMIND model (Climate Analytics, forthcoming) and (Basma & Rodríguez, 2023a) studies. Note: REMIND categorises trucks by weight, not operation, filtered for trucks above 18 tonnes.

Table 1: Projected TCO (EUR/km) for different powertrains of long-haul operations (Basma & Rodríguez, 2023a). We take the 2025 TCO to be the 2023 value and assume that TCO beyond 2040 remain the same.

Mission Profile	Powertrain	2023	2030	2035	2040
Long Haul Return Depot 500 km	BET	1.26	0.94	0.94	0.93
	ICE - Diesel	1.21	1.15	1.15	1.15
	FCET	1.95	1.22	1.14	1.08
	Gas Engine - Bio-CNG	1.49	1.38	1.38	1.38
Long Haul Return Depot 800 km	BET	1.31	0.93	0.91	0.93
	ICE - Diesel	1.19	1.13	1.13	1.13
	FCET	2.02	1.24	1.06	1.24
	Gas Engine - Bio-CNG	1.48	1.37	1.36	1.37
Long Haul Cross Border 1000 km	BET	1.23	0.91	0.90	0.89
	ICE - Diesel	1.12	1.06	1.06	1.06
	FCET	1.86	1.16	1.06	0.99
	Gas Engine - Bio-CNG	1.43	1.31	1.31	1.31

Comparison of upfront costs across different powertrains

While TCO parity between BETs and diesel trucks has already been achieved for urban and regional trucks and is expected to be reached for long-haul trucks in the near future, the upfront retail costs of BETs still remain significantly higher than those of diesel ICE trucks (Table 2).

The upfront capital costs of BETs are expected to drop significantly, with projections showing a 34% reduction from 2024-2030, bringing the average price of a vehicle to EUR 200,300 (USD 217,700) (IEA, 2025b). In the case of long-haul trucks BET prices will fall by 72% by 2040 compared to 2024, while diesel trucks are expected to become more expensive (by 18%) over the same period. This reduction is primarily driven by lower battery costs and greater manufacturing efficiencies. By 2040, medium and large long-haul BETs are projected to decrease in cost by up to 65% and 72%, respectively. This will make BETs competitive across all truck categories (TNO, 2022). For urban and regional delivery trucks, retail price parity is expected to be reached between 2030 and 2040 (TNO, 2022). However, for long haul trucks, the price gap will shrink, but medium and large BET trucks may still be 4-14% more expensive compared to diesel trucks in 2040. Financial support incentives such as grants, loans, and tax exemptions are powerful policy levers that member state governments can use to ease the burden on companies, particularly SMEs, to support the purchase of BETs (Ricardo, 2025).

Table 2: Vehicle pre-tax retail price (in thousand EUR) including mark-up factor and trailer taken from (TNO, 2022). Highlighted values represent the cheapest power train for a given year.

Truck type	Powertrain	2020		2030		2040	
		k€	% relative to diesel	k€	% relative to diesel	k€	% relative to diesel
Rigid urban	Diesel	79		87		92	
	BET medium	147	86%	88	1%	80	-13%
	BET large	159	101%	91	5%	81	-12%
Articulated regional	Diesel	144		159		170	
	BET medium	355	147%	183	15%	162	-5%
	BET large	413	187%	193	21%	167	-2%
Articulated long haul	Diesel	144		159		170	
	BET medium	498	246%	207	30%	176	4%
	BET large	690	379%	236	48%	193	14%
	FCET	494	243%	274	72%	226	33%

TCO comparison for different long-haul operations

It should be noted that cost parity projections vary across studies and operations, with estimates ranging from 2023 (Transport Intelligence, 2024) to 2026 (Basma & Rodríguez, 2023a) for cross-border operations – the most difficult segment to decarbonise – reflecting differences in methodological approaches, market assumptions, and variations based on operational range and mission profiles. This analysis adopts the more conservative 2026 timeline to ensure robust projections throughout the modelling.

Other studies show that by 2030, long distance operations (~600 km) can achieve 9% cost savings, with regional operations (~400 km) reaching 25% advantages, and urban distribution (~300 km) delivering 29% cost reductions compared to diesel counterparts (PWC, 2024). This TCO supremacy accelerates through the decade, with electric trucks expected to maintain approximately 15% lower total costs than diesel across heavy-duty applications, with the possibility of dynamic charging technologies delivering an additional 20% operational savings beyond static charging systems.

FCETs, however, face higher operational costs. Their fuel costs are substantially higher, and their overall operating expenses are expected to be double that of BETs by 2035. FCETs are therefore projected to be less economically viable than BETs for large-scale zero-emission freight operations, making BETs the preferred choice for achieving zero-emission targets before 2035 (Rogstadius et al., 2024).

Return-to-depot long-haul operations (500-800 km daily) follow predictable long-distance routes with overnight depot return, allowing controlled refuelling and charging. This predictability enables fleet operators to invest in private depot infrastructure and optimise energy costs through strategic charging/refuelling timing. Battery capacity and range of BETs have increased significantly since 2019, reaching 532 kWh in 2025, providing 500 km nominal driving range (Ragon, 2025). This is a major advancement and alleviates previous range anxiety concerns in this sector. Recent megawatt charging technology further supports faster charging during mandatory driver rest periods. For cross-border operations, mixed infrastructure including public corridor refuelling is also required (Basma & Rodríguez, 2023c).

The traditional weight penalty of large battery systems is being transformed through advanced battery chemistry and design optimisation. Current 500-800 kWh battery systems for long-haul operations are heavy compared to diesel fuel, but manufacturers are achieving substantial efficiency gains that offset weight disadvantages. Battery electric trucks demonstrate 55% higher energy efficiency than diesel equivalents (IEA, 2025b), meaning that while batteries add weight, the superior powertrain efficiency can create net operational advantages for return-to-depot operations.

In cases where longer-range return-to-depot long-haul operations are transporting excessively heavy payloads for operations requiring more flexibility, hydrogen FCETs may be more suitable. The 500-800 km range fits within FCET capabilities without payload compromise, and fast refuelling enables higher utilisation and operational flexibility (Basma & Rodríguez, 2023c; IEA, 2025b; Rogstadius et al., 2024; Rout et al., 2022).
Cross-border long-haul operations (greater than 800 km daily) often involve irregular international routes away from depot infrastructure, representing less than 3% of Europe's

truck market but some of the most energy-intensive freight. Electrification in this segment requires larger, more expensive batteries and high-powered charging infrastructure, as well as strategically placed public corridor stations to address route unpredictability and international coordination challenges (Basma & Rodríguez, 2023c; Mission Possible Partnership, 2022; Rout et al., 2022). Large batteries can limit payload capacity by up to ten times that of diesel (IEA, 2025b), though improvements in energy density may mitigate this. Hydrogen fuel cell vehicles currently offer the most suitable zero-emission solution for cross-border long-haul operations, providing faster refuelling and maintaining payload capacity similar to diesel trucks. Fuel costs and station availability, however, remain limiting factors (Basma & Rodríguez, 2023c; Mission Possible Partnership, 2022; Rogstadius et al., 2024).

Cost-competitiveness of other truck operations

While this study mainly prioritises the long-haul segment, companies must also address light- and medium-duty trucks in urban and regional segments, as most European road freight logistics companies operate mixed fleets with various truck types and operations. For these segments, BETs are the cost-effective and optimal choice. Urban and regional delivery BET trucks have already reached TCO parity with diesel trucks (Basma & Rodríguez, 2023a; Transport Intelligence, 2024). Their range aligns with current BET capabilities, and their stop-start driving pattern allows for regenerative braking, enhancing efficiency. BETs also benefit from depot-return patterns, enabling overnight charging via standard AC infrastructure, which is less costly than fast charging networks (Basma & Rodríguez, 2023c). These vehicles typically cover 300 km per day, requiring around 220 kW of power with predictable routes (Basma & Rodríguez, 2023a) BETs are well-suited for metropolitan distribution hubs, offering quiet operations that help fleet operators comply with urban noise restrictions and access zero-emission zones that limit diesel vehicle entry (Basma & Rodríguez, 2022; Wang et al., 2025).

Hydrogen FCETs, on the other hand, offer limited advantages in these segments. While overnight charging is feasible for BETs, hydrogen's high cost and the need for specialised refuelling infrastructure are not justified by the operational demands, except in high-utilisation or weight-sensitive applications where battery weight is a constraint (Basma & Rodríguez, 2023c).

Current trends in delivering BETs

The European Commission's revised HDV CO_2 standards are expected to result in a substantial increase in the uptake of zero emission trucks, reaching 36% of zero emission truck sales by 2030. (Table 3). This still leaves quite a large ambition gap with what other studies indicate is required to reach net-zero or real zero emission reductions. Studies show that a jump from a 43% to a 100% BET sales share are required by 2030. These are above what the revised EU HDV CO_2 standards regulation can deliver – leaving an ambition gap of 7% - 64%. All studies show that a 100% BET market by 2050 is needed – this is 23% above what the EU HDV CO_2 standards are expected to deliver. Other studies are more ambitious with accelerated BET uptake scenarios achieving 100% BET market penetration by 2040 (Mission Possible Partnership, 2022) or in the case of (Transport & Environment, 2022a), as early as 2030. The REMIND real zero pathway suggests that real zero emissions by 2050 can be achieved with an 82% BET market share by 2030. This represents an ambition gap of 46%. Meanwhile, alternative fossil fuel vehicles, such as CNG and LNG trucks, continue to outsell BETs, but face the risk of becoming stranded assets as the market shifts. BETs are projected to overtake CNG trucks in new truck sales by 2025, becoming the most popular alternative-fuel option, accounting for 4% of total truck sales – a significant milestone for the sector.

The IEA STEPs current projections for BET sales estimate that by 2030, BETs will only make up 24% of the market. This leave an implementation gap of 12% to be filled to meet the EU's revised HDV CO_2 standards. If considering the 1.5°C compatible real zero pathway from REMIND, that implementation gap grows to 58%.

The ability of European vehicle manufacturers to deliver on the BET demand aligns with the IEA STEPS projections. The actual production capabilities in Europe are far behind what both the EU's CO_2 standards on new truck sales and real zero pathways require. By 2030, only 24% of the trucks produced will be BETs (PWC, 2024). This could mean that zero emission trucks will likely need to be imported from outside Europe to meet the growing demand – a potentially major issue if Europe wants to maintain the position of its vehicle manufacturing sector.

Table 3: Summary of Zero-Emission Truck (ZET) Adoption Scenarios for EU. IEA Stated Policies Scenario, EU revised CO_2 regulations, and ambitious scenarios from various literature from 2030 - 2040.

Scenario	2030	2035	2040	Policy Assumptions	Source
Revised EU HDV CO_2 standards (new truck fleet emission reductions)	-45%	-65%	-90%	2023 revised CO_2 standards with extended scope covering heavy lorries, medium lorries, city buses, coaches, and trailers.	(European Commission, 2024b)

Revised EU HDV CO_2 standards – sales share	36% (ZET)	-	77% (ZET)	The impact of the revised HDV CO_2 standards will have on the sales of zero emission trucks.	(Sen et al., 2025)
REMIND - Real Zero Pathway – sales share	82% (BET)	98% (BET)	100% (BET)	Integrated Assessment Model REMIND modelled sales share of BETs needed to reach real zero emissions of entire truck fleet by 2050.	Climate Analytics, forthcoming
IEA STEPS Projection (Europe) – sales share	24% (BET)	-	-	IEA's Stated Policies Scenario using current BET adoption trajectory.	(IEA, 2025a)
MPP Accelerated	58% (43% BET, 15% HET)	100 %	100% (68% BET, 32% HET)	Diesel ban by 2040 (latest for zero fleet by 2050) combined with escalating carbon cost \$0-250/tCO_2.	(Mission Possible Partnership, 2022)
T&E Central – sales share	59% (ZET)	100% (ZET)	100% (ZET)	Zero-emission sales target of 100% by 2035 (same timeline as passenger cars/vans) with -65% CO_2 target for 2030. Achieves 95% CO_2 reduction by 2050 with 0.9 million diesel vehicles (13% of fleet) remaining.	(Transport & Environment, 2022a)
T&E Accelerated -sales share	100% (ZET)	100% (ZET)	100 % (ZET)	Zero-emission sales target of 100% by 2030 (fastest technically feasible timeline). Achieves 98% CO_2 reduction by 2050 with 0.6 million diesel vehicles (8% of fleet) remaining.	(Transport & Environment, 2022a)
ETC PBS	N/A	N/A	100 % (ZET)	Technically/economically feasible but requires significant strengthening of current commitments and policies; combined with carbon removals delivers 50% chance of limiting warming to 1.5°C.	(ETC, 2023)
PWC – production share	24% (BET)	56% (BET)	91% (BET)	EU CO_2 regulation requiring 90% fleet emission reduction by 2040 regulatory pressure forces action with Europe producing 120-160k BET units by 2030.	(PWC, 2024)

In 2025, the European Commission published a communication on decarbonising corporate fleets, which aims to accelerate the transition of these vehicles, including trucks, to zero-emission powertrains by addressing barriers such as high purchase costs and insufficient charging infrastructure. The communication focuses on developing fast-charging hubs along logistics corridors through the European Clean Corridor initiative, enhancing fiscal policies to make zero-emission trucks more financially attractive, and encouraging member states to adjust tax regimes to support zero-emission vehicles. These measures are designed to stimulate demand for zero-emission trucks, ensure seamless long-distance operations, and contribute to the EU's decarbonisation and industrial competitiveness goals (European Commission, 2025). Further details on how implementation will be achieved have not yet been published, which presents a major opportunity for policymakers to ensure that this package aligns with real zero pathways.

The cost implications of charging infrastructure

European charging infrastructure has seen a significant expansion, with a 16% year-on-year growth and 43% compounded annual growth between 2020 and 2025 (EAFO, 2025). This figure reflects public and private charging infrastructure needs for all forms of vehicles including passenger vehicles (much of this would not be available to trucks). Nevertheless, significantly more BET charging infrastructure is being deployed compared to any other alternative fuel (i.e. CNG, LNG, LPG or hydrogen). Despite this progress, significant gaps still remain in truck specific high-power charging infrastructure.

As of 2024, around 10,000 public and private charging points for medium- and heavy-duty trucks are installed across Europe. It is estimated that, by 2030, Europe will need 200,000 charging points to meet the growing demand of BETs (McKinsey & Company, 2024). By contrast, ICCT's analysis indicates that between 213,000-257,100 chargers will be required by 2030, with private depot infrastructure accounting for the majority – around 68-70% of total chargers – compared to 30-32% that will be publicly accessible. Germany, Poland, France, Spain, and Italy are expected to require more than 70% of Europe's total charging needs. AFIR is expected to cover between 50-70% of public charging needs by 2030 (Basma & Schmidt, 2025).

AFIR's limitations stem from its distance-based deployment methodology rather than traffic-intensity-based requirements. The implied country-specific targets are two to three times lower than projected needs in half of EU member states while fully covering needs in others. Gaps are significant in countries with high freight traffic but small TEN-T network shares, such as the Netherlands and Belgium, while Romania's AFIR target exceeds expected needs by 200% due to its large road network share and relatively low freight activity (Basma & Schmidt, 2025).

Infrastructure deployment costs are one of the major barriers influencing investment decisions. Charging infrastructure costs vary significantly by power level. The combined hardware and installation costs for fast-charging systems today are around EUR 230,000 per unit and are expected to fall by 28% by 2030. Meanwhile, overnight charging systems (for depots), currently cost EUR 67,500 per unit, and are expected to fall in cost by 28% by 2030 (Basma, Saboori, & Rodriguez, 2021).

Depot (overnight) charging is a highly compatible and cost-effective approach for operation cycles across many European countries. About 40-50% of trucks travelling less than 200-300 km/day will be easily covered by overnight charging (Fraunhofer Institute, 2024). Depot charging is increasingly recognised as the backbone of cost-effective truck electrification in Europe.

SMEs typically operate smaller fleets, from a single truck to a few hundred trucks (Transport Intelligence, 2024) and often lack capital to invest in infrastructure, making them especially reliant on public changing infrastructure or public policy support (Fraunhofer Institute, 2024). Landlord restrictions and space limitations further complicate installation, while uncertainty around taxation and levies on stored electricity reduce the attractiveness of advanced solutions like vehicle-to-grid (Fraunhofer Institute, 2024). For long-haul trucks, depot charging alone is insufficient, as very long daily ranges still require public fast or megawatt charging (Shoman et al., 2023; TNO, 2022).

Nonetheless, enablers are strong. A study of 2,410 trucks in Germany showed that more than 95% of overnight charging events could be satisfied at ≤44 kW (Speth & Plötz, 2024). Cost advantages are also clear with industrial tariffs of EUR 0.10-0.15/kWh, undercutting public charging prices of EUR 0.20–0.30/kWh (TNO, 2022). In Fraunhofer's case study, 50 kW depot charging resulted in EUR 0.37/km operating costs, compared to EUR 0.52/km for diesel (Hacker et al., 2025; Shoman et al., 2023; TNO, 2022).

New business models such as shared or semi-public depots are emerging, particularly in logistics parks in Spain (Fraunhofer Institute, 2024). Depots may also evolve into energy hubs, combining solar PV, storage, and V2G, with potential for cost savings and new revenue streams from providing grid services (Speth & Plötz, 2024). Companies that electrify early can capture green logistics contracts from shippers demanding climate-neutral transport (Transport & Environment, 2023b).

The grid challenge

Grid infrastructure transformation requirements are the most critical bottleneck facing the expansion of charging infrastructure (Burges et al., 2022). Connection demands vary significantly based on traffic intensity and deployment scenarios. High-power charging stations along major motorways will need grid connections of up to 33 MW per direction. Commercial logistics hubs face substantial requirements, needing a 10-20 fold increase compared to the current situation (Burges et al., 2025). The scale of grid transformation required exceeds current investment patterns and threatens to become the primary barrier to truck electrification.

Despite AFIR targets not being sufficient to meet public charging needs, if AFIR is fully implemented, the scale of required charging infrastructure will pose a major challenge for local grids, leading to grid congestion across the Trans-European Transport Network (TEN-T) (Basma & Schmidt, 2025).

Without immediate regulatory reform that incorporates accelerated grid planning, current network regulations will create significant barriers to the investments needed for rapid deployment (Burges et al., 2025).

Best cost-competitive pathways for the zero emission truck transition: modelling outputs

The literature review demonstrated the cost-competitiveness of BETs compared with diesel trucks across different vehicle types and mission profiles. This section presents results from quantitative modelling that illustrate how a company's fleet composition and powertrain mix could evolve over time, depending on its chosen strategy. It also shows the resulting emission reductions and TCO outcomes in real-world financial terms, based on a hypothetical fleet comprising 85% long-haul and 15% regional delivery operations.

Modelling outputs illustrate how the fleet will age over time (Figure 2). Assuming that a company fleet's growth and age distribution are the same as the EU total fleet (0.04% annually) the total fleet grows by 13% in 2050 compared to 2020. This translates to 11,272 trucks in 2050 from an initial fleet of 10,000. Again, we assume this company to have a mixed fleet, with 15% regional delivery trucks and 85% long-haul trucks. We assume that truck owners keep their trucks for 10 years before replacing them, 4-5 years before the end of their average lifespan. In southern and eastern EU member states, trucks remain on the road beyond 15 years (Eurostat, 2024). As the majority of trucks manufactured between 2015-2020 largely contain diesel powertrains, this emission-intensive cohort will result in significant emissions until 2035. The next big cohort of new trucks to enter the fleet will come in 2030 and will remain until 2040. This further underlines that a phase-out year of internal combustion truck sales before 2035 is crucial. Logistics companies otherwise risk being trapped further in costly, emissions-intensive stranded assets.

If logistics companies keep their trucks for 10 years, by 2030, about 60% of the fleet would be replaced with new trucks – making it a critical opportunity to invest in BETs. This highlights that purchase decisions made this decade have long term economic and emission implications.

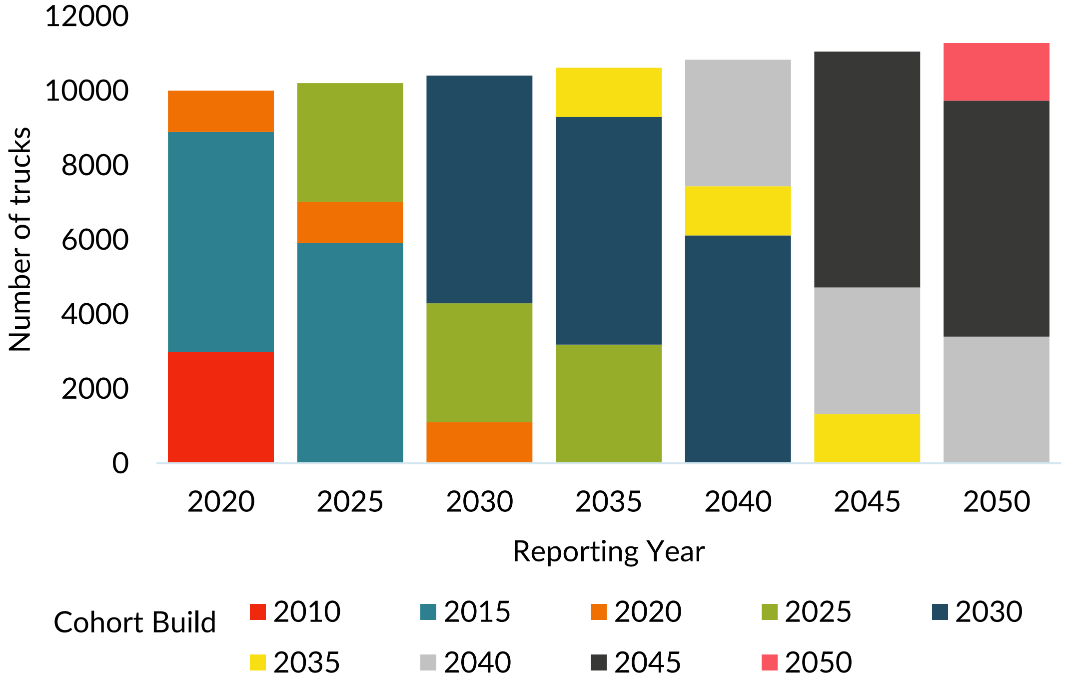


Figure 2: Fleet age-structured composition based on an initial fleet of 10,000 trucks in 2020 covering all truck types, operations, and powertrains. Legend represents the build year for each cohort of trucks.

As the average lifespan of trucks is about 14-15 years, and given that many companies sell their trucks at a heavily discounted rate after five to 10 years of ownership, there is a sizeable second-hand market for these vehicles. If large logistics truck companies act as early adopters of BETs – given they have the financial resources to do cover the upfront costs – then a healthy second-hand BET market can exist for SMEs to acquire affordable BETs.

Based on the age-stock model, Figure 3 illustrates the powertrain breakdown and transition pathways under different company scenarios. Early BET adopters would be expected to reach 100% BET penetration by 2045 without requiring accelerated truck retirements. Our early action scenario aligns with BET uptake rates from the REMIND real zero pathway

(Climate Analytics, forthcoming). Full results on fleet composition are presented in Appendix B – Table B5.

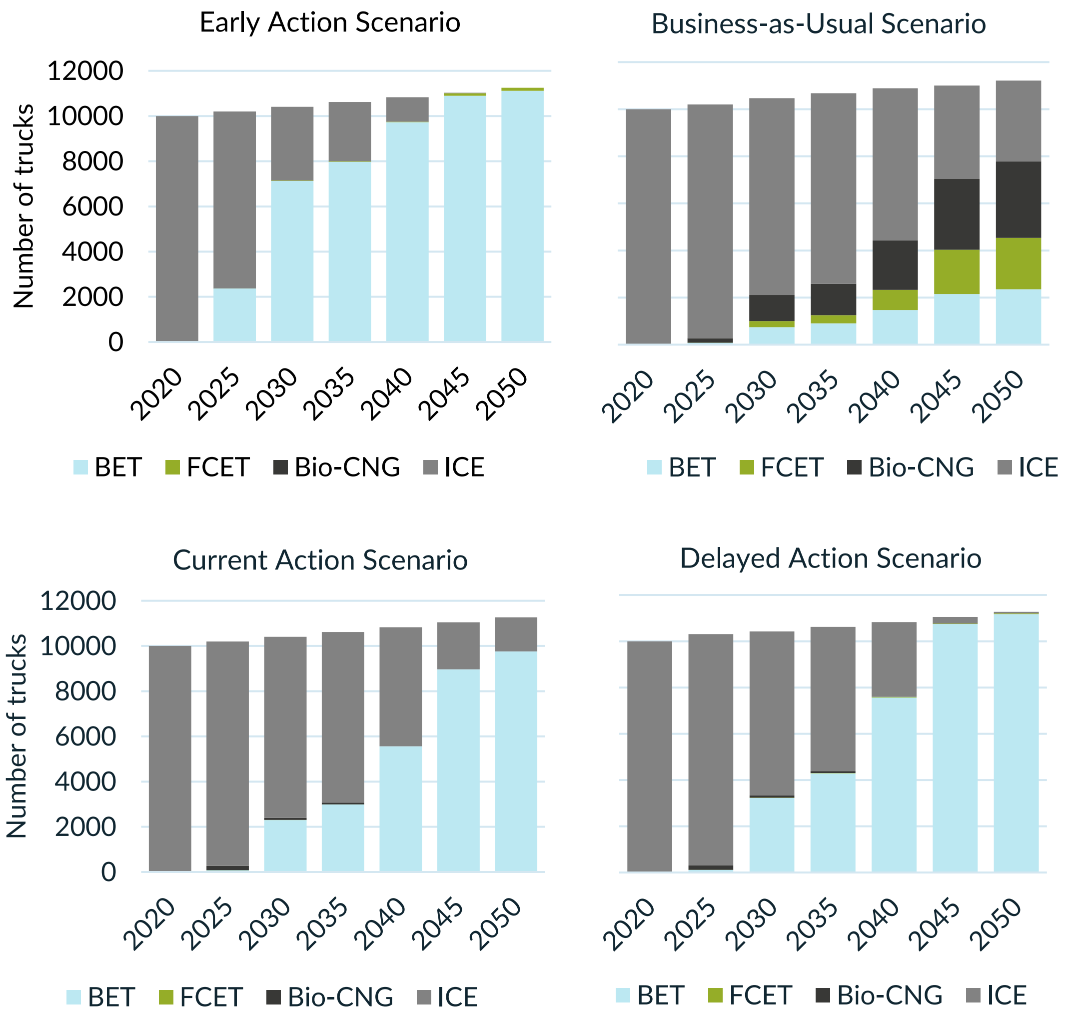


Figure 3: Modelled fleet composition changes by powertrain for different transition scenarios, assuming a constant annual fleet growth rate of 0.04%.

Companies aligning their electrification strategies with the expected uptake rates in the BET market driven by the EU's HDV CO_2 standards represent our Current Action scenario, pursuing decarbonisation at the pace set by existing EU policy frameworks.

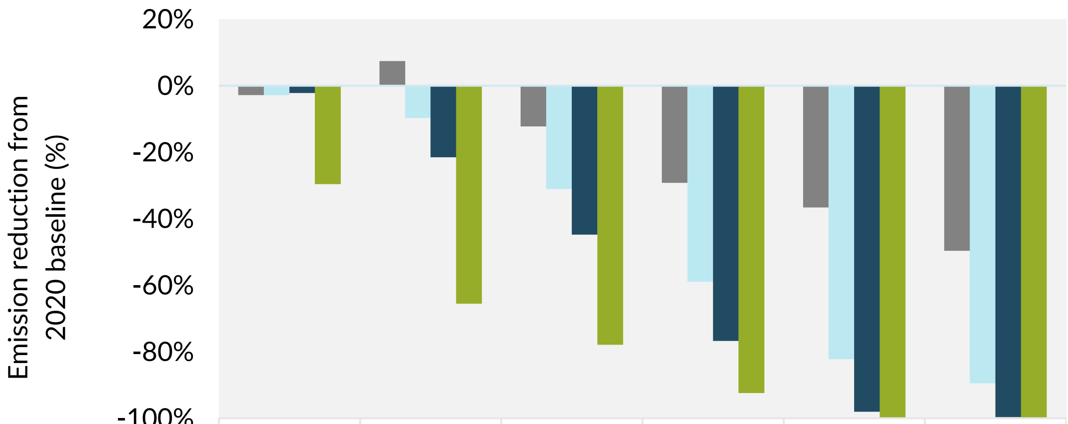
Companies which have not been early adopters of BETs can follow a Delayed Action approach. This scenario reflects firms with currently low BET uptake that began rapidly scaling adoption toward the end of this decade, reaching around 30% BET share by 2030, and nearly 100% by 2045. Under the current ambition level set under the EU HDV CO_2 standards, expected BET sales growth would still lead to an increase in zero-emissions trucks but at a pace too slow to achieve real zero emissions reductions by 2050.

Company fleet level emission reductions

The rapid adoption of BETs, as reflected in the early action scenario, translates to deep emission reductions, reaching a 66% drop by 2030 compared to 2020 levels and a 100% reduction by 2045 (Figure 4). By 2030, a Delayed Action approach would achieve only a 22% emission reduction. Over the next 25 years, this approach would have a slightly higher carbon budget remaining (i.e. emission different between an Early and Delayed Action pathway). These companies will need to close the remaining carbon budget, which can be achieved by rapidly increasing their 2030 BET uptake to reflect that of early adopters (68% BET share in 2030). This demands significantly more action this decade. Alternatively, long-term measures could also include diverting a portion of delivery operations towards rail, which would limit the number of diesel trucks being used. Companies can also choose to keep their BET trucks for longer (i.e. more than 10 years), however this will have downstream negative impacts for smaller companies relying on a more affordable second-hand BET market.

In maintaining a BAU approach towards a split powertrain mix, emissions can be expected to rise by 7% in 2030 relative to 2020, due to the growth in CNG/LNG trucks. Under this scenario, companies limiting their BET uptake result in only a 50% emission reduction by 2050. If all companies choose to implement transition strategies in line with our Current Action scenario, they will not be able to achieve 100% emission reductions by 2050. This therefore jeopardises the EU's own goal to reach net-zero emissions by 2050. A full electrification approach under current EU policy directions brings them close with an 89% emission reduction.

Companies following an early action approach can reach real zero emission by 2045. Following a delayed action approach can reach 100% emission reduction by 2045 but will have a larger carbon budget which will need to be cut.



	2025	2030	2035	2040	2045	2050
BAU	-3%	7%	-12%	-29%	-37%	-50%
Current Action	-3%	-10%	-31%	-59%	-82%	-89%
Delayed Action	-2%	-22%	-45%	-77%	-98%	-100%
Early Action	-30%	-66%	-78%	-92%	-100%	-100%

Figure 4: Emission reductions for different transition scenarios relative to 2020.

Total cost of ownership across different scenarios

Our modelled results illustrate fleet-wide annual TCOs for a logistics road freight company with an initial fleet of 10,000 trucks covering both long-haul and regional delivery operations. From 2030 onwards, the early action real zero approach becomes the cheapest option. Figure 5 illustrates what the added TCO costs of the other scenarios will be relative to the early action scenario.

The added cost gap between earlier adopters and laggard companies transitioning their fleets under a BAU scenario will continue to widen from 16% in 2030 to 23% in 2050. For Current and Delayed Action approaches, companies would see the annual TCO cost gap shrink over time relative to the early action real zero approach as they eventually adopt more BETs, just at a slower rate. This is the case with and without the added costs associated with the ETS II.

By 2030, laggard companies following the BAU scenario with a split powertrain mix, represented by an 11% share of CNG/LNG trucks, and only a 7% share of BETs (Appendix B – Table B5), will end up spending 16% more in costs compared to early action companies with a 68% BET fleet share. Similarly, companies pursuing Current Action or Delayed Action strategies will see total costs that are 9% and 7% higher, respectively, compared to the early action pathway.

Fleet wide annual TCO parity between a Delayed Action approach and an Early Action approach is reached by 2045 because by this point Delayed Action would have caught up to real zero action, with 100% BET fleet and 100% emission reductions. However, cumulatively, the Delayed Action approach would have accrued higher TCO costs between 2025 and 2045 because of the slower BET uptake. By 2050, if companies adopted BETs at the same rate currently prescribed by the market forces under the revised EU HDV CO_2 standards regulation (i.e. Current Action scenario), they would pay 3-6% more annually compared to Delayed and Early (real zero) Action pathways.

In monetary terms, the total cost of ownership of an Early Action company in 2030 with an initial fleet of 10,000 trucks will be EUR 670 million, without the ETS II. For laggard companies, the added total ownership costs could be EUR 719 million if taking a BAU approach, or a EUR 108 million annual cost difference compared to Early Action. Current or Delayed Action result in EUR 62- or EUR 49- million euros annually relative to an Early Action scenario (see Appendix B – Table B6). By 2050, the cost difference between an Early Action and BAU approach increases to EUR 132 million annually (Appendix B – Table B6).

The ETS II, which extends carbon pricing to fuels used in road transport, will increase diesel prices, with the added costs expected to be passed on to consumers. Our modelling shows that the economic impact for logistics companies operating diesel trucks in their fleet could be sizeable. The ETS II price will be determined by how fast economy-wide emissions in the EU are falling. Stronger economy-wide emission reductions will result in lower ETS II prices, while weak implementation of EU mitigation measures will result in higher ETS II prices. Even if the ETS II did not exist, real zero, full electrification pathways will be cheaper over time. The projected ETS II carbon price is expected to increase over time, peaking in 2035 (Günther et al., 2025).

Modelling results find that the ETS II could be expected to increase the annual TCO across all scenarios by 2030. Under a high ETS II carbon price scenario, an Early Action company of 10,000 trucks could face an additional 3% in annual TCO in 2030, due to the remaining diesel trucks in their fleet (Appendix B - Table B7). On the other hand, the same company taking a BAU approach would have their annual TCO increase by 7%. At a low ETS II carbon price, the added costs are expected to be negligible. The added costs of the ETS II are expected to peak in 2035.

Following a BAU approach, companies would pay 11% annually under a high ETS II price compared to a scenario without the ETS II in 2035. At a low 2035 ETS II price, this falls to 3%. On the other hand, the Early Action approach will see companies paying only 1% - 4% in ETS II premiums, depending on the ETS II price.

Relative to an Early Action approach, the BAU, Current and Delayed Action scenarios are expected to pay 3% - 4% more in costs in 2030.[2] In monetary terms, a BAU approach would cost a company an additional EUR 5 to 66 million annually in 2030. In total, BAU companies would be paying 20% more in 2030 and 29% more in 2050, compared to an Early Action approach (Figure 5). A Delayed Action approach would see companies paying a maximum of 10% more in 2030, which falls to 7% by 2040 of additional TCO plus ETS II premiums compared to Early Action companies.

[2] In 2030, even under an Early Action real zero scenario, companies will have some diesel trucks in their fleet, leading to cost increases. However, the figures presented here reflect only the added costs of different scenarios on top of what would be paid under an Early Action scenario.

Following a real zero approach results in the largest TCO reductions over time, even without the ETS II. The ETS II will make owning and operating diesel trucks more uneconomical – driving the case to switch to BETs as early as possible.

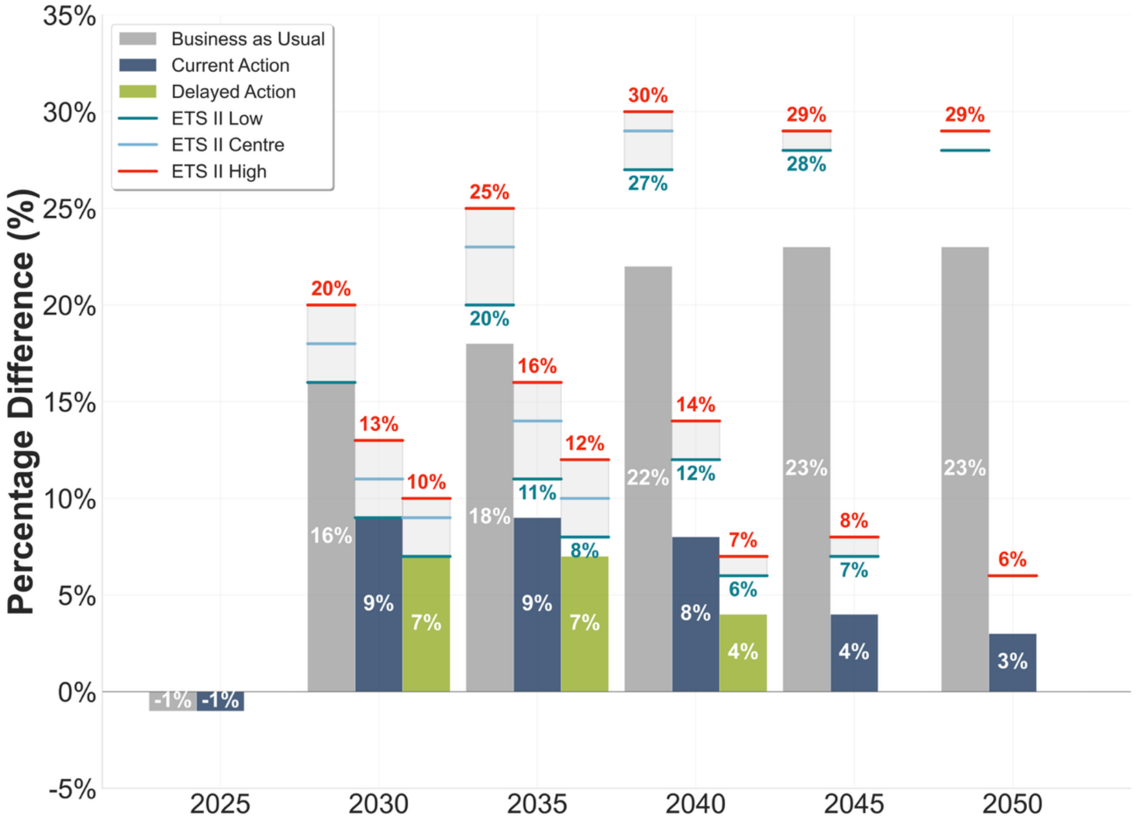


Figure 5: Differences in annual TCO for scenarios relative to the real zero Early Action scenario. Columns represent the TCO difference under a no ETS II scenario and bars represent the added TCO cost when considering the impact of the ETS II at different carbon price projections.

The combination of the underlying TCO with the added ETS II premium could see cost differences between a real zero Early Action and BAU scenario peak and plateau in 2040. In 2040, BAU laggard companies could be paying up to 27% -30% more than Early Action companies. This will more or less stay at 29% through to 2050 and beyond. Meanwhile, following the Current Action approach would still see companies paying at least 6% more annually compared to Early and Delayed Action approaches by 2050.

This analysis highlights the importance of the ETS II as a major financial driver and argument for companies to transition to BETs as early as possible. Even without the ETS II the cost savings of switching to BETs following a real zero pathway would be significant. The ETS II offers the added benefit that the revenues generated from laggard companies can be directed towards supporting the uptake of BETs in smaller companies which might not have the resources to cover upfront costs. This is a key consideration for EU and national policymakers to make when deciding on the use of the ETS II funds.

Conclusion

The transition to real zero emission freight trucking in Europe presents significant economic opportunities from the point of view of the total cost of ownership. The sector would need to reach real zero emission by 2045 to align with 1.5°C compatible pathways. BETs are rapidly becoming the most cost-effective option, particularly for urban and regional logistics. Long-haul BETs across all mission profiles are on the verge of TCO parity with diesel trucks, largely driven by reductions in battery costs and lower electricity prices, while in the case of urban and regional trucks, TCO parity has already been achieved. Charging infrastructure for BETs, while initially requiring investment, is becoming more economically viable as charging technologies improve and public networks expand. The cost of installing fast chargers has decreased, and growing support for infrastructure development is making it more accessible to fleet operators. With the right infrastructure in place, charging for BETs is expected to be significantly cheaper than hydrogen refuelling.

The EU maintains a technology neutral approach, meaning companies can take up any powertrain to decarbonise their fleets, so long as they are less carbon intensive than existing diesel trucks sold. With this approach, vehicle manufacturers can still technically comply if they continue to sell CNG and LNG trucks, which will jeopardise achieving a real zero transition, while at the same time pressuring logistic road freight companies to invest in these false solutions. Furthermore, this technology neutral approach opens the door for biofuels, namely HVOs, to grow substantially, presenting further sustainability and scalability challenges.

The transition to real zero emission freight trucking in Europe is a vital goal, both for meeting climate objectives and enhancing the economic competitiveness of the logistics sector. However, several challenges must be addressed to facilitate this transition.

Key findings

Achieving real zero emission reduction pathways is possible for the road freight logistics sector with the existing starting point. To align with real zero pathways, logistics companies would need to transition their fleet to be 68% BETs by 2030 and 100% by 2045. This results in the lowest total cost of ownership savings (i.e. capital and operating costs) and the highest savings in the long-term compared to any slower BET uptake scenarios, especially ones that include the uptake of CNG and LNG trucks.

For the separate truck groups, long-haul BETs are projected to reach total cost of ownership parity with diesel long-haul trucks by 2026, with TCO for BETs expected to be 15-22% lower than diesel trucks by 2030. By that time, BETs will also be 15% cheaper to own and operate than biofuel-powered CNG trucks, with this gap widening to 32% by 2030. In contrast, hydrogen FCETs are not expected to reach TCO parity with diesel trucks until 2035.

It is still not too late for delayed players, but significantly more effort will be needed to transition within the next five years. Following a Delayed Action approach can still achieve real zero emissions by 2045. However, to close the carbon budget gap left by the added emissions relative to the real zero Early Action pathway, additional measures would be needed, such as diversifying some of their operations to rail, reducing utilization of their existing diesel truck fleet and/or the earlier replacement of their diesel fleet to match to BET uptake rates of a real zero pathway. The latter effectively means acting within this decade to become an early adopter. This translates to switching out their fleet to be 68% BET by 2030. In this case, delayed actors may become early actors.

The ETS II will be a crucial policy driver to encourage logistics companies to transition to BETs faster, from the demonstrate higher TCO costs diesel trucks will bring. By 2035, the ETS II will make TCO costs up to 11% more expensive under a BAU scenario compared to a situation without the ETS II. Comparatively, in 2035, the early action real zero approach would only result in an 1% - 4% cost increase. Comparing the cost TCO cost differences between a BAU and Early Action scenario, in 2040 and beyond, BAU companies will pay 27% - 30% more in TCO with ETS II added premiums.

The ICCT proposes strengthening the HDV CO_2 standards by bringing forward the Commission's deadlines to be 60% by 2030 and 100% by 2040 (Basma & Rodríguez, 2023c). Transport & Environment advocates for the phase-out of ICE truck sales as early as 2030-2035 to match passenger vehicle timelines, while the Energy Transitions Commission identifies 2040 as a technically and economically feasible milestone for 100% adoption with strengthened policies. Transport & Environment also suggests putting forward further interim checkpoints in 2027 to prevent manufacturers from delaying action until final deadlines, while expanding the scope of the regulations to include more HDV categories currently not included in CO_2 standards (Transport & Environment, 2022). Similarly, Mission Possible Partnership and PwC's analyses show feasible production scaling to 58-65% adoption by 2030 through enhanced regulatory pressure and carbon pricing mechanisms. The convergence of these independent assessments around accelerated timelines suggests that current EU targets, while representing meaningful progress, may be insufficiently ambitious relative to both climate requirements and industrial capabilities.

As part of the EU's Green Freight Package, mandating the adoption of BETs for logistics companies is another critical policy measure to accelerate the decarbonisation of the freight sector. Setting mandatory targets for fleet electrification would ensure that companies commit to transitioning away from diesel and fossil fuel-based powertrains, driving significant reductions in CO_2 emissions across the sector.

For policymakers, facilitating the transition will require targeted investments in infrastructure and incentives that support fleet operators throughout the process. Together, these actions will ensure that Europe's freight sector is on track to achieve real zero emissions by 2050, securing both environmental and economic benefits for the industry. Policymakers should address AFIR's 50-70% coverage shortfall by promoting initiatives that focus on HDV-specific charging infrastructure deployment across key transport corridors. This can be achieved by expanding the Clean Transport Corridor Initiative to accelerate charging deployment in TEN-T network corridors and enabling best practice applications across other corridors. These efforts should combine EU countries including their permitting authorities, grid operators, energy regulators and other stakeholders to enable a comprehensive cross-border charging network (Basma & Schmidt, 2025; Mission Possible Partnership, 2022). Furthermore, categorizing HDV charging stations and grid connections as infrastructure in the public interest, and enabling project fast-tracking and streamlining processes across the EU, could reduce charging point burdens (Basma & Schmidt, 2025).

Large operators are particularly well-positioned to enable the rollout because they own depots and operate under long-term contracts. As such, they can reduce risk and extend access to subcontractors through semi-private or shared depot charging (Fraunhofer Institute, 2024; Transport & Environment, 2023b). Policy support is improving, too, with France and Spain offering subsidies for depot infrastructure and grid upgrades (Shoman et al., 2023; Speth & Plötz, 2024). From 2025, DSOs will also be required to publish grid capacity maps, aiding investment decisions (Fraunhofer Institute, 2024).

Recommendations for fleet operators:

- Strive to transition fleets to 68% BET share by 2030. The earlier logistics companies adopt BETs across their operating truck fleets, the lower their overall costs will be. Companies that have been slow to begin electrifying should accelerate their uptake to avoid higher long-term expenses.

- Investing in private depot charging infrastructure can enable fleets to optimize energy costs by leveraging off-peak electricity prices. This will reduce reliance on public charging stations and lower charging costs.

Recommendations for EU policymakers:

- Accelerate charging infrastructure deployment: Expand charging networks along key transport corridors and in logistics hubs to support the widespread adoption of BETs.
- Provide financial incentives for early adoption: Subsidies and financial support for BET purchases and charging infrastructure at depots will be essential to reduce initial costs for fleet operators. This could be earmarked under EU financing requirements for member states, especially in the ongoing negotiations for the MFF 2028-2032 budget.
- Support green hydrogen development: While hydrogen is expected to play a limited role, investing in its infrastructure and reducing the cost of green hydrogen production will ensure that hydrogen remains a viable option for long-haul operations.
- Support the acceleration and diversification of the ZET supply chain through supply-side policies to accelerate product diversification and promote availability of affordable ZETs.
- Bring forward the revised HDV CO_2 standards targets to ensure truck operators will have a supply of BETs in the future as well as signal to vehicle manufacturers the scale of BET production required to allow for long-term planning.
- Adopt mandates for the uptake of BETs at large road freight companies to limit and possibly eliminate the further uptake of fossil gas-powered trucks. This mandate could require companies to progressively increase the share of BETs in their fleets, with clear deadlines for full electrification by a specified year, aligning with broader EU climate goals. To support this transition, the EU would need to implement robust incentives and support mechanisms, such as subsidies for fleet operators, tax rebates for charging infrastructure, and access to financing for SMEs. This policy would not only drive emissions reductions but also ensure that logistics companies are prepared for the forthcoming regulations under the EU ETS II, which will make fossil fuel-based vehicles increasingly expensive to operate. By integrating BET adoption into the Green Freight Package, the EU can create a clear and enforceable pathway towards a decarbonised, economically competitive freight sector.
- Strengthen carbon pricing: EU carbon pricing mechanisms under ETS II should continue to penalise diesel and gas trucks, providing financial incentives for logistics companies to adopt zero-emission technologies.

- Continue efforts to phase-out harmful fossil fuel subsidies that target diesel and fossil gas fuels at the member state level, which would otherwise undermine the efforts of the EU ETS II.

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Appendices

Appendix A: Approach and methodology

Literature review

We reviewed and synthesised existing literature on the TCO, leveraging the extensive data available on operating costs, as well as collected data on the assumptions such as average annual mileage, fleet size, fleet composition by truck type, age and powertrain. Notably, the ICCT has studied this extensively in Europe (Basma & Rodríguez, 2023a). They estimate TCO for different operational mission profiles for 2023, 2030, 2035 and 2040. Their definition of TCO is made up of five cost components that cover:

Vehicle retail price: The most substantial upfront cost difference, with diesel as the baseline pricing and various alternative technologies, commanding higher process that will fall between 2025 and 2050.

Fuel price: The main operational cost variable with large differences across energy carriers. Electricity has a lower cost per energy unit, diesel provides the baseline at current market rates, and green hydrogen commands premium pricing but is expected to decline over time.

Labour costs: Driver wages and benefits as a share of the total cost are expected to remain unchanged across technologies and operational patterns (i.e., regional, long haul etc), along with consistent driver requirements.

Insurance: Basic vehicle insurance, cargo, and general liability costs show little to no variation across powertrains with emerging technologies sometimes facing slight premiums that are diminishing as markets mature.

Maintenance: These requirements vary by technology. BET derive trains benefit from fewer moving parts and reduced wear components reducing maintaining costs. Diesel combustion engines require regular and costlier maintenance patterns, while hydrogel fuel cell systems can have uncertain maintenance profiles due to stack placement requirements.

Road tolls and charges: This refers to the aggregated cost of national toll and carbon prices, through the implementation of the Eurovignette regulation.

Regulatory compliance costs: Additional policy cost impact from the EU ETS II are not included in the ICCT TCO values.

In addition to the Basma & Rodríguez (2023a) study, the REMIND real zero pathway for the trucking sector also provides TCO for the capital expenditure, operating fuel and non-fuel costs[3] (Climate Analytics, forthcoming). We compare the TCO trends quantified by Basma & Rodríguez (2023a) with the REMIND values to explore the alignment in cost-competitiveness predictions for different powertrains.

Quantitative modelling: Building the age-stock model component

We developed a hybrid top-down and bottom-up approach as illustrated in Figure A1. A bottom-up age-stock turnover model simulates a company's fleet configuration and how it will change over time, with aging trucks being phased out and new trucks of different powertrains being phased in. This is coupled with an economic component using TCO factors to quantify the annual TCO in EUR, which are summed over the 25-year period to get the total costs. Simulations are run for each scenario, and the results are then compared as the cost difference of each scenario relative to the Early Action real zero scenario.

IAMs are global and regional perspective models that combine the full energy system, including both supply-side (e.g. electricity generation) and demand-side sectors, to analyse and project the feasibility of high-ambition climate pathways, assessing sectoral interlinkages and the pace of energy transitions towards achieving global climate goals, such as real-zero emissions. We extract the truck sector emissions pathways from the REMIND model to define the emissions reduction pathway for our Early Action scenario by using the projected powertrain fleet shares.

[3] The REMIND model does not specify in literature what non-fuel operating costs entail.

The top-down component is reflected in the phase-in of new truck powertrains, defined by the annual share of different powertrains in the truck fleet between 2025 and 2050 from the REMIND model (Climate Analytics, forthcoming).

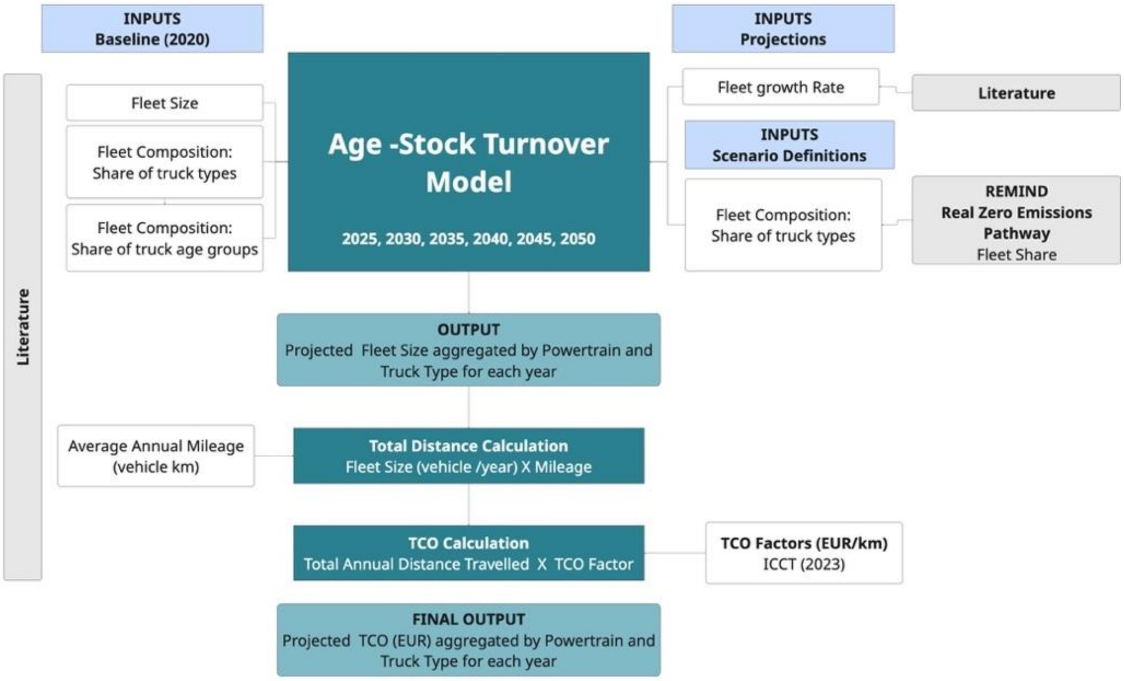

Figure A 1: Diagram of modelling approach

Setting up the truck fleet assumptions

Our model uses vehicle age shares split into three age groups of zero (i.e. new), five and 10 years based on the best available data that provide the fleet age share breakdown by tkm (Eurostat, 2024). As the reported age ranges do not perfectly align with our defined categories, we apply the closest available groupings to match our model structure. The assumed average age of a truck is 14 years, while the assumed average age for new truck ownership is five to 10 years, after which it is expected that a company sells it (European Commission, 2023). With 2020 as our base year, we infer the build year groups for trucks to be 2010, 2015 and 2020.

For all scenarios, we assume the future annual fleet will grow between 2020 and 2050 at a constant annual growth rate of 0.04% based on the past 10-year average of the European truck fleet (Eurostat, 2024). We also assume that our case example reflects a typical company that operates a mixed mission operation portfolio (i.e. they operate several different types of trucks). As no company-level fleet composition data are available, we assume the total European fleet composition (Table A2) is also reflected in our hypothetical company. For the purpose of this report, we only assess the TCO for the regional and long-haul segments. In the case of the long-haul segments, we further split each VECTO sub-group into three different operation profiles (return depot 500 km journey, return depot 800 km journey, and cross border >800km journey) as defined by Basma & Rodríguez, 2023c.

Table A 1: Truck type composition of fleet in 2020 (Mulholland et al., 2023). We analyse only the long-haul component of the fleet in the report.

Truck Type	Share of truck type
4-RD	6%
4-LH	2%
5-RD	1%
5-LH	70%
9-RD	8%
9-LH	10%
10-RD	0%
10-LH	3%

As European logistics freight company fleets vary in size, our initial modelling analysis is based on our hypothetical company having a fleet of 10,000 trucks. This puts it within the top 30% of companies (Transport Intelligence, 2024). With our assumed 0.04% annual fleet growth rate, the fleet will grow to 11,268 trucks by 2050.

The age-structured turnover model tracks vehicle age for each fleet type by year. It begins by estimating the 2020 fleet size, using truck type (Mulholland et al., 2023) and age group shares (Eurostat, 2024), which forms the baseline for subsequent projections. For each projection year (2025, 2030, 2035, 2040, 2045, 2050), the fleet is adjusted by a 0.04% annual growth rate (Eurostat, 2024) , with fleet composition (age and type) held constant.

The model simulates the aging process, phasing out older trucks and introducing new vehicles. The number of new trucks entering the fleet is determined by subtracting trucks younger than 10 years from the total projected fleet. Each projection year reflects both aging and new vehicle inflow while maintaining the same truck type and age group distribution.

The model's two-dimensional matrix shows the evolution of truck cohorts, with vehicles progressing from zero age at their build year to retirement after 20-25 years. Retirements occur at a 10-year removal rate, without considering accelerated scrappage.

Table A 2: Vehicle age-stock turnover model structure

Build Year	2020	2025	2030	2035	2040	2045	2050
2010	10 years old						
2015	5 years old	10 years old					
2020	0 years old (new)	5 years old	10 years old				
2025		0 years old (new)	5 years old	10 years old			
2030			0 years old (new)	5 years old	10 years old		
2035				0 years old (new)	5 years old	10 years old	
2040					0 years old (new)	5 years old	10 years old
2045						0 years old (new)	5 years old
2050							0 years old (new)

Historical uptake rates of BET, FCET, CNG/LNG, and diesel ICE trucks for 2020 and 2025 are derived from the sales share from the IEA EV Database (IEA, 2025b) and the European Alternative Fuel Observatory (European Commission, 2024a). The underlying powertrain assumptions for the sales shares (i.e. uptake of new truck) are presented in Table A3. The connection with real zero emission reduction pathways, as outlined by Climate Analytics, forthcoming, is reflected in the sales share (i.e. uptake rate) assumptions for the different powertrains. As such, only the Early Action scenario is reflective of a real zero transition because we take the exact powertrain fleet share projections from the real zero REMIND model pathways. We also harmonise 2025 powertrain fleet shares based on historical data. The IEA (2025) shows that BETs make up only 0.9% of the total fleet stock in 2024. Similarly, the Delayed Action scenario lags by 15 years and will only achieve a 77% BET stock share in 2050. The BAU and Current Action scenarios are not real zero. If action is taken to offset their emissions or fuel their remaining ICE fleet with biofuels, this could make them net-zero but will come at a higher cost.

Quantitative modelling: Quantifying fleet TCO and ETS II impact

We use the TCO factors (EUR/km) from the ICCT (Basma & Rodríguez, 2023a). We extract the breakdown of TCO component (retail price, fuel, maintenance, insurance, labour and tolls and charges) costs from the graphics. We therefore maintain any and all of the underlying assumptions made by the ICCT studies (Basma, Saboori, & Rodríguez, 2021; Basma & Rodríguez, 2023a, 2023c) – including any assumptions on infrastructure costs.

The TCO calculations are done by extracting the number of trucks for different categories and powertrains for each reporting year and multiplying by the average annual mileage for the respective truck category for each year. The average annual mileage is assumed to decrease over the lifetime of a truck, so we match a depreciated average annual mileage according to the age category of the fleet.

This provides the total vehicle km (vkm) for each powertrain and truck group. Finally, we apply the ICCT TCO projections (EUR/vkm) (Basma & Rodríguez, 2023a) to the corresponding powertrain fleet vkm to quantify the annualised and total TCOs.

We assess the impact of the EU ETS II on the fuel TCO for diesel ICE trucks by first extracting the fuel TCO component from the ICCT (Basma & Rodríguez, 2023a). Transport & Environment (2025a) outlines that every 10 EUR increase in carbon price (EUR/t CO_2) results in a 2.7 cent per litre increase in the diesel price, excluding VAT. We apply this ratio to different ETS II price projections (Günther et al., 2025). These include a high, limited, and low ETS prices of 261, 160, and 71 EUR/tCO_2 in 2030, which increase over time (see Table B2 in the Appendix B). Using the fuel economy conversion factor from the ICCT (Basma & Rodríguez, 2023a, 2023c), the total amount of diesel consumed is derived from our total annual vkm calculation. We use this to derive what the added EUR/km TCO for the fuel costs and insert it back into the total TCO (i.e. along with retail, maintenance, labour costs, etc).

Table A 3: Assumptions of the new trucks entering the fleet for a given year as an input into the stock turn over model. New trucks shares by powertrain are taken to be the sales share from combined sources.

Scenario	Powertrain	2020	2025	2030	2035	2040	2045	2050
Early Action - Full Electrification	BET	0.1%	52%	82%	98%	100%	98%	98%
	FCET	0.0%	0%	0%	0%	0%	2%	2%
	Bio-CNG	0.2%	0%	0%	0%	0%	0%	0%
	ICE	99.7%	48%	17%	2%	0%	0%	0%
Business-as-Usual (BAU) - Split Powertrain Mix	BET	0.1%	1.4%	11%	14%	18%	21.3%	25.1%
	FCET	0%	0%	4.0%	8.0%	15%	20%	26.3%
	Bio-CNG	0.2%	2.5%	16%	21%	25%	29.7%	33.9%
	ICE	99.7%	96.1%	70.0%	57.0%	42.0%	28.3%	13.8%
Current Action - Full Electrification	BET	0.1%	1.4%	36%	57%	77%	89%	100%
	FCET	0%	0%	0%	0%	0%	0%	0%
	Bio-CNG	0.2%	2.5%	0%	0%	0%	0%	0%
	ICE	99.7%	96.1%	64%	44%	23%	12%	0%
Delayed Action - Full Electrification	BET	0.1%	1.4%	52%	82%	98%	100%	98%
	FCET	0%	0%	0%	0%	0%	0%	2%
	Bio-CNG	0.2%	2.5%	0%	0%	0%	0%	0%
	ICE	99.7%	96.1%	48%	17%	2%	0%	0%
Early Action - Full Electrification	Assumes the sales share by powertrain taken from the REMIND EDGE-T model (Climate Analytics, forthcoming).							

Business-as-Usual (BAU) - Split Powertrain Mix	Values for 2020 and 2025 are derived from IEA (2025) and reflect current sales shares of the market. The sales share for the years after 2030 are derived from the European Commission's baseline scenario from its impact assessment of the revised HDV CO_2 standards regulation.
Current Action – Full Electrification	Values for 2020 and 2025 are derived from IEA (2025) and reflect current sales shares of the market. The sales share for 2030 and beyond are derived from Sen et al. (2025).
Delayed Action – Full Electrification	Values for 2020 and 2025 are derived from IEA (2025) and reflect current sales shares of the market. The sales share for 2030 and beyond apply the same sales shares from the REMIND EDGE-T model but lagged by five years compared to the Early Action scenario.

Appendix B: Supporting Material

Table B 1: Summary of regulated VECTO truck groups details with the share of CO_2 emission each group contributed to in 2019/2020 and their carbon intensity (ACEA, 2020; Transport & Environment, 2021).

VECTO Group	Gross Vehicle Weight (t)	Axle Configuration	CO_2 Share of sales (2019)	Average CO_2 (gCO_2/tkm)
4-RD	> 16	4×2, 6×2	5%	197
4-LH			2%	106
5-RD			0.6%	84
5-LH			68%	57
9-RD			4%	111
9-LH			10%	65
10-RD			0.1%	83
10-LH			10%	58

Table B 2: Projected ETS II prices under different conditions (low, limited, high between 2030 and 2050 (Günther et al., 2025).

Projection Scenario	2030	2035	2040	2045	2050
ETS II Low price (EUR/tCO_2)	71	147	278	403	460
ETS II Centre price (EUR/tCO_2)	160	260	384	441	474
ETS II High price (EUR/tCO_2)	261	390	430	462	476

Table B 3: ICCT European Charging Infrastructure Requirements by 2030 - Market Scenario Comparison (Basma & Schmidt, 2025).

Scenario	Type	22 kW	50 kW	100 kW	150 kW	350 kW	750 kW	Total
Low BET Scenario – 45% EU target compatible	Private	27,165	43,717	76,242	439	2,143	0	149,706
	Public	0	8,439	41,053	1,756	8,572	4,061	63,882
	Subtotal	27,165	52,156	117,295	2,195	10,715	4,061	213,588
High BET Scenario	Private	21,843	47,906	103,090	353	2,659	0	175,852
	Public	0	8,362	55,510	1,413	10,635	5,335	81,255
	Subtotal	21,843	56,269	158,600	1,766	13,294	5,335	257,107

Table B 4: Summary table of the largest road freight logistic company fleets and their current and planned uptake of alternative fuel trucks (adapted from (Transport Intelligence, 2024).

Company	Fleet Size (Europe)	Electric Trucks (BET)	HVO/Biofuels	LNG/CNG/Biomethane	Other Technologies
DB Schenker	2,500 (owned) 22,000 loading units	53 Renault E-Tech D (from 2024) 100 Mercedes-Benz eActros (from 2024) Transition to zero-emission urban fleets by 2030	30% of France fleet on HVO (2023) ~180,000 tCO_2 savings by 2025		eTrailers pilot (2024)
DHL Group	13,648	~2,000 EV trucks across 17 countries 100% HVO in UK fleet by end-2024 >1000 HDVs in 2025	>30% of fleet on HVO (by 2026) –33 $MtCO_2$ by 2030	LNG insetting (growing usage), including CNG and LPG	
DSV Road	23,000 (mostly subcontracted)				
Kuehne & Nagel	8,000	23 Renault E-Tech D trucks (2023) 100 EVs in France (groupage) 60% fleet low/zero-emission by 2030			
FedEx	6,500	3,552 EVs globally, targeting 100% electric PUD fleet by 2040	48% of fleet on HVO (FY2022)	Has a sizable LNG/CNG fleet which is growing (233 trucks). Their LPG fleet has grown rapidly between 201 and 2022 (2192 trucks)	LNG-powered yard tractors (ongoing trials) Also has a sizable Hybrid fleet (244 trucks) FCETs are a minor component of fleet (2 trucks)

GEODIS	3,960	23,000 EVs (increase by 2022) Urban-focused projects with 16-t BE trucks (Renault, 2023)	420 biogas trucks in 40 cities (2023)		
XPO Logistics	8,000	105 Renault E-Tech T (order placed 2024)	HVO insetting program (scalable)		
Nagel Group	7,000	Scania 18-t e-truck (2023 trial) Electric refrigerated trucks		LNG and Biogas trials (under exploration)	
Raben Group	9,997	14 Volvo FH electrics (DE–NL) Zero-emission route trials (2023)	13 HVO-100 trucks trialled (2023)		
Girteka	19,000	600 Scania BETs (order placed for delivery by 2027)			
Hellmann Worldwide	5,000	EV truck trials (expanded 2022–2023)			
H Essers	1,420	Exploring potential BEVs	Uses HVO insetting	Uses LNG	Exploring potential of hydrogen trucks
NTG	1,000		330,000L of HVO in 2023		Offsetting via SBTi

Table B 5: Modelled results of company level stock share by powertrain for the different scenarios.

Scenario	Powertrain	2020	2025	2030	2035	2040	2045	2050
Early Action - Full Electrification	BET	0%	23%	68%	75%	90%	99%	99%
	FCET	0%	0%	0%	0%	0%	1%	1%
	Bio-CNG	0%	0%	0%	0%	0%	0%	0%
	ICE	100%	77%	31%	25%	10%	0%	0%
Business-as-Usual (BAU) - Split Powertrain Mix	BET	0%	1%	7%	8%	13%	20%	21%
	FCET	0%	0%	3%	3%	8%	17%	19%
	Bio-CNG	0%	2%	11%	13%	19%	27%	29%
	ICE	100%	97%	80%	76%	59%	36%	31%
Current Action - Full Electrification	BET	0%	1%	22%	28%	51%	81%	87%
	FCET	0%	0%	0%	0%	0%	0%	0%
	Bio-CNG	0%	2%	1%	1%	0%	0%	0%
	ICE	100%	97%	77%	71%	49%	19%	13%
Delayed Action - Full Electrification	BET	0%	1%	31%	40%	70%	97%	99%
	FCET	0%	0%	0%	0%	0%	0%	0%
	Bio-CNG	0%	2%	1%	1%	0%	0%	0%
	ICE	100%	97%	68%	59%	30%	3%	1%

Table B 6: Modelled company level TCO calculations (million EUR/year) for the different modelled scenarios based on an initial fleet of 10,000 trucks.

	2030			2040			2050		
Scenario	TCO	Diff.	% Diff.	TCO	Diff.	% Diff.	TCO	Diff.	% Diff.
Early Action	670			534			567		
BAU	778	108	16%	653	119	22%	699	132	23%
Current Action	732	62	9%	575	42	8%	582	15	3%
Delayed Action	719	49	7%	553	19	4%	568	1	0%

Table B 7: Modelled increase in TCO cost on relative to the TCO without ETS II for the different modelled scenarios based on an initial fleet of 10,000 trucks.

	ETS II Price Scenario	Early Action	BAU	Current Action	Delayed Action
2030	Low price	0%	0%	0%	0%
	Centre price	1%	3%	3%	3%
	High price	3%	7%	7%	6%
2035	Low price	1%	3%	3%	2%
	Centre price	2%	7%	7%	5%
	High price	4%	11%	11%	9%
2040	Low price	1%	6%	5%	3%
	Centre price	1%	8%	7%	4%
	High price	2%	10%	8%	5%
2050	Low price	0%	5%	3%	0%
	Centre price	0%	6%	3%	0%
	High price	0%	6%	3%	0%

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