E-fuels in trucks: expensive, scarce, and less green than batteries

Why there should be no role for fuels in the truck CO_2 rules

November 2022

Summary

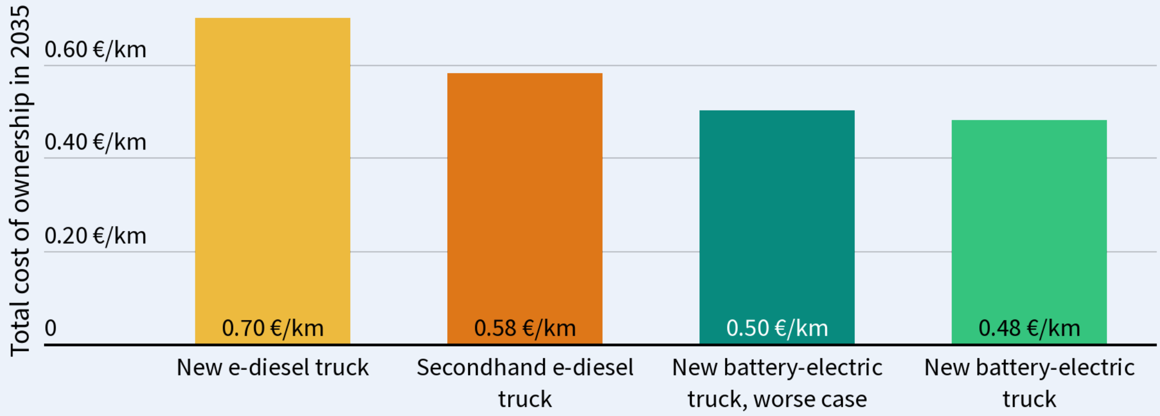
The European Commission will review the truck CO_2 standards in December 2022, key to fully decarbonise road freight. Ahead of the proposal, the oil industry and automotive suppliers are once again advocating to throw internal combustion engines a lifeline by including CO_2 credits for bio- and synthetic fuels in the regulation. T&E analysed how trucks running on synthetic fuels (e-fuels) compare to battery-electric trucks (BETs) in 2035 on both total cost and lifetime emissions, and found that e-fuels make no economic or environmental sense in trucks.

Running a truck on e-diesel would always cost more

Buying and refuelling a new diesel truck in 2035 with pure e-diesel would cost 47% more than an equivalent BET. Even in the most favourable case for e-diesel (i.e. in secondhand trucks and with higher battery and electricity prices for BETs), e-diesel would not be cost-competitive. This is because the higher upfront purchase costs of BETs are quickly offset by their lower energy and maintenance costs. The cost of e-diesel is expected to be 52% more than fossil diesel in 2035.

Refuelling with e-diesel costs more than going electric

Even in secondhand trucks

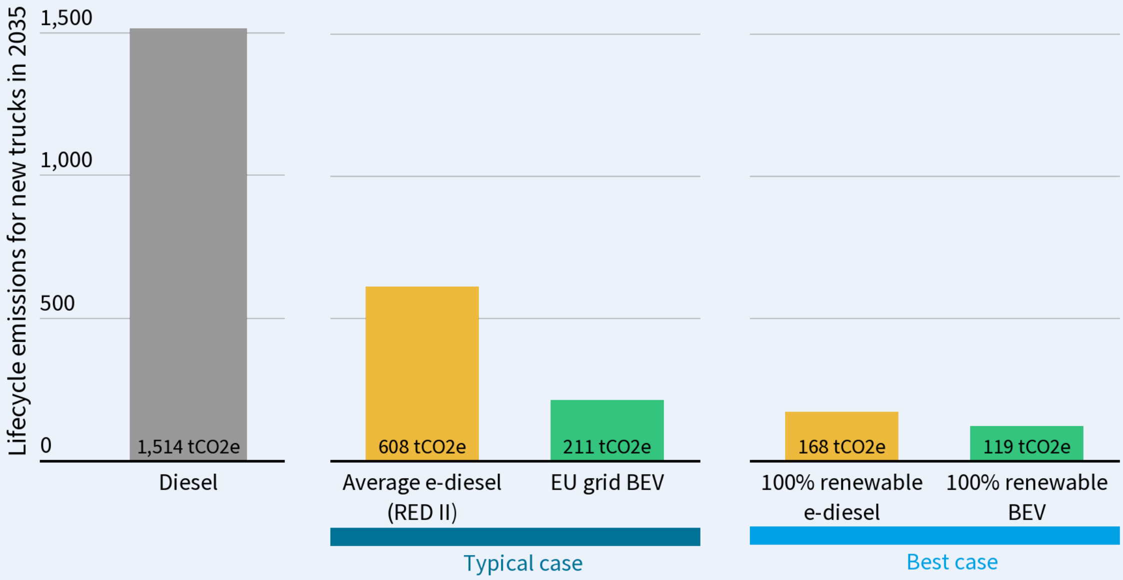


Note: The worse case for battery-electric trucks includes higher prices for battery packs and fast-charging.

E-diesel would save less GHGs than switching to electric

BETs bought in 2035 charged with EU grid electricity save 86% GHGs over their lifecycle relative to conventional diesel trucks. In contrast, a diesel truck fuelled with e-diesel compliant with the Renewable Energy Directive (RED II) would save 60% greenhouse gas (GHG) emissions over its lifetime compared to fossil diesel, but would emit almost three times as much as an equivalent BET over its lifetime. If 100% renewable electricity is used for e-diesel production and BET charging, the e-diesel truck would still emit 41% more GHGs over its lifetime than the BET.

e-diesel emits more greenhouse gases than direct electrification



Note: In the best case, e-diesel is produced from renewables averaging a GHG intensity of 19 gCO_2e/kWh, while battery-electric trucks are charged with roof-mounted solar PV with a GHG intensity of 37 gCO_2e/kWh, or almost twice as high.

Scarce e-fuels would be wasted in trucks

Green hydrogen will likely remain scarce in the medium term. Diverting e-fuels to trucks could jeopardise the transition of hard-to-abate sectors, such as aviation and shipping. Based on oil industry modelling, e-fuels could fuel up to 6% of EU trucks in 2035. But if all EU production were allocated to ships and planes instead, e-fuels could meet almost 6% of energy demand from shipping and 13% from aviation in 2035. This would put both sectors on track for net-zero by 2050.

Why fuels should not have a role in regulating new truck sales

Using e-fuels for trucks is inefficient and unnecessary as cheaper and cleaner zero-emission alternatives exist. Including a fuel crediting system in the truck CO_2 standards could delay the transition to zero-emission, by fostering market and investment uncertainty.

It would also undermine regulatory credibility and enforceability. Truckmakers do not directly control how their vehicles are fuelled and cannot guarantee trucks registered as zero-emission using fuel credits will effectively run on e-fuels. The administrative burden for EU and national authorities would increase to track credit trading and sustainability criteria, avoid double-counting of e-fuels under RED and the CO_2 standards, and monitor overall compliance.

⇒ T&E urges the Commision not to propose a fuel crediting mechanism in its revision of the truck CO_2 standards.

1. Introduction

Trucks emit a quarter of CO_2 emissions from road transport in the EU, despite making up only 2% of vehicles on the road[1]. Heavy-duty vehicles also cause 65% of NO_x emissions and 17% of $PM_{2.5}$ emissions from all road transport[2]. Driven by increasing activity, emissions from trucks are set to keep increasing under current policies, reaching 26% above their 1990 level in 2050[3]. A rapid transition to zero-emission technologies is necessary to put trucks on a trajectory compatible with the ambition of the European Green Deal and climate neutrality by mid-century.

Zero-emission trucks already exist, with battery-electric trucks (BETs) being the most mature of these options. By 2025, freight BETs will likely beat their diesel counterparts on cost and capabilities in almost 80% of cases[4]. Other zero-emission technologies are also being developed, e.g. fuel cell electric trucks.

Afraid to lose market share to a whole new e-mobility value chain, the fuels industry and automotive suppliers are however promoting a way to keep internal combustion engines (ICE) alive by replacing fossil fuels with synthetic electrofuels, or e-fuels. E-fuels are fossil fuel substitutes created using hydrogen and CO_2. Though they are not zero-emission, e-fuels could be considered climate-neutral if the hydrogen used is green (i.e. produced using fully renewable electricity), the CO_2 used is captured directly from the air, and transport and distribution are fully decarbonised.

For sectors where direct electrification or the direct use of hydrogen are not credible or scalable climate solutions, including aviation and maritime shipping, climate-neutral e-fuels like e-kerosene and e-ammonia are the best way to decarbonise. Road transport is clearly not one of those sectors.

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[1] T&E. (2022). EUTRM.
[2] ICCT. (2022). Remote sensing of heavy-duty vehicle emissions in Europe https://theicct.org/wp-content/uploads/2022/08/remote-sensing-hdvs-europe-aug22.pdf
[3] T&E. (2022). EUTRM.
[4] T&E. (2022). Electric trucks take charge. https://www.transportenvironment.org/discover/electric-trucks-take-charge/

This briefing considers the economic and environmental costs of operating a long-haul truck running on e-fuels bought in 2035, compared to an equivalent battery-electric truck. Vehicle characteristics are detailed in Annex 1. Annex 4 also includes results for trucks purchased in 2030 and 2040. Whenever available, data on e-fuels produced in and imported from the Middle East and North Africa is used.

What about biofuels?

In addition to e-fuels, some tout biofuels as a climate solution for road transport. The damage to food security, biodiversity, and climate associated with food- and feed-based biofuels is already well documented[5,6]. Advanced or waste-based biofuels are supposed to be more sustainable and lower-carbon than their predecessors but many concerns remain as to their availability and origin.

FuelsEurope, a key oil lobby, claims that there are enough advanced biofuels to decarbonise road transport[7], citing a study by Imperial College London (ICL) Consultants commissioned by Concawe[8], the fuel industry's research group. However, the ICL Consultants study includes unsustainable practices — such as cutting down trees or harvesting tree stumps — and biomass with existing use — such as agricultural and secondary forest residues, or used cooking oil — which can lead to high indirect emissions.

When only truly sustainable biomass is included and competition with other industries is taken into account, only very limited quantities of advanced biofuels can be produced in the EU or anywhere. Therefore, their use should be reserved to sectors where electricity or hydrogen are not direct solutions.

2. Trucks running on e-fuels would cost more

Trucks are bought and operated by commercial users, who make vehicle purchase decisions based on total cost of ownership (TCO) including vehicle purchase, energy, and maintenance costs. Between a battery-electric truck and a truck running on 100% e-diesel with equivalent operational capabilities, a fleet manager buying a new truck will presumably choose the cheaper option.

The data and methodology used to estimate the TCO of (e-)diesel trucks and BETs in 2035 are detailed in Annex 2. E-diesel price assumes e-fuels are produced from solar PV in North Africa[9].

[5] T&E. (2022). Biofuels. https://www.transportenvironment.org/challenges/energy/biofuels/
[6] T&E. (2022). Food not fuel: Why biofuels are a risk to food security. https://www.transportenvironment.org/discover/food-not-fuel-why-biofuels-are-a-risk-to-food-security/
[7] FuelsEurope. (2022). Sustainable biomass availability in the EU, to 2050. https://www.fuelseurope.eu/publications/publications/sustainable-biomass-availability-in-the-eu-to-2050
[8] ICL Consultants. (2021). Sustainable biomass availability in the EU, to 2050. https://www.concawe.eu/wp-content/uploads/Sustainable-Biomass-Availability-in-the-EU-Part-I-and-II-final-version.pdf
[9] Agora Energiewende et al. (2018). PtG/PtL calculator. https://www.agora-energiewende.de/en/publications/ptg-ptl-calculator/.

The analysis shows that running a new diesel truck on pure e-diesel would always be significantly more expensive than running a comparable battery-electric truck (Figure 1). On average, a litre of pure e-diesel is projected to cost 52% more than a litre of fossil diesel in 2035. As a result, refuelling a truck bought in 2035 with e-diesel would increase its TCO by 22% (Figure 1). In contrast, opting for a new BET in 2035 instead of a diesel truck reduces the TCO by 17%. Overall, a new truck bought in 2035 running on pure e-diesel would cost 47% more to own and operate than an equivalent BET.

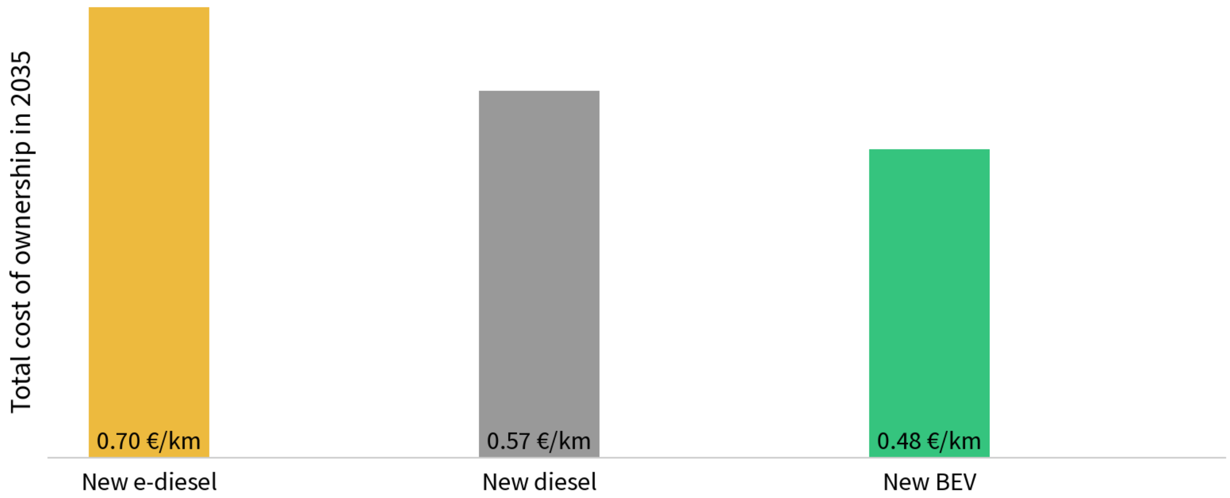

Figure 1. TCO for new long-haul trucks bought in 2035

Even when considering higher prices for battery packs and fast-charging, BETs would remain 13% cheaper to own than a diesel truck, and 29% cheaper than a truck running on e-diesel (Figure 2). Even when an existing secondhand truck is fuelled with e-diesel, the e-diesel truck remains the most expensive option. A 5-year-old truck running on 100% e-diesel in 2035–2039 still costs 20% more than buying and operating a typical new BET, and 15% more than a worse-case new BET.

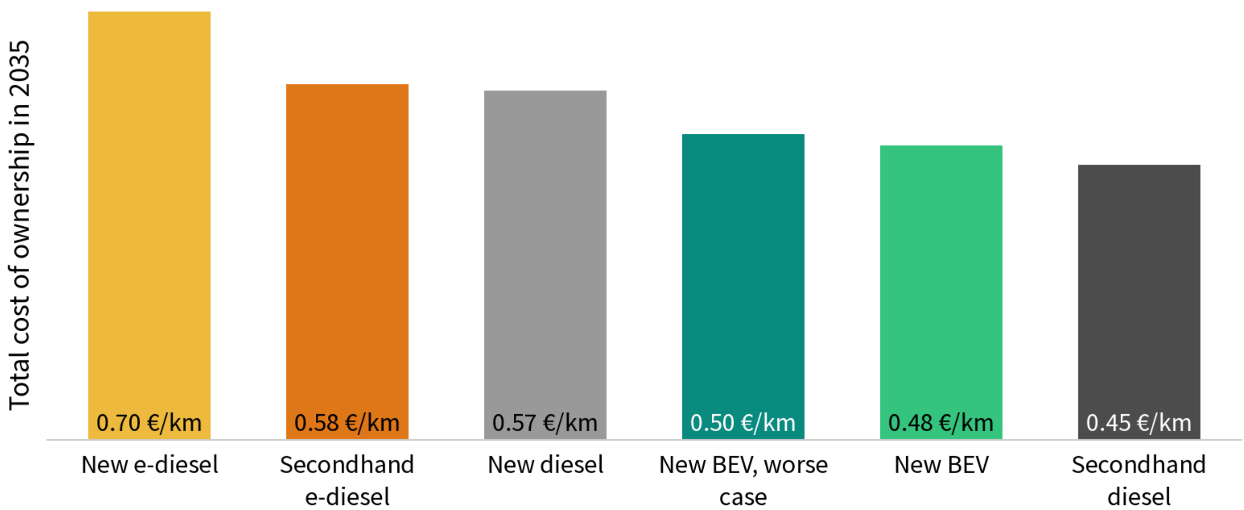

Figure 2. TCO for long-haul trucks bought in 2035

As Figure 3 makes clear, BETs have lower maintenance and energy costs than ICE trucks. These lower operating costs quickly offset their higher purchasing costs. On the contrary, e-fuels promise to decarbonise new and existing trucks without having to buy more expensive vehicles. But the much higher fuel and maintenance costs mean that e-fuels are not a cost-competitive technology for trucks.

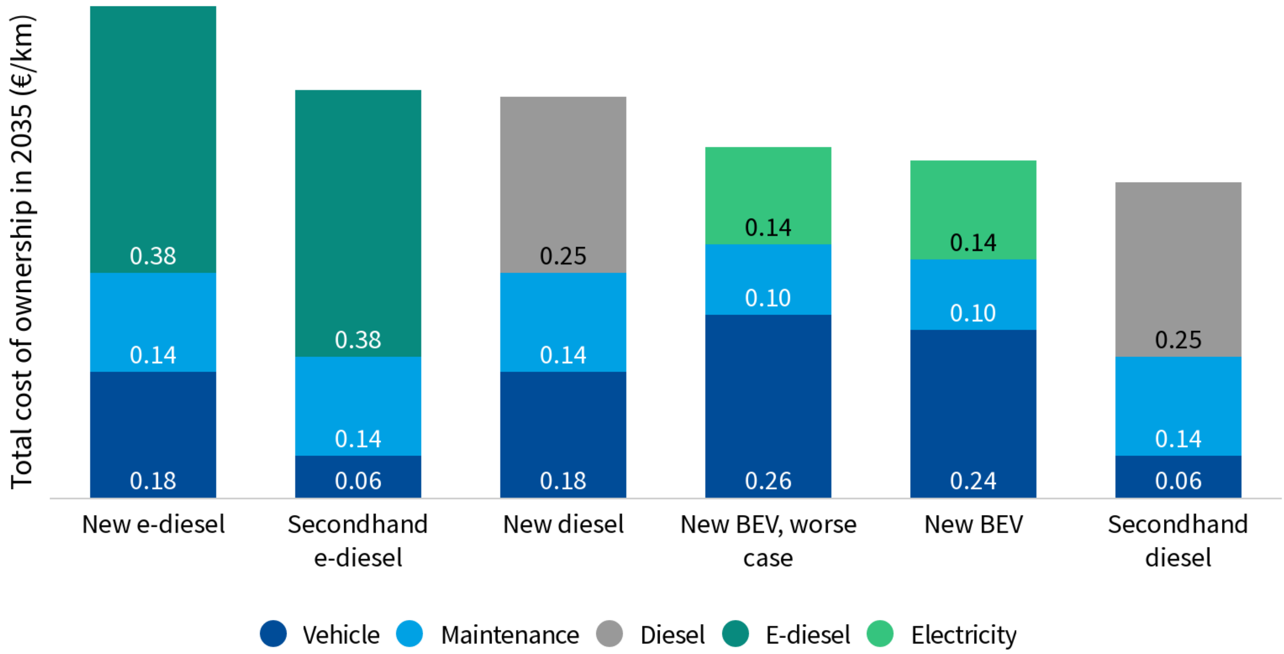

Figure 3. TCO for long-haul trucks bought in 2035, broken down by cost category

3. E-fuels would save less GHGs than going electric

Beyond cost, T&E also compared the climate benefits of both technologies. This section looks first at the lifecycle emissions under typical conditions for trucks bought in 2035: minimal RED II compliance for e-diesel production, and charging with grid electricity for BETs. Results for a best-case scenario where 100% renewable electricity is used to produce e-fuels and charge BETs are presented later.

The data and methodology used to estimate their lifecycle greenhouse gas (GHG) emissions are detailed in Annex 3. To determine the footprint of e-diesel production, the projected renewable energy mix of all planned electrolysers in Europe, the Middle East, and Africa is considered[10].

The Renewable Energy Directive II (RED II) mandates that renewable fuels of non-biological origin (RFNBOs, i.e. synthetic fuels) save at least 70% GHG emissions relative to a baseline of 94 gCO_2eq/MJ[11].

[10] BNEF. (2022). Hydrogen Production Database.
[11] This falls between the GHG intensities of petrol (93.3 gCO2e/MJ) and diesel (95.1 gCO2e/MJ), as set in the regulation. EC. (2022). Renewable energy – method for assessing greenhouse gas emission savings for certain fuels. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12713-Renewable-energy-method-for-assessing-greenhouse-gas-emission-savings-for-certain-fuels_en

This is assumed to be the typical case, where industry focuses on complying with the regulation but does not go beyond. Under RED II, fully-renewable electricity is considered zero-emission. From a lifecycle perspective however, infrastructure-related GHG emissions are included, so RED II e-diesel saves only 61% of GHG emissions compared to the RED II baseline.

In the typical case, opting for a BET in 2035 reduces lifecycle GHG emissions by 86% relative to a fossil diesel truck (Figure 4). In contrast, refuelling a truck with e-diesel would reduce its lifecycle GHG emissions by 60% relative to fossil diesel. But a typical e-diesel truck bought in 2035 would still emit almost three times as much GHG as an equivalent BET over its lifetime.

Under a best case scenario, 100% renewable electricity is used to produce e-fuels and charge BETs. For e-fuels, the average GHG intensity of the electricity used is 19 gCO_2e/kWh, based on planned electrolysers in Europe, the Middle East, and Africa[12]. For BETs, roof-mounted solar PV is assumed for electricity generation, with a GHG intensity of 37 gCO_2e/kWh[13]. In this scenario, refuelling an ICE truck bought in 2035 with e-diesel would save 20% of lifecycle emissions relative to a typical BET charged with EU grid electricity, but would emit 41% more than an equally optimistic BET charged with solar PV electricity.

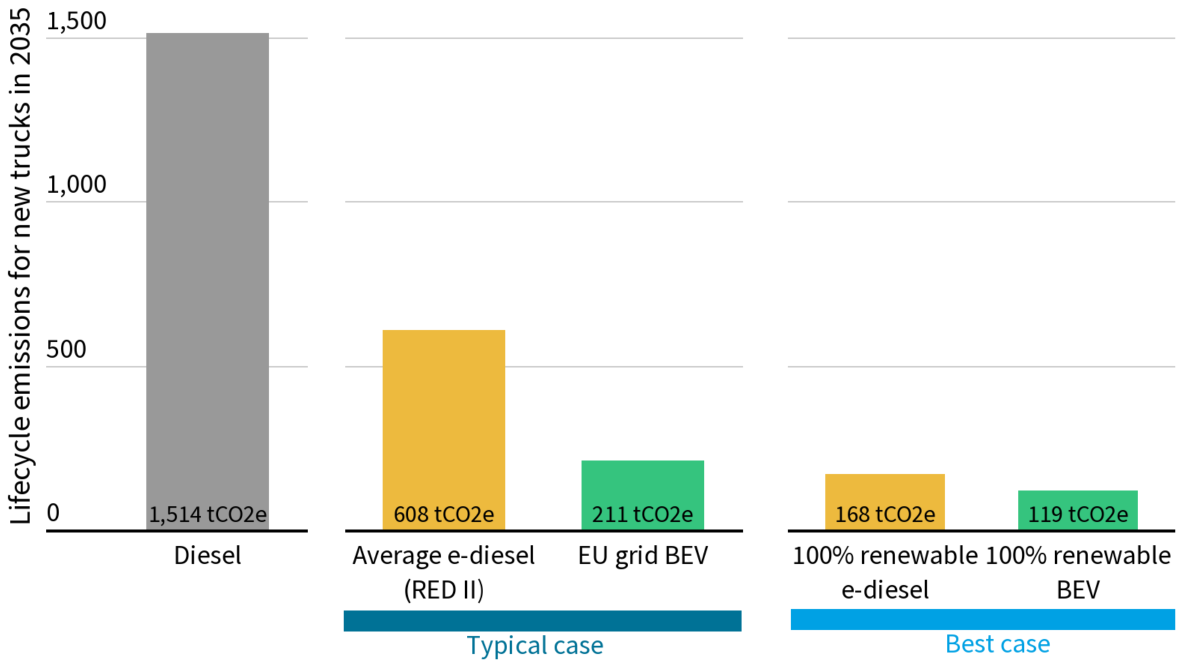

Figure 4. Lifecycle GHG emissions for new long-haul trucks in 2035

As Figure 5 shows, the majority of truck GHG emissions occur during the use phase. For ICE trucks bought in 2035, use-phase emissions make up 99% of lifecycle emissions if the truck is fuelled with fossil diesel, 97% if fuelled with RED II e-diesel, and 88% if fuelled with 100% renewable e-diesel.

[12] BNEF. (2022). Hydrogen Production Database.
[13] UNECE. (2021). Life Cycle Assessment of Electricity Generation Options. Table 14. https://unece.org/sites/default/files/2021-10/LCA-2.pdf

For BETs bought in 2035, use-phase emissions account for 74% of lifecycle emissions if the truck is powered using average EU grid electricity, and 54% if charged with solar PV. For BETs, lower use-phase emissions quickly pay back higher initial emissions incurred during battery production.

Emissions incurred during vehicle and battery production are partially offset by recycling at the end of life, which saves future GHG emissions. For new long-haul trucks in 2035, recycling credits are equivalent to 32% of the original production footprint for diesel trucks, and 20% for BETs[14]. This would reduce lifetime GHG emissions by 9 tCO_2e for diesel trucks and 14 tCO_2e for BETs.

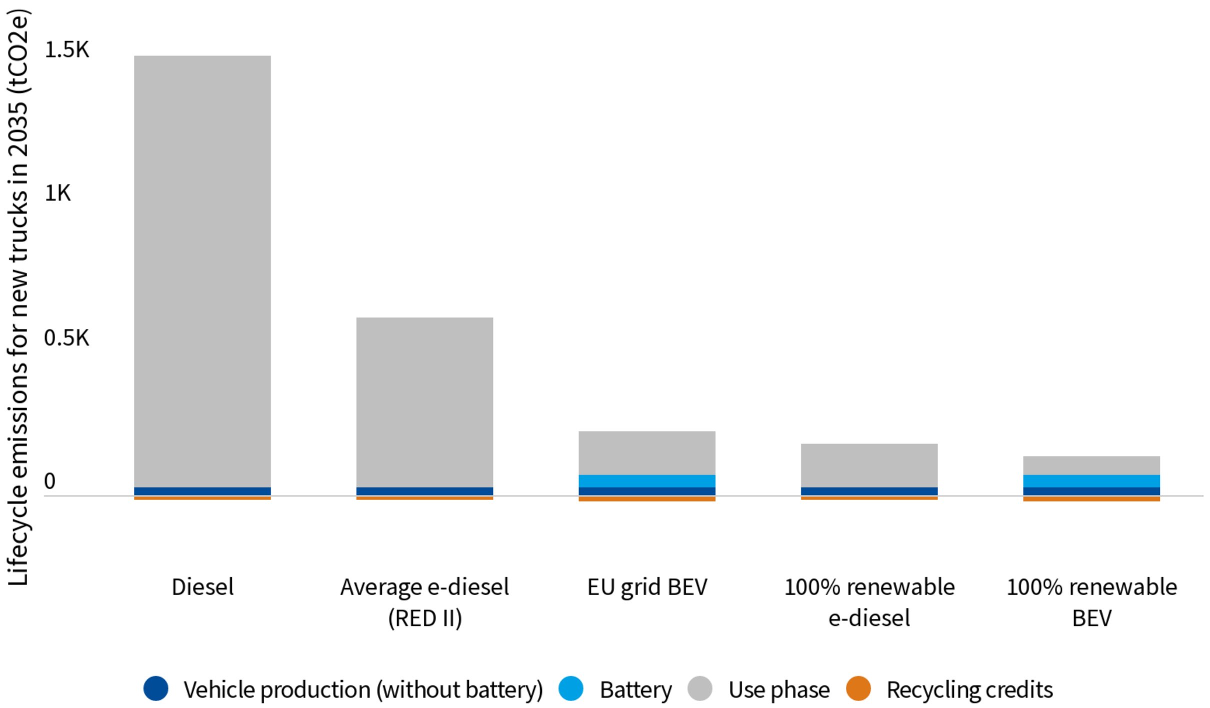

Figure 5. Lifecycle GHG emissions for new long-haul trucks in 2035, broken down by emissions category

4. E-fuels will be too scarce for trucks

The lifecycle analysis presented above compares the climate impact of BETs and e-diesel trucks on a one-to-one basis. However, supplying e-fuels in road transport would also have serious indirect climate consequences by diverting e-fuels away from shipping and aviation, which will rely on these fuels to decarbonise.

[14] Ricardo Energy & Environment. (2020). Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA.
https://op.europa.eu/en/publication-detail/-/publication/1f494180-bc0e-11ea-811c-01aa75ed71a1

In 2021, Concawe, the oil lobby's research group, modelled that e-fuel production in Europe would reach 9 Mtoe in 2035, with road transport responsible for two-thirds of e-fuel demand (6 Mtoe) in 2035[15]. If all 6 Mtoe destined for road transport went to trucks, then e-fuels could meet the fuel demand from 315,000 long-haul diesel trucks[16], making up 5.6% of the 5,638,000 trucks on EU roads in 2035[17]. If road e-fuels were allocated to road transport modes according to their current share of oil consumption, trucks would receive 27% of e-fuels in 2035[18], or 1.6 Mtoe. This would be enough for only 84,000 long-haul trucks, or 1.5% of all EU trucks on the road in 2035.

Though the analyses presented above assumed that e-fuels could be imported from abroad, imports of e-diesel are unlikely to materialise in significant volumes. The Hydrogen Council foresees that by 2050 the only hydrogen-derived fuels imported in Europe will be synthetic kerosene and ammonia, not road fuels[19].

What's more, green hydrogen supply remains highly uncertain. In spite of a large number of electrolysis projects being announced, green hydrogen will likely remain scarce until 2030 in the EU and until 2035 globally[20]. Electrolysis capacity is expected to rapidly scale up once a breakthrough occurs, but this breakthrough is unlikely to happen before 2036 in the EU and before 2043 globally. This means Europe will likely be unable to rely on large imports in the medium term to supplement its own production.

Although the EU has the renewables potential required to decarbonise transport using renewable electricity, it does not have room for inefficient uses such as producing e-fuels for road transport. The overall efficiency of power-to-liquid in trucks is 23% (29% in 2050), much lower than that of direct electrification (77% in 2020, 81% in 2050)[21]. Producing e-diesel for trucks would be a waste of renewables.

Scarce e-fuels should therefore be reserved for hard-to-abate sectors where direct electrification or hydrogen use are not feasible solutions. Instead of wasting e-fuels in cars and trucks, e-fuels should be used to decarbonise planes and ships.

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[15] The study does not include estimates for e-fuel imports. Concawe. (2021). Transition towards Low Carbon Fuels by 2050: Scenario analysis for the European refining sector.
https://www.concawe.eu/wp-content/uploads/Rpt_21-7.pdf
[16] Assuming long-haul diesel trucks in 2035 have an average efficiency of 27.5 l/100km, a lifetime mileage of 1.49 million km, and an average retirement age of 18.4 years. From TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe; and ICCT. (2022). Survival curves for heavy-duty vehicles in the EU.
[17] T&E. (2022). EUTRM.
[18] Share of road transport emissions due to heavy-duty vehicles in 2019. UNFCCC. (2022). National GHG Inventories.
[19] Hydrogen Council. (2022). Global Hydrogen Flows.
https://hydrogencouncil.com/wp-content/uploads/2022/10/Global-Hydrogen-Flows.pdf
[20] Odenweller, A., Ueckerdt, F., Nemet, G.F., Jensterle, M., and Luderer, G. (2022). Probabilistic feasibility space of scaling up green hydrogen supply. https://www.nature.com/articles/s41560-022-01097-4
[21] T&E. (2022). Electrofuels? Yes, we can … if we're efficient.
https://www.transportenvironment.org/wp-content/uploads/2020/12/2020_12_Briefing_feasibility_study_renewables_decarbonisation.pdf

For aviation, the European Commission, Parliament, and Council all support a 5% synthetic fuel sub-target in 2035 in ReFuelEU, equivalent to 2.7 Mtoe of e-kerosene[22]. However, T&E calculates that a sub-target of 13% would be required to sufficiently deploy e-fuels in aviation to decarbonise the sector, equivalent to 7.2 Mtoe[23].

For shipping, the Commission's FuelEU Maritime proposal does not include a RFNBO subquota (i.e. for synthetic renewable fuels). But the Parliament voted to include a 2% subquota from 2030 onwards[24], corresponding to 0.6 Mtoe of shipping e-fuels. An amendment to increase the RFNBO subquota to 6% in 2035 was rejected, mainly due to concerns about lack of supply[25]. This would be equivalent to 2 Mtoe, and could put ships on a path to full decarbonisation by mid-century[26].

3 Mtoe, i.e. what Concawe allocates to aviation and shipping, would be the bare minimum these sectors need to comply with ReFuelEU and FuelEU Maritime. But if the volumes dedicated to road transport also went to planes and ships, then both sectors would be on track for net-zero emissions by 2050.

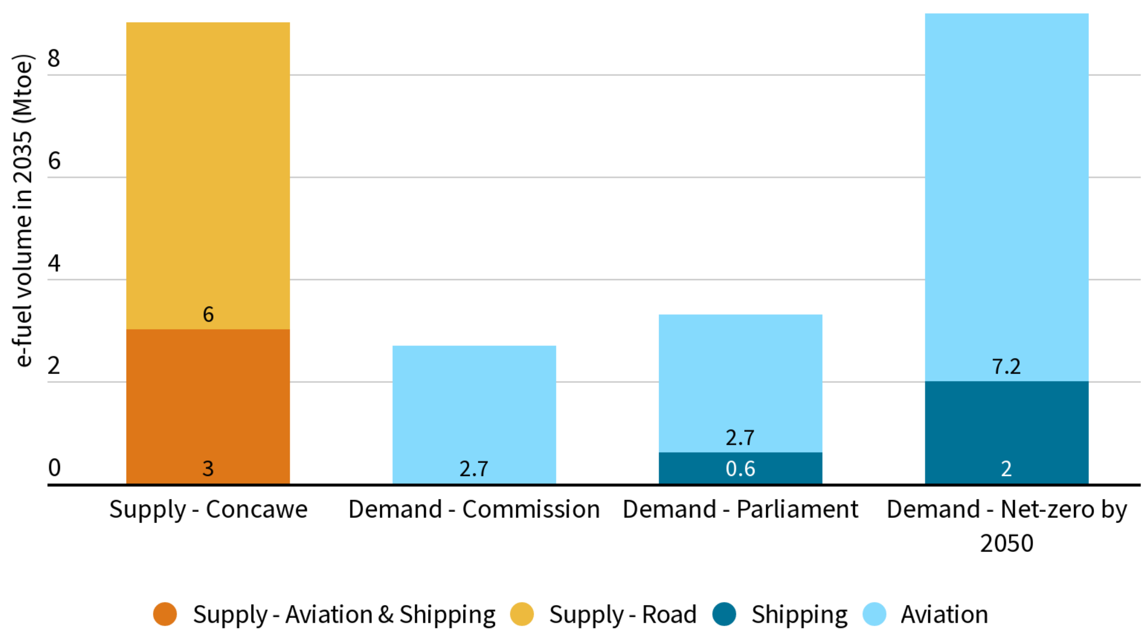

Figure 6. Supply and demand of e-fuels in 2035

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[22] ICCT. (2022). Considerations for the ReFuelEU aviation trilogue Table 1. https://theicct.org/wp-content/uploads/2022/09/refueleu-definitions-trilogue-sep22.pdf

[23] T&E. (2022). ReFuelEU Aviation: T&E's recommendations. Annex 1. https://www.transportenvironment.org/wp-content/uploads/2021/11/Updated-ReFuelEU-TE-position-paper.docx.pdf

[24] Only for large companies. T&E. (2022). Europe's lawmakers vote for world's first green shipping fuel requirement https://www.transportenvironment.org/discover/europes-lawmakers-vote-for-worlds-first-green-shipping-fuel-requirement/

[25] Reporting from Politico, on October 20th, 2022. "MEPs rebuffed a proposal to add a higher green fuel subquota of 6 percent in 2035. [...] Concerns about the availability of RFNBOs had been the main reason."

[26] T&E.(2021). A clean shift for EU transport fuels? - T&E recommendations for the RED review

5. Why fuels should not have a role in regulating new truck sales

E-fuels make no economic or environmental sense in trucks. As seen above, they would be the costliest option for hauliers to go to zero-emission. Despite costing more than a BET, buying and running a truck on e-diesel would emit more GHG emissions. E-fuels would not meaningfully reduce air pollution either[27]. Producing e-fuels for trucks would waste renewable electricity, and deprive hard-to-abate sectors where direct electrification or hydrogen are not feasible solutions, such as aviation and shipping.

Introducing a fuel crediting mechanism in the CO_2 standards could also delay the transition to zero-emission vehicles and undermine the regulation.

The truck CO_2 standards apply to manufacturers, who have to bring down their average fleet emissions in line with set targets. Truckmakers only have direct control over tailpipe emissions, which they can reduce through efficiency improvements or zero-emission vehicle sales. They **cannot guarantee how their vehicles will be used or fuelled** over their lifetime. Therefore, the truck CO_2 standards should only regulate what truckmakers are fully responsible for. The RED and the Fuel Quality Directive already regulate the amount of renewable energy used in transport fuels along with their quality, and can be used to promote higher uptake of e-fuels in transport.

Maintaining the separation between vehicle and fuel regulations is necessary to ensure their effectiveness. On the vehicle side, allowing truckmakers to buy credits from fuel suppliers to comply with their obligations under the CO_2 standards would create market uncertainty regarding trucks' path to decarbonisation. This could **lead to lower investments and a slower transition to zero-emission** vehicles. On the fuel side, additionality would not be guaranteed, i.e. fuel suppliers could sell credits for e-fuels that they would have supplied regardless of the crediting system.

In addition, including a fuel credit system would **undermine** the **enforceability** of the regulation. It would heighten the administrative burden borne by EU and national authorities to verify sustainability criteria, avoid double-counting of e-fuels under RED and the CO_2 standards, and track overall compliance.

In conclusion, **T&E urges the Commission not to propose a fuel crediting mechanism in its review of the heavy-duty vehicle CO_2 standards.**

Further information

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[27] T&E. (2021). Magic green fuels: Why synthetic fuels in cars will not solve Europe's pollution problems.

Annex 1. Vehicle characteristics

The vehicle characteristics presented here are taken from TNO's study, commissioned by T&E, on the techno-economic potential of zero-emission trucks in Europe[28]. For BETs, the larger of the two battery sizes is assumed.

Table A1.1 Vehicle characteristics of long-haul trucks by drivetrain and year of first purchase

Drivetrain	Year of first purchase	Empty weight (kg)	Nominal battery capacity (kWh)	Energy consumption (l/100 km or kWh/100km)
ICEV	2025	15,524		30.6
ICEV	2030	15,318		27.5
ICEV	2035	15,318		27.5
ICEV	2040	15,318		27.5
BEV	2030	17,295	966	105.6
BEV	2035	16,661	956	104.2
BEV	2040	16,027	946	102.8

[28] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Tables 6, 7, 9. https://www.transportenvironment.org/wp-content/uploads/2022/10/202210_TNO_-techno_economic_uptake_potential_of_zero_emission_trucks_in_Europe.pdf

Annex 2. Total Cost of Ownership

This analysis assumes a discount rate of 9.5%, a first ownership period of 5 years, and 265 operational days per year. Average annual distances are from TNO, and are assumed equal for first and secondhand trucks[29]. This is assumed to represent a hypothetical scenario where a fleet manager who wants to go to zero-emission needs a truck to perform a given workload, and wants to know the cheapest option between buying and running a new BET, or buying a 5-year-old diesel truck and refuelling it with e-diesel.

Table A2.1 Average annual distance by year (km)

Year 1	Year 2	Year 3	Year 4	Year 5
160,115	149,712	139,872	130,875	122,300

All price data is in $€_{2020}$. Vehicle prices are from TNO[30]. For diesel trucks, retail prices increase over time due to efficiency improvements and decreased economies of scale. For BETs, prices decrease over time due to cheaper battery packs and increased economies of scale. In the central scenario, battery packs are projected to cost 63 €/kWh in 2030, 44 €/kWh in 2035, and 37 €/kWh in 2040; while in the worse-case scenario, battery packs are projected to cost 81 €/kWh in 2030, 58 €/kWh in 2035, and 50 €/kWh in 2040[31].

Table A2.2 Pre-tax retail truck price including mark-up in the central case

Drivetrain	2025	2030	2035	2040
ICEV	€151,500	€159,000	€164,500	€170,000
BEV		€236,000	€214,500	€193,000

Depreciation costs are estimated by assuming a fixed rate of 37.5% of vehicle purchase price after 5 years, and a variable rate of 4.19% per 10,000 km, which corresponds to full vehicle depreciation after 1,490,000 km[32]. For secondhand vehicles, purchase price is based on the expected residual value after a first ownership period of five years.

[29] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Tables 16 and 34. https://www.transportenvironment.org/wp-content/uploads/2022/10/202210_TNO_-techno_economic_uptake_potential_of_zero_emission_trucks_in_Europe.pdf
[30] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Table 14. https://www.transportenvironment.org/wp-content/uploads/2022/10/202210_TNO_-techno_economic_uptake_potential_of_zero_emission_trucks_in_Europe.pdf
[31] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Supplementary data.
[32] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Table 10. https://www.transportenvironment.org/wp-content/uploads/2022/10/202210_TNO_-techno_economic_uptake_potential_of_zero_emission_trucks_in_Europe.pdf

Diesel and electricity prices are from TNO[33]. For BETs, it is assumed that 10% of their electricity comes from fast-charging, though their range (800 km) is superior to their average daily distance (530 km). In the worse-case scenario for BETs, fast-charging costs are increased to 0.28 €/kWh in all years.

Table A2.3 Diesel and electricity prices including all non-recoverable duties

Energy	2030	2035	2040
Diesel (€/l)	1.14	1.17	1.20
Depot charging (€/kWh)	0.17	0.17	0.17
Fast charging (€/kWh)	0.22	0.20	0.18

E-diesel price assumes synthetic fuels are produced from green hydrogen and solar PV in North Africa — where e-fuels can be produced cheaply — and includes transport and distribution costs[34]. E-diesel costs 1.50 €/l in 2030, 1.37 €/l in 2035, 1.27 €/l in 2040, and 1.18 €/l in 2045 before taxes and levies[35]. The excise duty on e-diesel is assumed to equal the average EU excise duty on diesel in 2020, or 4.42 €/1000l[36]. In order to account for the large decline in e-diesel cost over the ownership period, prices between 2030, 2035, 2040, 2045 have been linearly interpolated, and the e-diesel price for a truck purchased in a given year considers the average price for the 5 relevant years, weighted by annual distance driven.

Table A2.4 Average e-diesel price including excise duty, weighted by annual distance travelled

Ownership period	Average e-diesel price (€/l)
Over 2030-2034	1.90
Over 2035-2039	1.78
Over 2040-2044	1.68

Maintenance costs are 18.50 €/100km for ICE trucks and 13.24 €/100km for BETs for all years[37].

[33] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Tables 38–40. https://www.transportenvironment.org/wp-content/uploads/2022/10/202210_TNO_-techno_economic_uptake_potential_of_zero_emission_trucks_in_Europe.pdf
[34] Agora Energiewende et al. (2018). PtG/PtL calculator. https://www.agora-energiewende.de/en/publications/ptg-ptl-calculator/.
[35] Cost estimates from 2018 have been adjusted for 1.45% inflation between 2018 and 2020. InflationTool. (2022). https://www.inflationtool.com/euro?amount=100&year1=2018&year2=2020 frequency=yearly Accessed November 6th, 2022.
[36] ACEA. (2020). Tax guide. https://www.acea.auto/files/ACEA_Tax_Guide_2020.pdf
[37] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Table 15.

Annex 3. Lifecycle Analysis

Annex 3.1. Production and End-of-Life (EoL)

The GHG intensity of truck production in 2020 (excluding battery production) is 4.0 $kgCO_2e$/kg of truck produced[38]. As the GHG intensity of average EU grid electricity declines (see Annex 3.2), it is expected to be 39% lower in 2030 than in 2020, 53% lower in 2035, and 67% lower in 2040.

Similarly, the GHG intensity of Lithium-ion batteries produced with average EU electricity decreases over time. From 55 $kgCO_2e$/kWh in 2030, it drops to 45 $kgCO_2e$/kWh in 2035 and 36 $kgCO_2e$/kWh in 2040[39].

Battery energy density is also projected to improve from 280 Wh/kg in 2030, to 328 Wh/kg in 2035 and 376 Wh/kg in 2040. This assumes that 80% of the cell volume market in the heavy-duty segment will be NMC811 and 20% will be LFP[40].

Recovering materials at the end-of-life (EoL) allows for future GHG emissions savings. As a result, recycling credits, expressed as a percentage of a truck's total production carbon footprint, are taken into account. The shares by powertrain and year are presented in Table A3.1[41].

Table A3.1 Recycling credits

Drivetrain	2030	2035	2040
ICEV	-22.9%	-32.4%	-42.0%
BEV	-22.0%	-19.9%	-17.8%

Annex 3.2. Energy consumption during the use phase

This study estimates the lifetime emissions of EU trucks bought in 2030, 2035, and 2040, assuming a retirement age of 18.4 years[42]. For the first five years of operation, the annual distances from the TCO

[38] Wolff, S., Seidenfus, M., Gordon, K., Álvarez, S., Kalt, S., and Lienkamp, M. (2020). Scalable Life-Cycle Inventory for Heavy-Duty Vehicle Production. https://www.mdpi.com/2071-1050/12/13/5396
[39] T&E. (2022). UPDATE - T&E's analysis of electric car lifecycle CO_2 emissions.
https://www.transportenvironment.org/wp-content/uploads/2022/05/Final-TE_LCA_Update.pdf
[40] TNO. (2022). Techno-economic uptake potential of zero emission trucks in Europe. Table 12.
https://www.transportenvironment.org/wp-content/uploads/2022/10/202210_TNO_-techno_economic_uptake_potential_of_zero_emission_trucks_in_Europe.pdf
[41] Ricardo Energy & Environment. (2020). Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA.
https://op.europa.eu/en/publication-detail/-/publication/1f494180-bc0e-11ea-811c-01aa75ed71a1
[42] 18.4 years corresponds to the average retirement age of trucks in the EU. ICCT. (2022). Survival curves for heavy-duty vehicles in the EU.

analysis are used. The annual distances travelled for the remaining 13.4 years are estimated using truck activity curves normalised to a new vehicle[43].

For conventional diesel trucks, the GHG intensity of fossil diesel is 3,301 gCO_2e/l[44].

In the typical case, battery-electric trucks are charged using average EU grid electricity, the GHG intensity of which declines over the truck lifetime. Excluding distribution losses, it is projected to be 160 gCO_2e/kWh in 2030 and 87 gCO_2e/kWh in 2040[45]. Electricity grid losses of 6.4% are assumed for all years[46]. In the 100% renewable case, BETs are charged using roof-mounted solar PV, with a constant GHG intensity of 37.2 gCO_2e/kWh[47].

In the typical case, e-diesel is assumed to be produced using a mix of fully renewable electricity, and of electricity generated from natural gas with a carbon intensity of 434 gCO_2e/kWh[48]. Renewable electricity is counted as 0 gCO_2e/kWh in RED II[49]. When infrastructure-related emissions are considered, electrolysers in Europe, the Middle East and Africa are projected to have an average GHG intensity of 18.83 gCO_2e/kWh in 2030, 18.78 gCO_2e/kWh in 2035, and 18.73 gCO_2e/kWh in 2040[50]. Synthetic diesel production is assumed to have an overall efficiency of 57% in 2030, assuming a conversion efficiency of 79% for water electrolysis and of 72% for Fischer-Tropsch synthesis[51]. The GHG intensity of pure e-diesel compliant with RED II is 1,302 gCO_2e/l in 2030, 1,301 gCO_2e/l in 2035, and 1,300 gCO_2e/l in 2040. In the 100% renewable case, the GHG intensity of e-diesel is 330 gCO_2e/l in 2030, 329 gCO_2e/l in 2035, and 328 gCO_2e/l in 2040.

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43 ICCT. (2022). Survival curves for heavy-duty vehicles in the EU.

44 Based on a carbon intensity of 92 gCO2/MJ and a volumetric energy density of 36 MJ/l. Concawe. (2021). Concawe's Transport and Fuel Outlook towards EU 2030 Climate Targets - Appendix. Table 35. https://www.concawe.eu/wp-content/uploads/Rpt_21-2A.pdf

45 Data for years beyond 2040 are extrapolated from the projected trend in 2030–2040. Derived from ENTSO-E. (2022). TYNDP 2022 Draft Scenario Report. https://2022.entsos-tyndp-scenarios.eu/ using emission factors from UNECE. (2021). Life Cycle Assessment of Electricity Generation Options. https://unece.org/sites/default/files/2021-10/LCA-2.pdf More information on the methodology can be found in T&E. (2022). UPDATE - T&E's analysis of electric car lifecycle CO_2 emissions https://www.transportenvironment.org/wp-content/uploads/2022/05/Final-TE_LCA_Update.pdf

46 T&E. (2022). UPDATE - T&E's analysis of electric car lifecycle CO_2 emissions https://www.transportenvironment.org/wp-content/uploads/2022/05/Final-TE_LCA_Update.pdf

47 UNECE. (2021). Life Cycle Assessment of Electricity Generation Options. Table 14. https://unece.org/sites/default/files/2021-10/LCA-2.pdf

48 Assuming no carbon capture and storage. UNECE. (2021). Life Cycle Assessment of Electricity Generation Options. Table 14. https://unece.org/sites/default/files/2021-10/LCA-2.pdf

49 EC. (2022). Renewable energy – method for assessing greenhouse gas emission savings for certain fuels. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12713-Renewable-energy-method-for-assessing-greenhouse-gas-emission-savings-for-certain-fuels_en

50 BNEF. (2022). Hydrogen Production Database.

51 This means e-diesel produced with up to 13% of gas-generated electricity and 87% of renewables can comply with RED II. T&E. (2020). Electrofuels? Yes, we can … if we're efficient https://www.transportenvironment.org/wp-content/uploads/2020/12/2020_12_Briefing_feasibility_study_renewables_decarbonisation.pdf

Annex 4. Results for trucks purchased in 2030 and 2040

Annex 4.1. Total Cost of Ownership

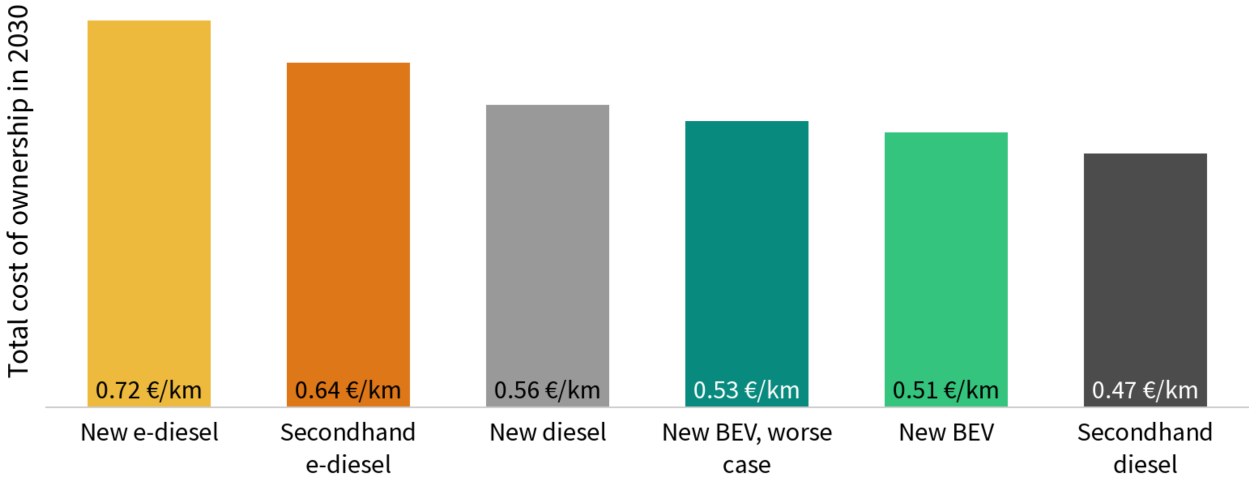

Figure A4.1. TCO for long-haul trucks bought in 2030

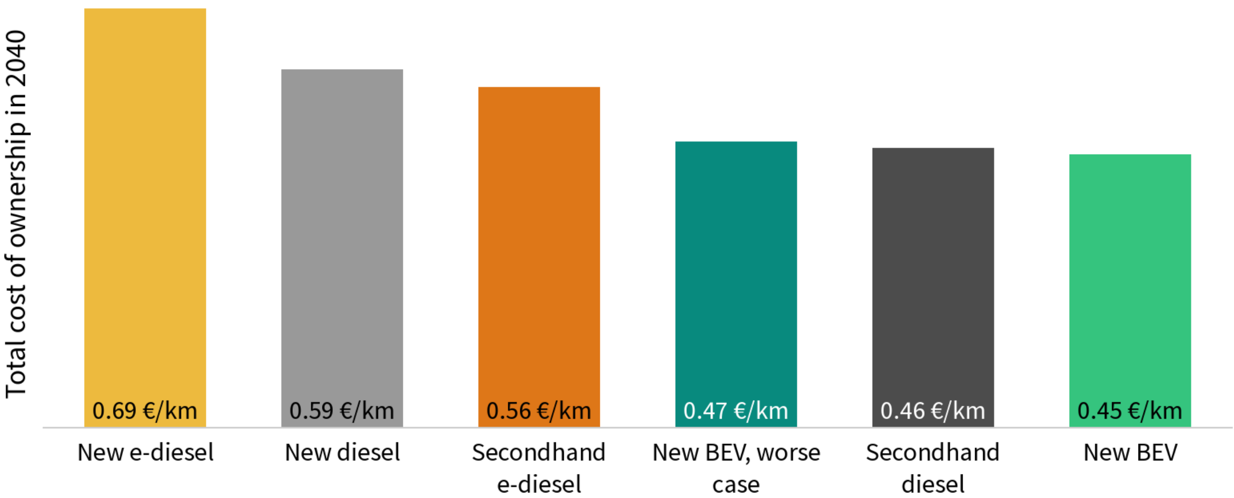

Figure A4.2. TCO for long-haul trucks bought in 2040

Annex 4.2. Lifecycle Analysis

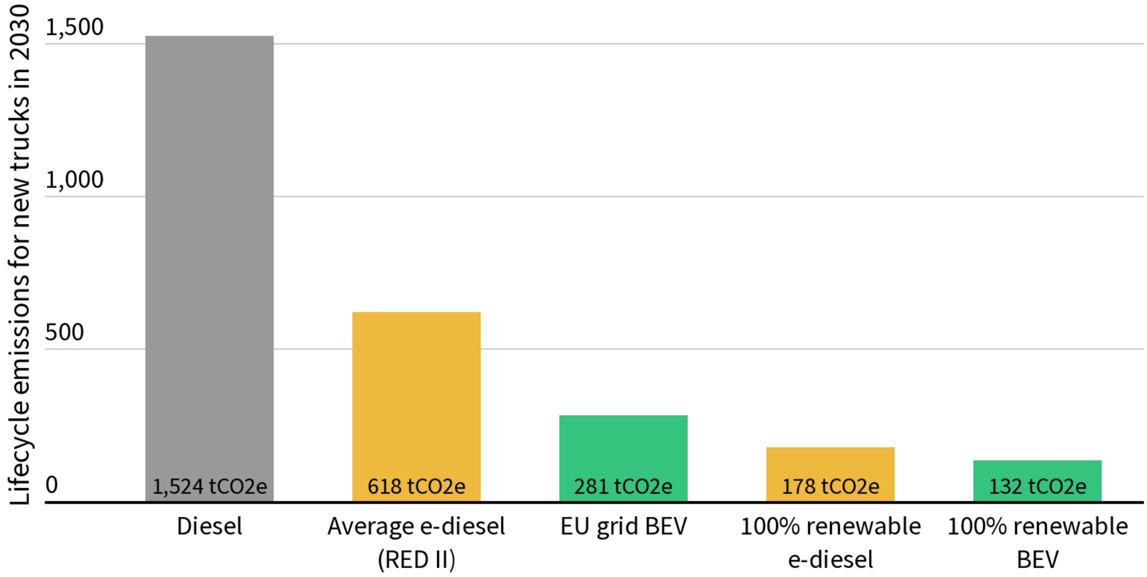

Figure A4.3. Lifecycle GHG emissions for long-haul trucks bought in 2030

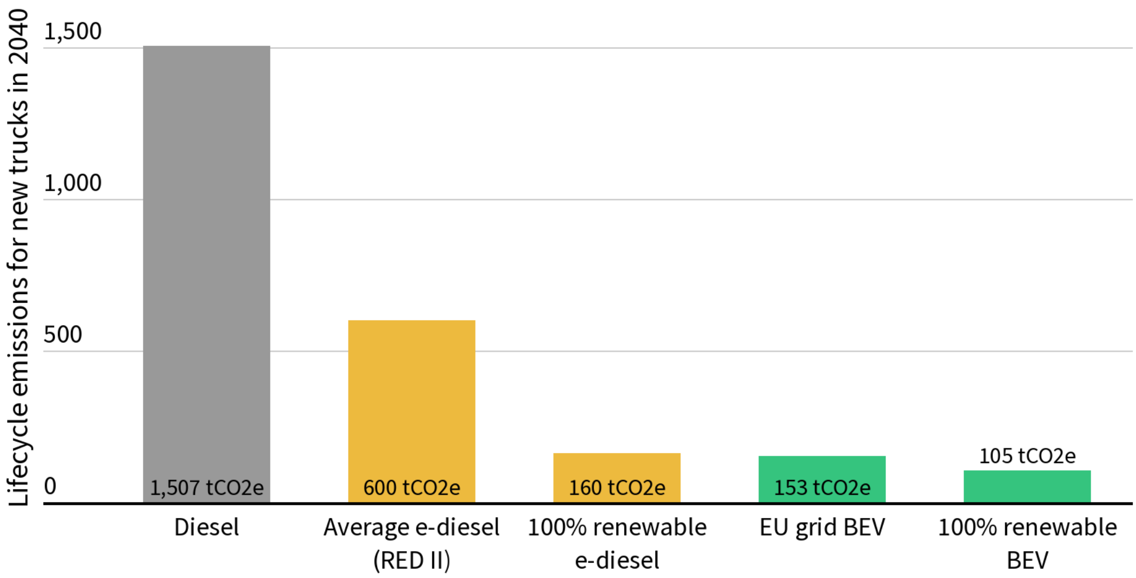

Figure A4.4. Lifecycle GHG emissions for long-haul trucks bought in 2040