Intelligence
Briefing.

Alternative vs traditional truck powertrains in the EU:

Total cost of ownership 2024

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Executive summary

This IRU Intelligence Briefing evaluates the total cost of ownership (TCO), as well as CO_2 emissions, for an articulated vehicle (a road tractor towing a semi-trailer) during its first six years of operation.

TCO measures all costs associated with owning a road tractor over its entire lifecycle, including acquisition, operation, maintenance and disposal. CO_2 emissions are the CO_2 molecules emitted by a vehicle, measured on a well-to-wheel basis. TCO and emission figures are calculated by distributing the total value for the period over the total mileage covered during that period.

Data from France, Germany, Poland, Spain and Italy, the five biggest EU road freight countries, reveals that national conditions significantly impact both TCO and CO_2 emissions. Advanced diesel trucks (based on class 2 of the Eurovignette Directive), which are more fuel-efficient than regular diesel road tractors (based on class 1 of the Eurovignette Directive), offer a common cost-effective solution. However, the most economical options vary by country.

In Italy, compressed natural gas (CNG) trucks have the lowest TCO, while being more expensive than diesel in France and Poland. In Germany, battery-electric vehicles (BEVs) have the lowest TCO following the increase in diesel toll fees in 2023. In Italy and Poland, BEVs have the second highest TCO. Fuel cell electric vehicles (FCEVs) have the highest TCO across the five countries. These results are mostly linked to energy prices.

In terms of emissions reduction, the effectiveness of different powertrains varies based on local conditions. BEVs emit the least amount of CO_2 in France, where the electricity grid relies heavily on renewable and nuclear power. In France, BEVs emit less than 100g per kilometre (15-tonne payload), while they emit ten times more CO_2 in Poland. In contrast to other powertrains, FCEVs do not reduce emissions as much if they do not run on green hydrogen.

In the other countries, hydrotreated vegetable oil (HVO) offers the most significant CO_2 emissions reduction, especially when combined with

advanced diesel engines. HVO currently provides the most optimal balance between TCO and CO_2 emissions in all five countries. Moreover, logistics and vehicle efficiencies show great potential to mitigate TCO increases associated with alternative fuels.

However, several uncertainties remain. Firstly, TCO is highly dependent on government decisions regarding subsidies and taxation. For example, a Polish subsidy could drastically lower the TCO of electric trucks. Secondly, electric and hydrogen options still require the right enabling conditions to achieve the TCO values calculated in this Intelligence Briefing. A significant improvement in the availability of recharging/refuelling stations is needed for operators to effectively use these two powertrains.

Contents

Glossary

A

AdBlue
A diesel exhaust fluid used in selective catalytic reduction systems to reduce diesel engines' nitrogen oxide emissions.

Alternative Fuels and Efficiency Model (AFEM)
IRU proprietary model to assess energy consumption, efficiency potential and alternative fuels' ease of use based on transport operators' own operations.

Axle
A central shaft for rotating wheels or gears. In vehicles, it supports the weight and facilitates wheel rotation.

B

Battery electric vehicle (BEV)
A vehicle powered entirely by electricity stored in rechargeable battery packs, with electric motors replacing traditional combustion engines.

C

Capital expenditure (CapEx)
Funds used to acquire, upgrade or maintain physical assets such as property, industrial buildings or equipment.

Carbon emission factor (CEF)
A coefficient representing CO_2 emissions per unit of activity, such as per unit of fuel consumed or distance travelled.

Carbon dioxide emissions
The release of carbon dioxide into the atmosphere from the burning of fossil fuels.

Compressed natural gas (CNG)
Natural gas compressed to less than 1% of its volume at standard atmospheric pressure.

D

Depreciation
The reduction in the value of an asset over time due to wear and tear, obsolescence or ageing.

Diesel
A type of fuel derived from crude oil used in compression-ignition engines.

E

Energy cost
The expense incurred from consuming energy resources, such as electricity, fuel or gas, for operating equipment or vehicles.

EUR/km
Euros per kilometre is a cost metric expressing the expense incurred for every kilometre travelled.

EUR/kg
Euros per kilogram is a pricing measure indicating the cost per unit weight of a product/fuel.

EUR/kWh
Euros per kilowatt-hour is a unit of energy cost indicating the price for consuming one kilowatt-hour of electricity.

EUR/L
Euros per litre is a common unit for pricing liquids like fuel, indicating the cost per litre.

F

Fuel cell electric vehicle (FCEV)
A vehicle that generates electricity through a fuel cell powered by hydrogen that emits only water vapor as a byproduct.

G

Gross combination weight (GCW)
Maximum authorised weight for a vehicle to run on public roads.

gCO_2/km
Grams of carbon dioxide emitted per kilometre is a measure of a vehicle's emissions intensity.

gCO_2/tkm
Grams of carbon dioxide emitted per tonne-kilometre is the emissions per unit of freight transported over a distance.

H

Hydrotreated vegetable oil (HVO)
A renewable diesel fuel produced by hydrotreating vegetable oils or animal fats. It serves as a sustainable alternative to fossil diesel.

I

Inflation
Inflation is the rate of increase in prices over a given period of time.

Insurance
A contractual agreement in which an individual or entity receives financial protection or reimbursement against losses from an insurance company.

Internal combustion engine (ICE)
An engine burning a fuel to produce mechanical energy.

K

$kgCO_2$/km
Kilograms of carbon dioxide emitted per kilometre is used for larger-scale emission measurements such as heavy-duty vehicles.

$kgCO_2$/tkm
Kilograms of carbon dioxide emitted per tonne-kilometre is a metric for assessing the carbon intensity of freight transport.

L

Liquefied natural gas (LNG)
Natural gas cooled to a liquid state at about -162°C for ease of storage and transport used as a fuel for heavy-duty vehicles.

Liquefied petroleum gas (LPG)
A mixture of propane and butane gases stored under pressure in liquid form. It is commonly used as fuel for heating, cooking and vehicles.

M

MJ/kg
Megajoules per kilogram is a unit of energy density indicating the amount of energy stored per kilogram of a substance.

N

N2 & N3
European vehicle categories for goods vehicles. N2 refers to vehicles weighing between 3.5 and 12 tonnes, while N3 includes vehicles weighing over 12 tonnes.

O

Operating expense (OpEx)
The ongoing expenses for running a business or system, including costs like utilities, rent, salaries and maintenance.

Ownership tax
Taxes levied on the ownership of assets like vehicles or property, often based on the value or type of the asset.

P

Payload
The carrying capacity of a vehicle, referring to the weight of the passengers or cargo that it can transport.

R

Registration fee
A mandatory charge paid to government authorities to register a vehicle, legally authorising it for use on public roads.

Residual value (RV)
The amount that an asset is worth after it has been used for a particular period.

Road freight
The transport of goods and cargo via roadways using trucks or other commercial vehicles.

Road tractor
Road motor vehicle designed, exclusively or primarily, to haul other road vehicles which are not power-driven (mainly semi-trailers).

S

Semi-trailer
A trailer without a front axle designed to be attached to a tractor unit (road tractor), with a significant portion of its weight supported by the towing vehicle.

T

T2S3
Acronym describing an articulated vehicle made of a two-axle road tractor pulling a three-axle semi-trailer.

TCO (Total cost of ownership)
The comprehensive total of all costs associated with owning an asset over its entire lifecycle, including acquisition, operation, maintenance and disposal expenses.

Toll
A fee charged for the use of certain roads, bridges or tunnels. It is typically used to fund maintenance and infrastructure projects.

Tonne-kilometre (tkm)
This is a unit of freight transport measure which represents the transport of one tonne of goods (including packaging and tare weights of intermodal transport units) by a given transport mode (road, rail, air, sea, inland waterways, pipeline, etc) over a distance of one kilometre.

V

VECTO (Vehicle Energy Consumption Calculation Tool)
A simulation software used in the EU to certify CO_2 emissions and fuel consumption of heavy-duty vehicles.

W

Well-to-wheel (WTW)
An analysis approach that evaluates all CO_2 emissions for a fuel, from its extraction (well) to consumption (wheel).

Z

Zero-emission vehicle (ZEV)
A vehicle that produces no tailpipe emissions from its onboard source of power, such as electric or hydrogen fuel-cell vehicles.

Introduction

The road freight sector is known for its operational efficiency, providing reliable, fast and low-cost solutions to its customers, including shippers and freight forwarders. A key factor influencing operators' strategic investment decisions is the total cost of ownership (TCO) for a vehicle. For a new vehicle technology, such as a new alternatively fuelled powertrain, to be successful, it should lower the TCO. In addition, with the sector's commitment to reach carbon neutrality by 2050, another key indicator is gaining momentum: carbon emissions (CO_2). This raises several important questions for road transport operators about the costs and benefits of adopting new technologies, such as battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), to reduce emissions.

The combined TCO-CO_2 indicator is also of interest for other actors in the road transport ecosystem, such as shippers and policymakers, to design new tenders or to meet their own targets. A comprehensive economic impact assessment is thus necessary to evaluate the feasibility of the green transition. Without a clear understanding of the TCO for alternative powertrains compared with current diesel solutions, making informed decisions is challenging.

This IRU Intelligence Briefing compares the TCO-CO_2 of different powertrains. It offers insights on the expected TCO and carbon dioxide reduction capacities of new powertrains. The analysis covers five types of powertrains: diesel, hydrotreated vegetable oil (HVO), gas, BEV and FCEV for the five biggest EU road freight countries (Poland, Germany, France, Spain and Italy). The Intelligence Briefing will be updated every semester to reflect the latest market and industry developments.

Chapter 1

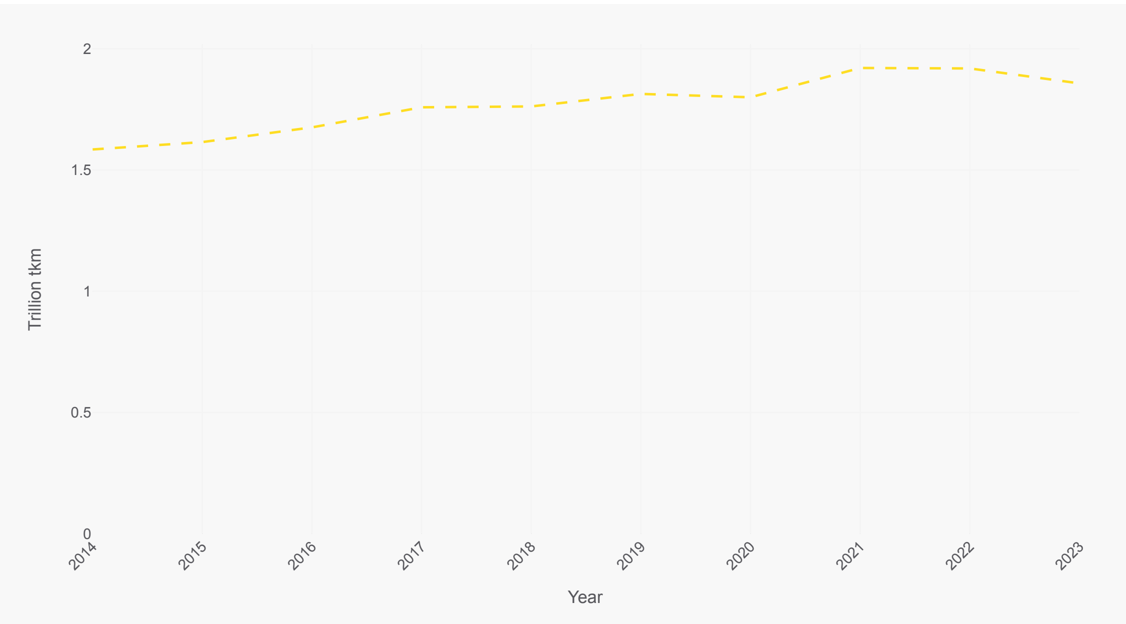
Context: Road freight performance and truck fleet compositions

1.1. Road freight performance

Fuel consumption is the key indicator linking TCO and CO_2, as the cost of energy is the most sensitive TCO component, and CO_2 emissions are a by-product of fuel combustion for a diesel engine. The relevant freight performance indicator to compare fuel consumption across different powertrains is "tonne-kilometres", as it accounts for the difference in payloads and distances. A geographical perspective is also important. TCO components vary due to the diversity of fuel prices, incentives and tax differences, and the carbon intensity of different energy sources.

EU road freight volumes have increased over the last decade, peaking at 1.92 trillion tonne-kilometres in 2022. In 2023, road freight volumes fell due to the economic downturn in the EU. Road freight is highly dependent on both economic (trade, manufacturing, consumption, etc) and geopolitical (oil shocks, uncertainty, etc) factors.

EU road freight volume



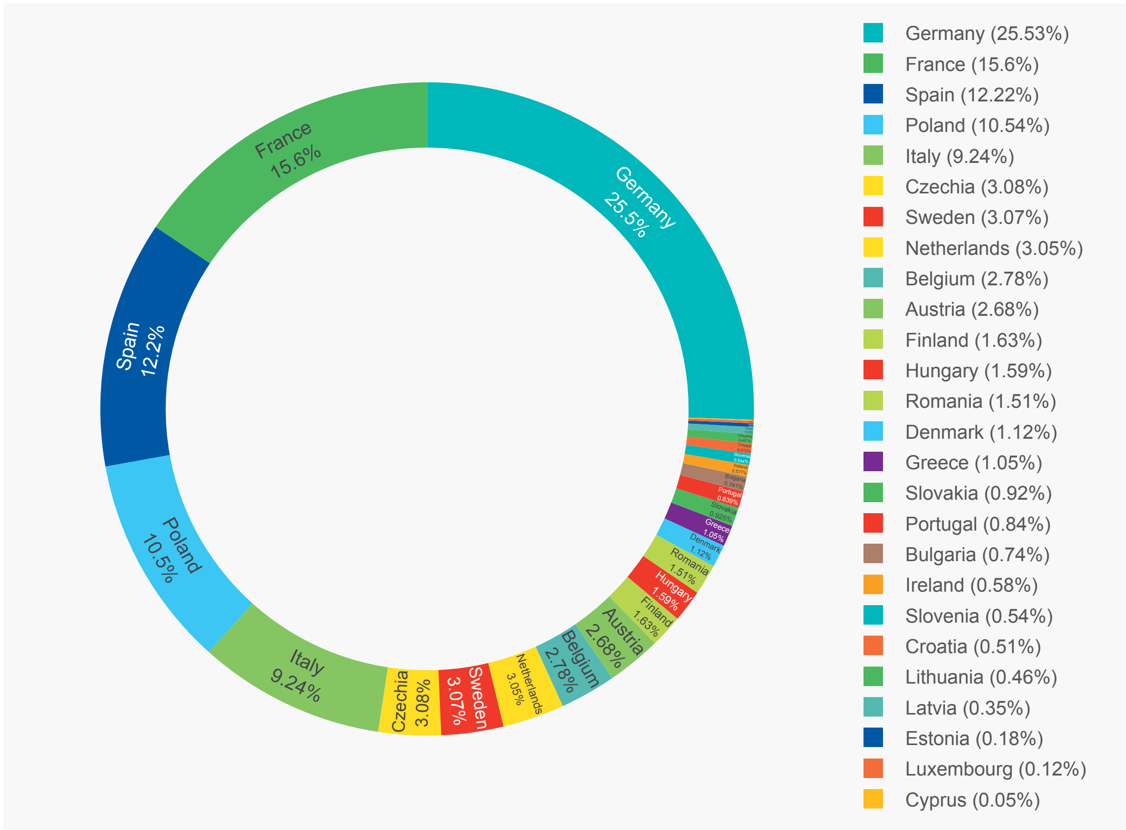
Source: Eurostat (road_go_ta_tott) extracted on 2024-10-23

There are two important road freight volume metrics:

- The national road freight volume reflects the volume of goods transported within a particular country or transited along its national roads, regardless of the truck's country of origin. This metric closely reflects the fuel needed for road goods transport per country.
- The road freight volume by national fleet looks at the road freight volume performed by a national fleet, which can operate in different countries. This metric helps to capture the specific characteristics that affect transport operators.

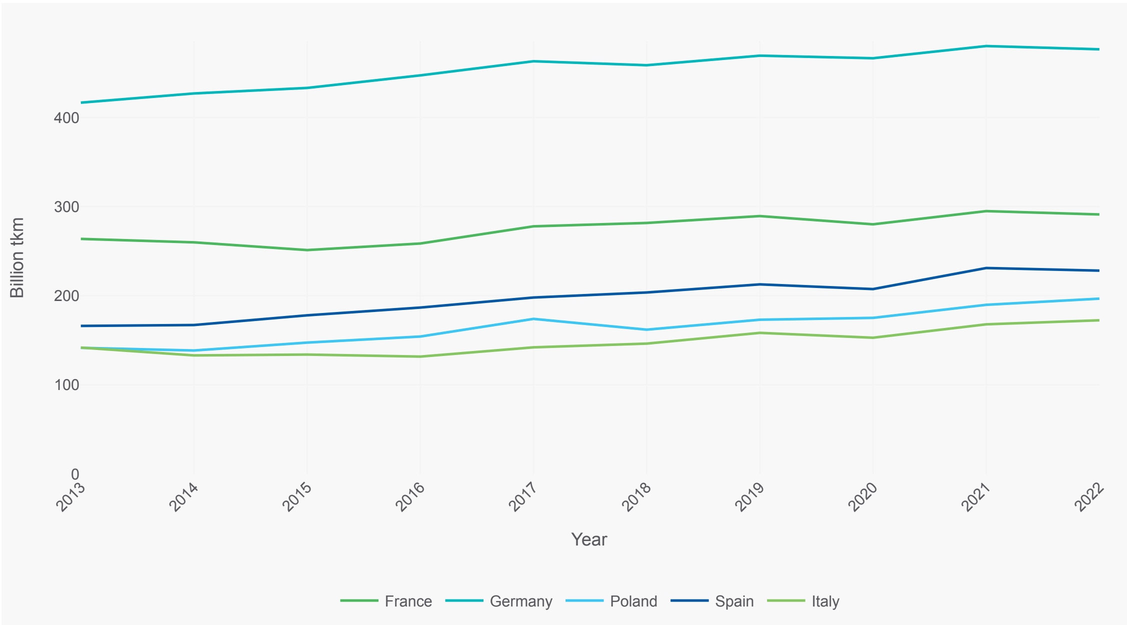
The following infographics present the distribution of EU national road freight volumes per country in 2022 (latest available data). Germany, followed by France and Spain, has the greatest volume of national road freight volumes in the EU, due to its economic weight, central geographical location, seaports, advanced transport infrastructure, and manufacturing capacity. Over the past decade, road freight volumes have been increasing for all countries, indicating sustained economic growth.

Total road freight volume per country in 2022 (tkm)



Source: Eurostat (road_tert_go) extracted on 2024-10-23

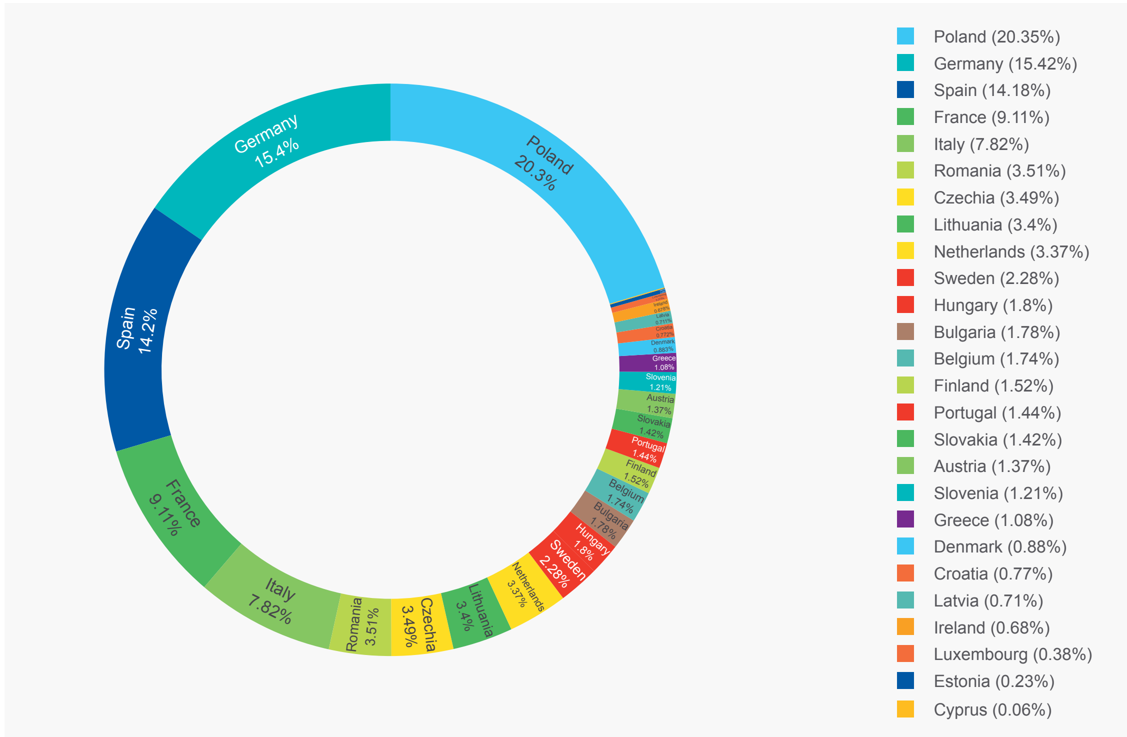
National road freight volumes



Source: Eurostat ([road_tert_go]) extracted on 2024-10-23

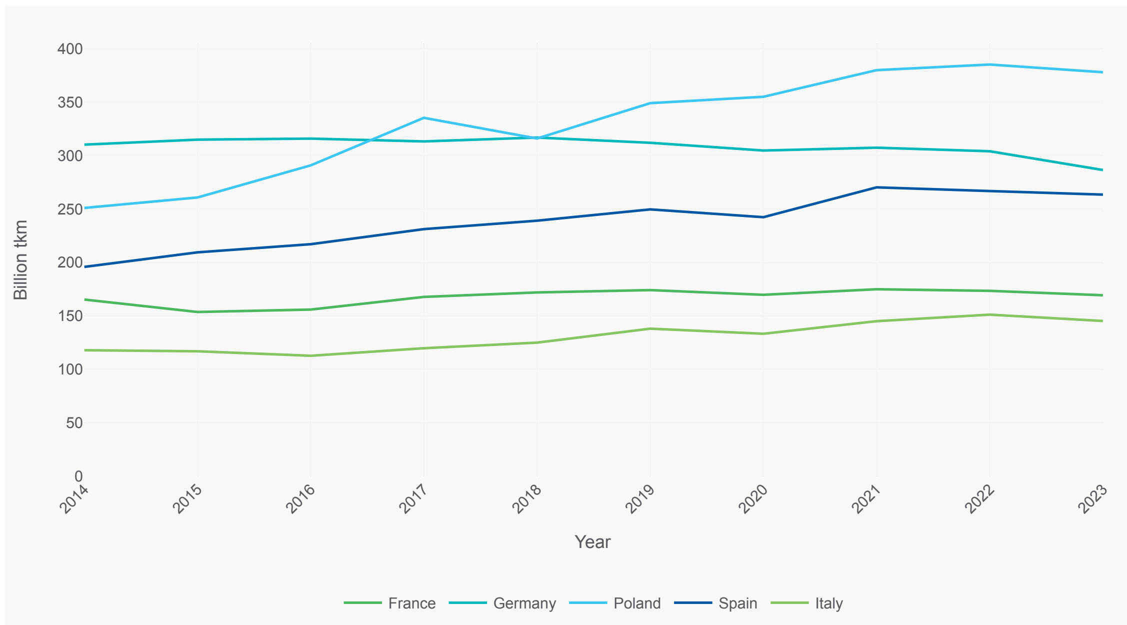
However, the distribution of freight volume by country needs to be complemented by the distribution of freight volume by national fleet. A vehicle registered in "country A" can operate in "country B" during cabotage or cross-trade operations. Additionally, today's diesel trucks have an average range of up to 2,500km, giving operators the flexibility to refuel where the price is the most competitive. The Polish fleet was the largest operating fleet in the EU in 2023, increasing its operation by 50% over the past decade. As seen in the previous graphs on national road freight volumes by country, it becomes clear that the Polish fleet operates internationally. This is explained by differences in the cost structure of operating expenses such as fuel prices, wages, fleet compositions and other economic factors. Previous Intelligence Briefings on [European road freight trends] and the [size and economic landscape] offer detailed information on these trends.

Total road freight volume per national fleet in 2023 (tkm)



Source: Eurostat ([road_go_ta_tott]) extracted on 2024-10-23

Road freight volume per national fleet

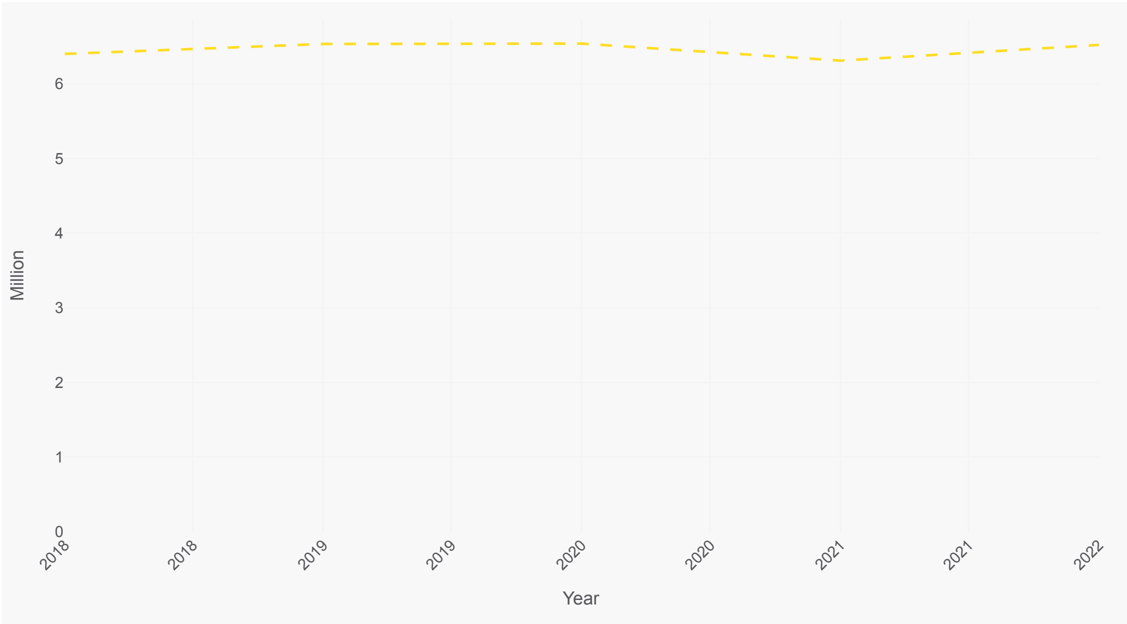


Source: Eurostat ([road_go_ta_tott]) extracted on 2024-10-23

1.2. EU fleet composition

The EU fleet is consistently growing. It currently consists of 6.5 million trucks. New trucks are added every year, while older trucks generally get sold to non-EU countries, or remain in use in the EU, finding new niche applications such as snow removal in small communities.

Total number of trucks in EU



Source: IRU estimates & Eurostat (road_eqs_lorroa) extracted on 2024-05-25

Currently, vehicle manufacturers offer several powertrain technologies:

- **Diesel powertrain:** Mechanical energy is generated by the combustion of diesel, using a compression-ignited internal combustion engine.
- **Gas powertrain:** Mechanical energy is generated by the combustion of methane, using a spark-ignited internal combustion engine. Methane can be stored in either compressed (CNG) or liquefied (LNG) form.
- **LPG powertrain:** Liquefied petroleum gas (LPG) is used in either a spark combustion engine or a dual-fuel engine where it is mixed with diesel. LPG is mostly fitted by converting existing trucks.
- **Electric powertrain:** Mechanical energy is generated by an electric engine converting electrical energy stored in a battery pack.
- **Hybrid powertrain:** A powertrain combining two other powertrains (such as diesel and electric).

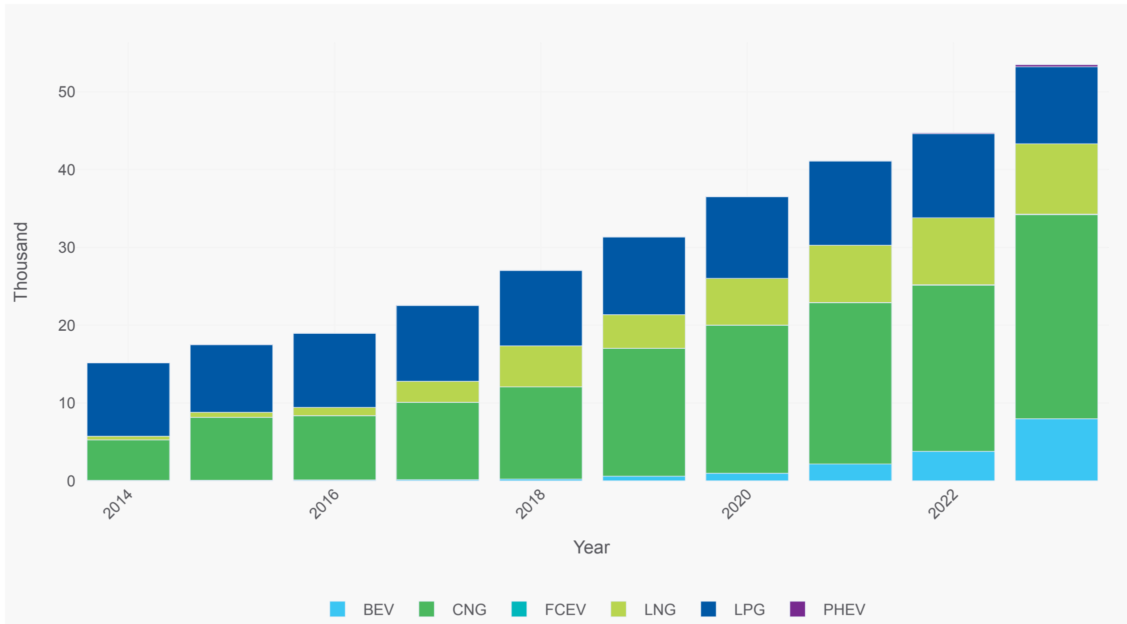
- **Hydrogen powertrain:** Mechanical energy is generated through the conversion of hydrogen, either by a fuel cell combined with a battery pack and an electric engine (the most common form today) or an internal combustion engine.

Today, diesel powertrain remains by far the most used (99% of trucks). Diesel engines have greater maximum torque values than an equivalent gasoline engine, enabling trucks to transport heavier loads. They also consume less fuel and tend to be more durable and reliable than other classic powertrains, as the engines run at lower revolutions per minute. These characteristics reduce vehicles' TCO and preserve uptime. However, there is a clear EU legislative pathway to move away from diesel, pushing lawmakers to guide truck manufacturers and road transport operators towards other fuels.

The next chart illustrates the number of alternative fuel trucks available on the market. The number of CNG and LNG trucks is expanding, but electric vehicles are being adopted more rapidly. Despite the large number of LPG vehicles, this fuel is not seen as a decarbonisation solution by some. Government subsidies, such as tax reductions, are being phased out for this fuel.

In 2023, there were 56,000 trucks running on alternative fuels in the EU. (Please note that there are no newly registered LPG trucks as they are the result of aftermarket diesel engine conversions.) The five biggest road freight countries – Germany, Poland, Spain, France and Italy – have 44,000 heavy-duty alternative fuel vehicles, representing 80% of the alternative fuel vehicle market.

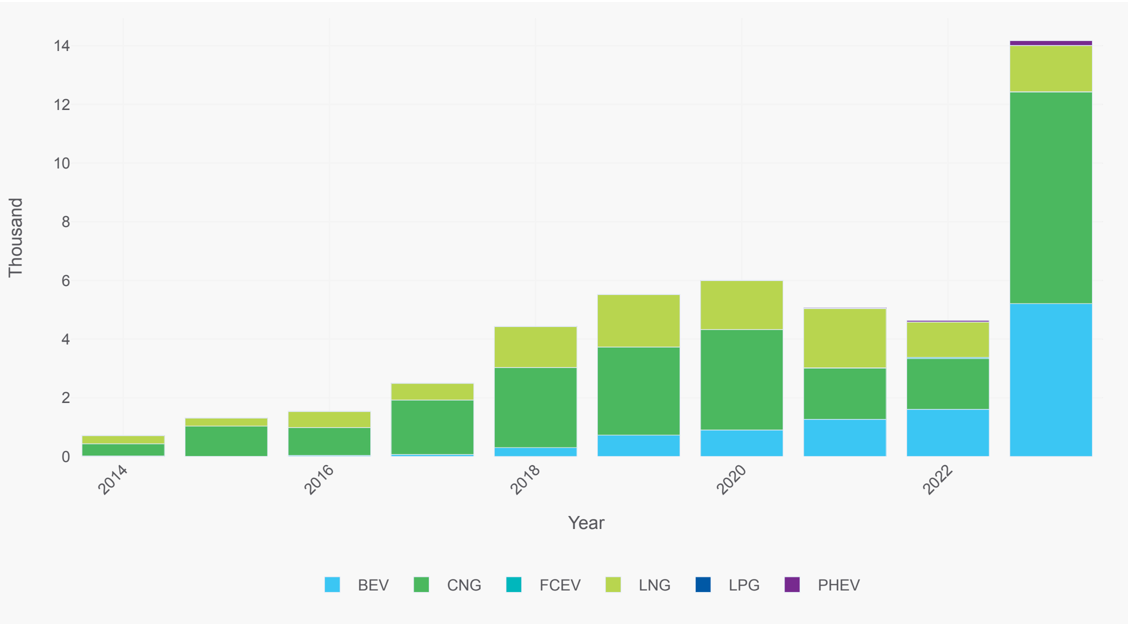
Distribution of alternative fuel trucks in EU



Source: EAFO extracted on 2024-10-23

In 2023, nearly 14,000 alternative fuel trucks were registered in the EU (62% CNG and LNG registrations; and 37% BEV registrations). Only six FCEV trucks were registered, highlighting that this technology is still at its early stages.

Registration of alternative fuel trucks in EU



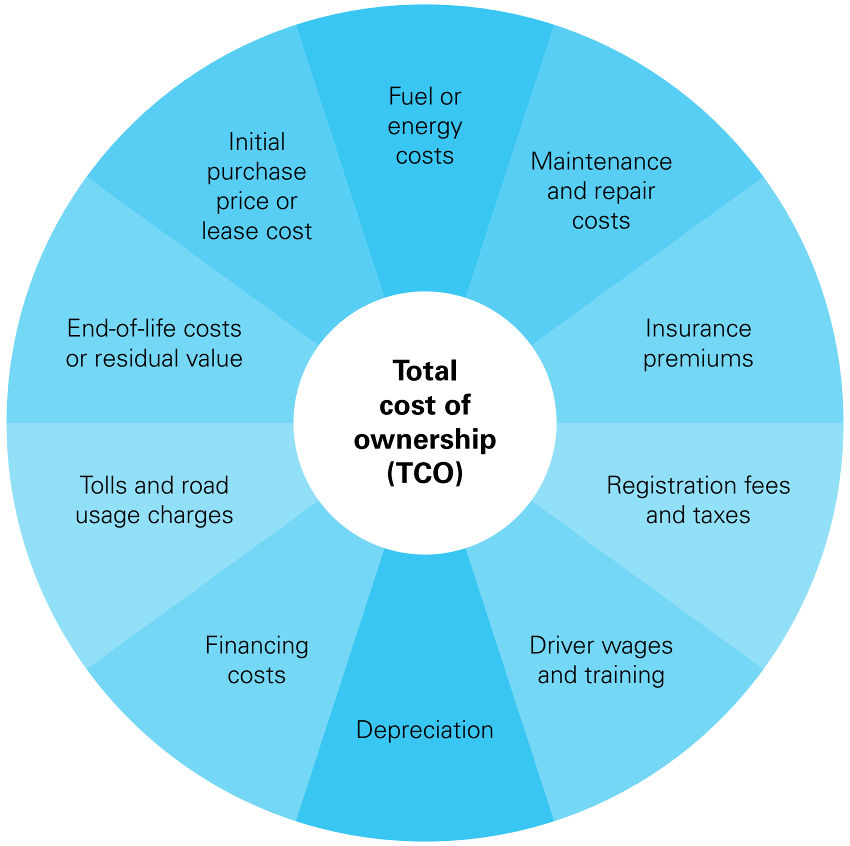
Source: EAFO extracted on 2024-10-23

Considering these aforementioned metrics, to obtain a holistic view on TCO in the EU, the analysis should start with the five key countries (Poland, Germany, France, Spain and Italy) and five types of powertrains (diesel, BEV, HVO, gas and FCEV).

Chapter 2

TCO components

TCO is a comprehensive financial metric that encompasses the full cost of acquiring, operating and maintaining a truck over its ownership cycle. It includes both direct and indirect costs associated with truck ownership and operation. TCO typically covers:

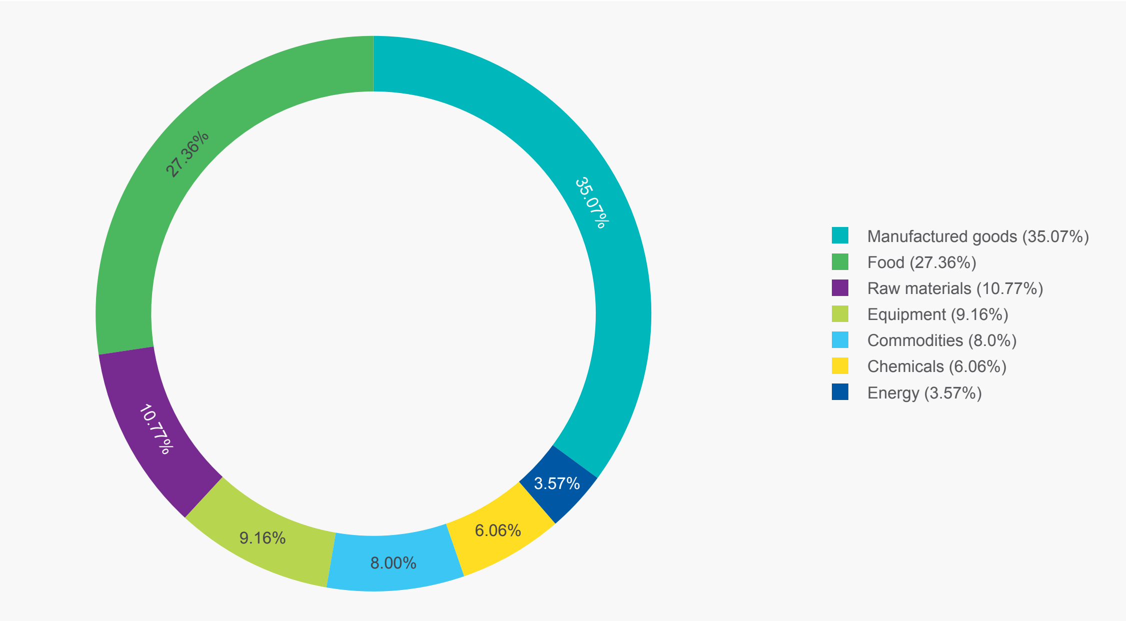


Driver wages and training do not vary for different powertrains, as the time of travel for a given trip is the same for all of them. It is also assumed that no specific training is required to use or recharge/refill energy tanks. Therefore, social charges will be excluded from future TCO figures. As for the rest, this section details all assumptions factored into the calculations.

2.1. Usage and ownership assumptions

The European truck fleet boasts a rich variety of vehicles, not only in terms of powertrains, but also in combinations, where lorries coexist with articulated vehicles and road trains. Such variety is needed to address all plausible road freight needs. The usage considered here involves carrying grouped goods and manufactured products on a long-haul cycle, as it is the most common type of transport in the EU.

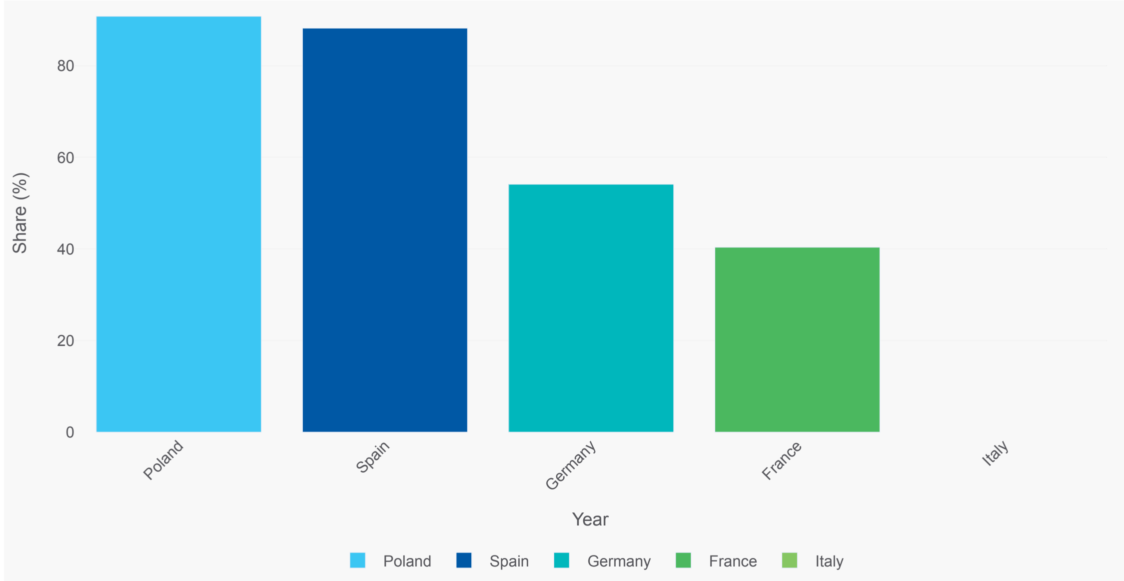
EU road freight volume by type of goods in 2023 (tkm)



Source: Eurostat (road_go_ta_dctg) extracted on 2024-10-23

The current analysis considers articulated vehicles made of two-axle road tractors pulling three-axle semi-trailers (T2S3), the most used combination in the five countries covered in this Intelligence Briefing (for Italy, there is no data to investigate, so it is assumed that it follows the same trend as the other four countries).

T2S3's share of freight volumes in 2023 (tkm)



Source: Eurostat (road_go_ta_axle) extracted on 2024-10-23

In this Intelligence Briefing, TCO includes the sum of all costs linked to the vehicle (except social charges and administrative costs), prorated based on the mileage accumulated by the first owner. It is considered that the first owner operates the vehicle for six years, with the vehicle being used the most during its first year, followed by a decreasing annual mileage over time. A constant yearly mileage could be a good approximation of vehicle usage, but it does not account for the effect of inflation and other cost increases, nor for the operational range of an electric vehicle, which will become less dependent on public charging over time.

The Conseil National Routier (CNR) conducts an annual survey to collect data on vehicle usage in France. It includes the yearly mileage recorded by road tractors during their first ownership life, as well as the number of operating days. The operating days are used to estimate daily vehicle mileage per year for other countries. As data only exists for France, it is assumed that vehicles' daily mileage per year is the same across the five biggest EU road freight countries. Other countries' yearly mileages are then calculated based on their national operating days.

	France	Germany	Poland	Spain	Italy
Operating days	227	232	265	244	230

Source: CNR extracted on 2024-10-23

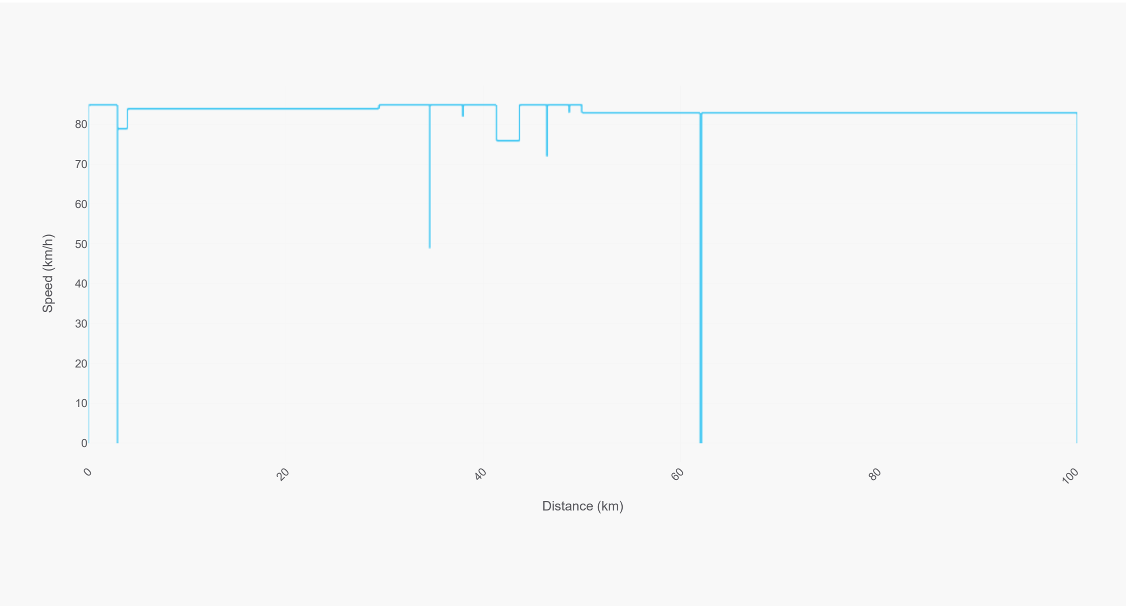
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
France	130,000km	120,000km	110,000km	105,000km	95,000km	90,000km
Germany	133,000km	123,000km	112,000km	110,000km	97,000km	92,000km
Poland	152,000km	140,000km	128,000km	123,000km	111,000km	105,000km
Spain	140,000km	129,000km	118,000km	113,000km	102,000km	97,000km
Italy	132,000km	122,000km	111,000km	106,000km	96,000km	91,000km

Source: IRU estimates & CNR extracted on 2024-10-23

The use case covered in this Intelligence Briefing is long-haul (daily mileage greater than 500km). To assess the energy consumption for every year, a speed profile is needed to reflect a long-haul use of an articulated vehicle.

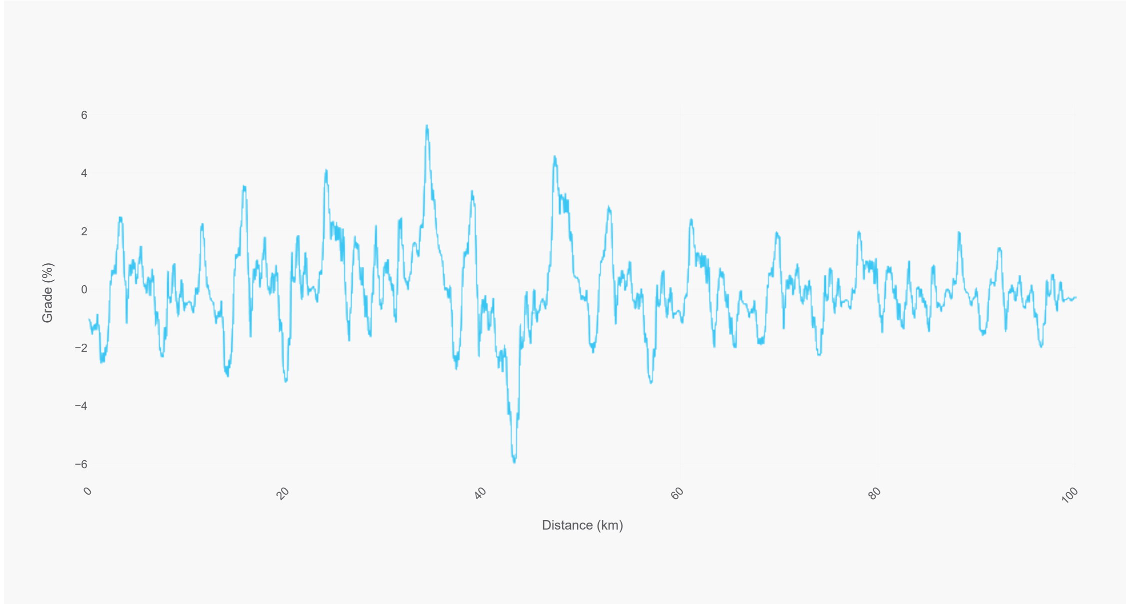
Using the IRU Alternative Fuels and Efficiency Model (AFEM) proprietary tool, vehicle characteristics are confronted to such speed profiles to estimate the amount of energy consumption. More details are given in the methodology section. The long-haul usage used by the Vehicle Energy Consumption Calculation Tool (VECTO) (version 4.2.5) is then taken as the calculation input. The speed and altitude profiles are shown below.

Speed profile of long-haul vehicles



Source: VECTO tool extracted on 2024-10-23

Altitude profile of long-haul vehicles



Source: VECTO tool extracted on 2024-10-23

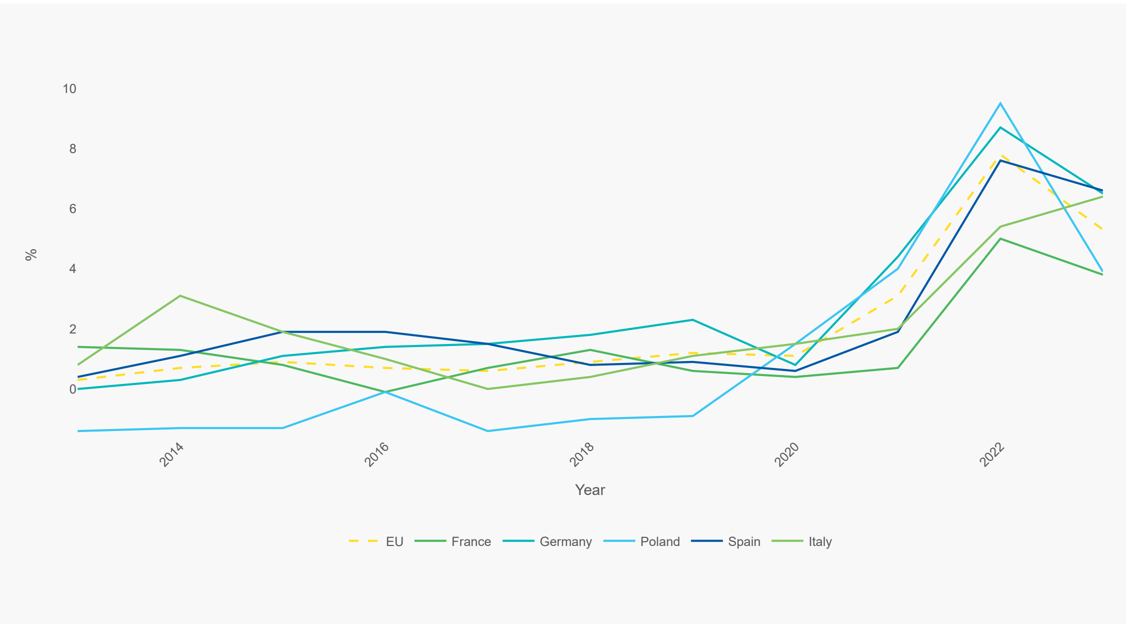
Regarding vehicle's technical description, values are provided at the end of the Intelligence Briefing. As for the payload, the Intelligence Briefing does not use only one average value per country, it rather considers the entire possible range of payload use.

2.2. Vehicle price components

The first TCO component covered is the price of the vehicle. For diesel vehicles, prices have been increasing over the past decade (on average by 24% in the EU) due to two main reasons. Firstly, new regulations have resulted in original equipment manufacturers (OEMs) implementing newer technologies and equipment. A recent example is the latest General Safety Regulation 2 (GSR 2) which requires trucks to be fitted with more advanced driver-assistance systems, such as advanced emergency braking systems. The second reason is inflation, which affects all costs related to manufacturing and delivering vehicles.

The following chart presents vehicle (cars, trucks and buses) inflation rates across the EU. In the past decade, most EU countries had vehicle inflation rates below 2% up until 2020. For the EU average, it increased to 7.8% in 2022, before starting to decrease in 2023. The sustained high level of vehicle inflation is mainly driven by higher production costs, but also component shortages, due to Covid-19 and the war in Ukraine. As a result, truck prices rose significantly over the past decade. In 2014, a Euro V road tractor cost EUR 80,000, on average, whereas a modern Euro VI truck costs EUR 110,000, on average. However, it is difficult to obtain an accurate view of road tractor prices, as it depends on many parameters such as fleets' bargaining power, the number of trucks ordered, and local truck dealers' incentives.

Vehicle price inflation



Source: Eurostat (prc_hcip_aind) extracted on 2024-10-23

As the analysis compares different powertrains, diesel road tractors need to be compared to gas-powered units (CNG and LNG), BEV and FCEV. Firstly, it is assumed that vehicles cost the same in the five countries. It is also assumed that a BEV costs 2.5 times more than a regular diesel truck (called class 1 in the table below), and that a FCEV vehicle costs 4.5 times more than a diesel one. Advanced diesel road tractors (which are more efficient) are also considered to benefit from lower toll prices (called class 2, see section on tolling) in countries applying the latest Eurovignette Directive. Finally, HVO is also considered in the powertrain comparison. HVO does not require any modifications to the diesel powertrain, thus it is assumed to have the same price. Below are the prices (without taxes). An additional EUR 30,000 is added to cover the price of semi-trailers (tautliner type).

	Regular diesel	Advanced diesel	Regular HVO	Advanced HVO	CNG	LNG	BEV	FCEV
Purchase price (w/o VAT)	110k€	120k€	110k€	120k€	135k€	155k€	290k€	495k€

Governments have the option of setting up national purchase incentives to support transport operators in their decarbonisation efforts. Such incentives are generally for the purchase of zero-emission vehicles (ZEVs). The following table presents the active purchase incentives instituted by governments for trucks. These subsidies are used to adjust the cost of road tractors in the TCO calculations.

Country	Status and conditions	Value per vehicle
France	• Up to EUR 20,000 for the purchase of an electric N2–N3 vehicles • 40% of additional depreciation for ZEVs	EUR 20,000 (BEV+FCEV) + EUR 30,000 BEV + EUR 50,000 FCEV
Germany	No purchase incentive	
Poland	• Subsides being discussed for N3, but no application yet. • Maximum of PLN 750,000 for a zero-emission N3 in 2025, or 60% for small operators, 50 for medium-size companies and 30% for large corporations	EUR 174,000 (BEV+FCEV) for small operators in 2025
Spain	Subsidy stopped in August 2024	
Italy	No subsidy for N3, N2 vehicles only	

In the analysis, it is assumed that transport operators purchase road tractors, although leasing remains a common alternative in the market. The purchase is considered to be financed with a bank loan. For calculation purposes, a 3.65% interest rate has been used uniformly across all road tractor powertrains for France, Germany, Spain and Italy, and a 5.75% interest rate has been used for Poland.

Another cost component to consider is the road tractor's residual value at the end of its first life (i.e. the value of the truck when the first owner sells it on the second-hand market). Residual values are difficult to estimate as they are influenced by many parameters such as:

- Comparison between pool of second-hand trucks available and the demand for such trucks
- Total vehicle mileage
- Vehicle age
- Physical state of the vehicle

For a typical diesel road tractor, the average residual value observed is about 20% after the six first years of use. As FCEV and BEV are just hitting the market, there is no solid data on residual values for such powertrains. For comparison purposes, a residual value of 20% is used for all powertrains. However, a TCO comparison is conducted without residual values for BEVs to assess the sensitivity of this component in Germany. Residual values for these new technologies could be lower than that of diesel trucks, as observed on the car market, due to progress brought by new models (lower retail price, greater range, etc), which lowers the value of older models.

Residual value for semi-trailers is about 25% after six years of use. Please note that the observed lifetime for a semi-trailer is 12 years for its first life with a residual value of 10%. However, to simplify the calculation, the value for a six-year lifetime is used.

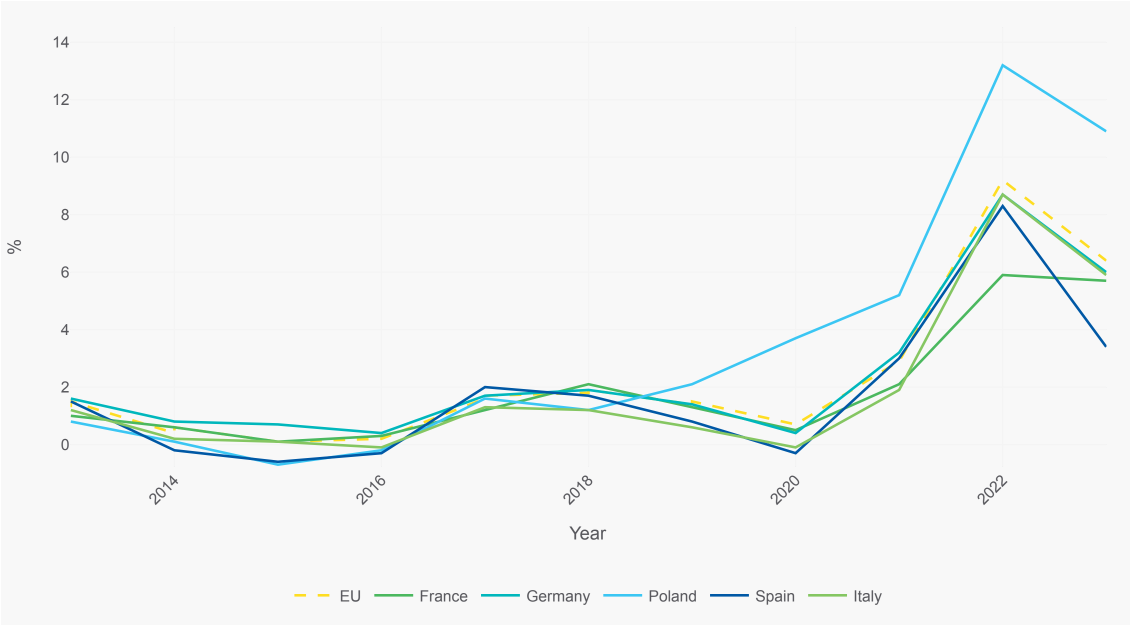
Finally, road tractors and semi-trailers must be insured to operate on public roads. Insurance policies differ greatly depending on the type of coverage, the company's history and its negotiating power. An average value observed in the market is approximately 2.5% of the vehicle price for diesel powertrains. The same insurance value is also applied for all types of powertrains and semi-trailers.

2.3. Inflation assumptions

In the methodology used to estimate the TCO, most prices are indexed to the inflation rate of the country, beginning from the second year of use until the end of the first ownership life.

The following graph presents inflation rates for the past ten years. Up until 2020, inflation had been fluctuating between 0% to 2%, on average. The decline in 2020 resulted from the reduction of economic activities caused by the Covid-19 pandemic. Afterwards, due to the combination of the post-pandemic economy rebound and the war in Ukraine, average inflation in the EU rose to 9%, before beginning to decline in 2023. The highest inflation was observed in Poland, with Polish diesel prices rising above Spanish prices for the first time since 2019.

Overall inflation rate



Source: Eurostat (prc_hcip_aind) extracted on 2024-10-23

Inflation forecasts made by the European Central Bank (ECB) and the National Bank of Poland (NBP) are around 2% and 3%, respectively. This table summarises the inflation forecasts for each respective country.

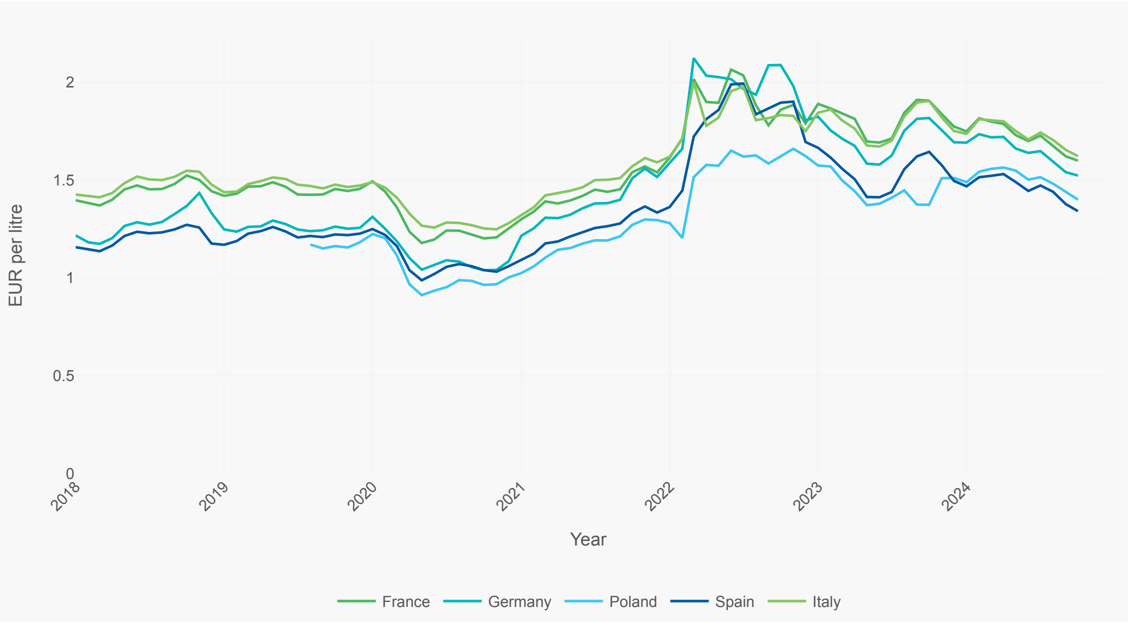
	2025 (%)	2026 (%)	2027 (%)	2028 (%)	2029 (%)
France	2.2	1.9	1.9	1.9	1.9
Germany	2.2	1.9	1.9	1.9	1.9
Poland	3.4	2.9	2.9	2.9	2.9
Spain	2.2	1.9	1.9	1.9	1.9
Italy	2.2	1.9	1.9	1.9	1.9

Source: ECB and NBP extracted on 2024-10-23

2.4. Fuel and energy cost assumptions

Diesel prices
The cost of energy is a critical component of the final TCO. The graph below compares diesel prices for the five biggest EU road freight countries between 2018 and 2024. During this recent period, Poland and Spain recorded the lowest diesel prices due to their lower taxes (excise duties below EU average) and crude oil prices. More detailed insights can be found in the IRU Intelligence Briefing on fuel prices in the EU.

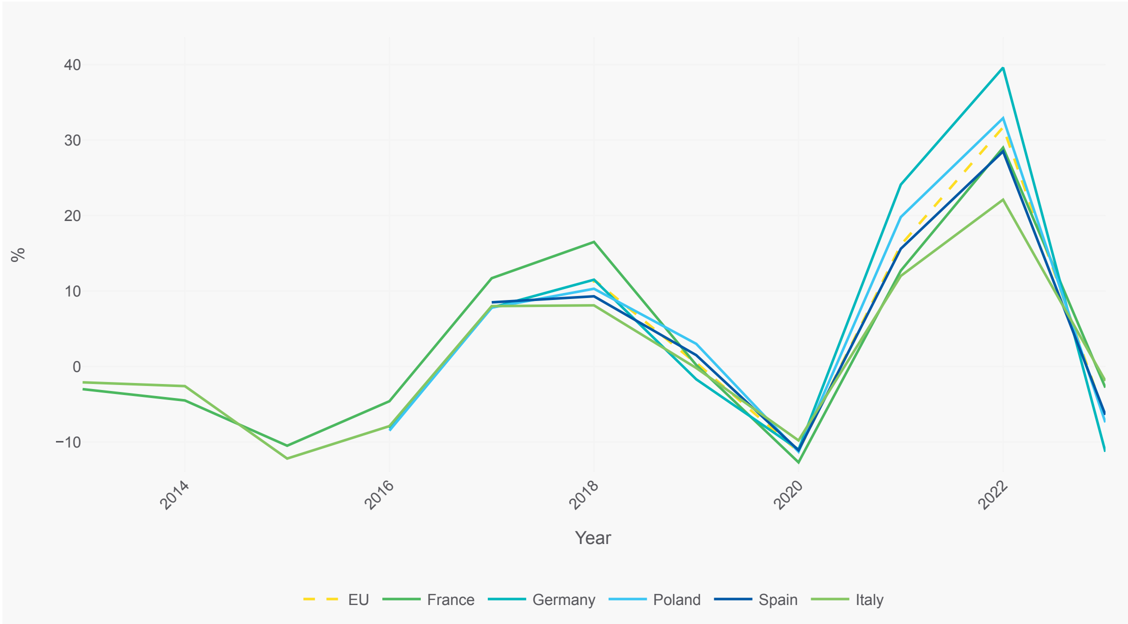
Diesel prices



Source: Xavvy extracted on 2024-10-23

The following graph presents diesel price inflation rates. Diesel prices across the EU experienced similar declines in 2020 (ranging from −9.8% in Italy to −12.7% in France) due to Covid-19, which restricted economic activity and lowered fuel demand. Diesel prices surged substantially in 2023, ranging from 22.1% in Italy to 39.6% in Germany. The post-Covid-19 economic rebound and the war in Ukraine impacted the demand-supply equilibrium for oil, creating short-term shifts, as demand grew but supply decreased due to sanctions.

Diesel inflation



Source: Eurostat (prc_hcip_aind) extracted on 2024-10-23

Diesel prices, which have been gradually declining since the beginning of 2024, are now very volatile despite continued reductions since the beginning of the year. As this Intelligence Briefing analyses the first six years of a vehicle, and due to pricing dynamic uncertainties, these prices will be adjusted by the forecasted inflation rate until 2029 within the calculations.

The table below summarises the latest diesel prices with and without recoverable taxes. Prices excluding recoverable taxes are considered in the TCO calculations.

Country	Price with taxes [€/L]	Price without recoverable taxes [€/L]
France	1.62	1.20
Germany	1.54	1.29
Poland	1.44	1.14
Spain	1.38	1.09
Italy	1.66	1.15

Source: Xavvy, average Septmber 2024 extracted on 2024-10-23

In addition, ETS2 taxation will be applied to these prices from 2027 onwards. It is assumed that the value of EUR 45 per tonne given by the EU directive is applied to diesel, AdBlue and natural gas prices, using a well-to-wheel carbon emission factor (see section 4).

HVO is expected to remain unaffected by such taxation. As the value of EUR 45 is based on 2020 prices, it needs to be adjusted for EU inflation.

The following values are used in the TCO calculations:

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
EU inflation [%]	Base	2.9	9.2	6.4	2.5	2.2	1.9	1.9	1.9	1.9
ETS2 [€/t]	0	0	0	0	0	0	0	58.5	59.6	60.8

These values are then transformed into a tax given in euros per litre or per kilogram, based on the carbon emission factors.

AdBlue prices

AdBlue is an additive required by diesel internal combustion engines to meet pollutant emission requirements. AdBlue consumption usually equates to about 5% of diesel and HVO consumption. Since AdBlue is mostly produced from natural gas, its price is closely tied to natural gas prices, which soared following the start of the war in Ukraine. The next chart examines the average price of AdBlue at the pump in the EU. AdBlue prices were below EUR 1 per litre before 2022 across the EU, peaking in 2023 (ranging from EUR 1.2 to 1.7 per litre), followed by a gradual decline and a stabilisation in 2024. Nevertheless, the increased distribution costs and the natural gas prices kept AdBlue prices above their 2022 levels.

AdBlue price for trucks

Source: Xavvy extracted on 2024-10-23

The following table summarises the most recent AdBlue prices with and without recoverable taxes. These prices are used to forecast future AdBlue prices when indexed to overall inflation rates (see section 2.3).

Country	Price with taxes [€/L]	Price without recoverable taxes [€/L]
France	0.73	0.58
Germany	1.21	0.98
Poland	0.88	0.68
Spain	0.92	0.73
Italy	1	0.78

HVO prices

Made from waste oils and fats, HVO is a drop-in replacement. Based on a well-to-wheel approach, it reduces CO_2 emissions, as well as pollutant emissions. However, HVO production is, and will remain, limited, raising questions about its long-term availability and pricing.

In this Intelligence Briefing, the pricing projection follows the same principle as diesel, with future values forecasted by indexing current prices to inflation. In the EU, transport operators can only recover VAT; no excise duty can be recovered.

HVO prices

Source: Xavvy extracted on 2024-10-23
(Spain, France and Poland data are missing)

HVO is not subject to the ETS2 taxation scheme. The vehicle characteristics are identical to those of diesel fuel, and the engine does not need any modifications to run on HVO. The same diesel tolling fee also applies, as the Eurovignette uses a tank-to-wheel approach, under which, both HVO and diesel engines emit the same amount CO_2 at the tailpipe.

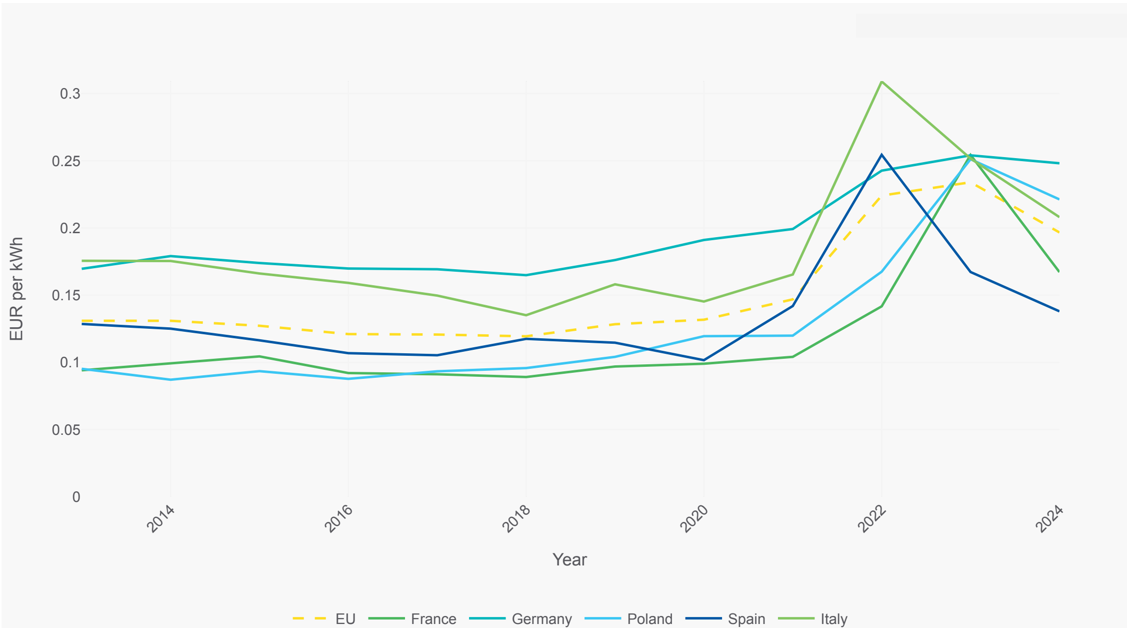
Country	Price with taxes [€/L]	Price without recoverable taxes [€/L]
France	1.78	1.42
Germany	1.61	1.27
Poland	1.58	1.22
Spain	1.52	1.20
Italy	1.62	1.26

Electricity prices

An electric truck can be charged at a depot, or at a public charging station, which generally offers higher power for quicker recharging, at the expense of the price. This results in two different prices for the same electrical kWh, with the cheapest option being at the depot.

To estimate the cost of depot charging, one must assess the consumption band the transport operator would fall into based on the size of its electric fleet. For a fleet of 25 BEV trucks, each running 100,000km per year, the annual energy consumption would be approximately 3,500MWh. The electricity prices provided below are for a consumption band between 2,000 and 19,999 MWh.

Wholesale electricity prices with taxes

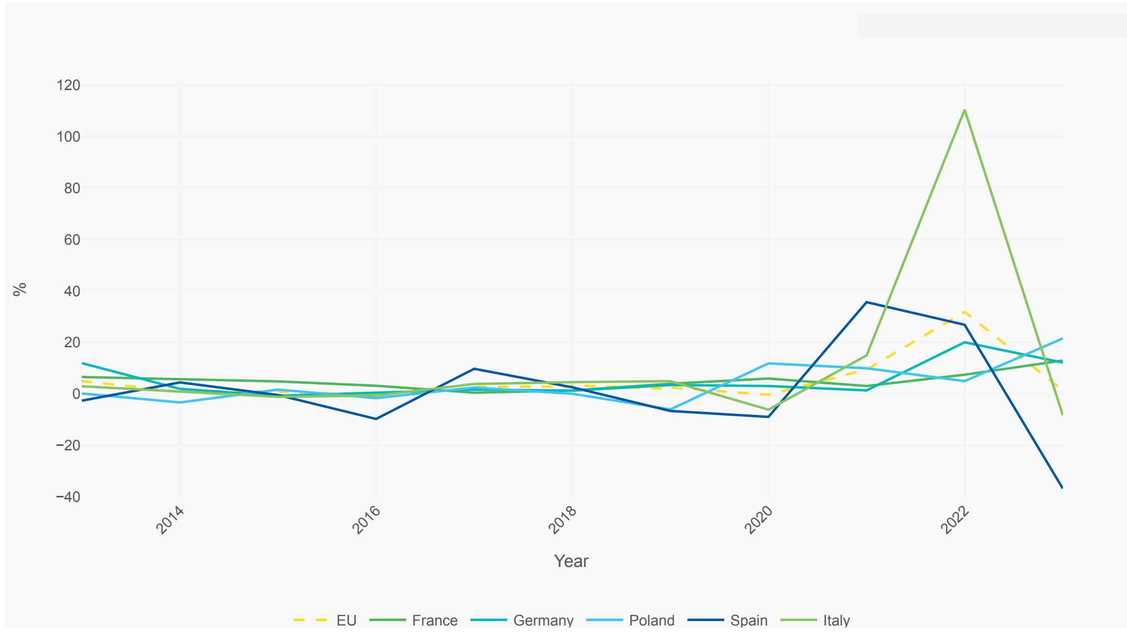


Source: Eurostat (nrg_pc_205) extracted on 2024-10-23

Wholesale electricity prices in the five biggest EU road transport countries began increasing in 2021, peaking in 2022, as shown above (69% increase in contrast to 2020). The Italian and Spanish markets were hit the hardest in 2022, but they recovered faster than other EU countries. France surpassed the EU average value in 2023 due to maintenance infrastructure issues and lower hydropower levels. In the first half of 2024, electricity prices fell in all countries except Germany, reaching their pre-2022 levels. Germany's switch from Russian CNG to LNG has resulted in consistently high energy costs. In contrast to CNG, LNG has higher transport costs and is mostly based on short-term market prices, resulting in higher overall costs.

The following graph illustrates the inflation of electricity prices across the EU. It shows that a substantial increase in electricity prices (more than 110% for Italy) occurred in 2022 due to the war in Ukraine. However, prices have been declining since then, returning to pre-2022 levels. In this Intelligence Briefing, the pricing projection follows the same principle as for diesel, with future values projected by indexing current prices to inflation. In the EU, transport operators can only recover VAT; no excise duty can be recovered on electricity.

Electricity inflation



Source: Eurostat (prc_hcip_aind) extracted on 2024-10-23

For depot charging, the electricity prices shared on the right are used, but the cost of chargers needs to be included. Assuming that there is a need for one 100kW charger priced at EUR 50,000, plus another EUR 20,000, this charger will cost EUR 0.03 per kWh. This calculation is based on a 15-year life expectancy, with the charger being used six days per week, 52 weeks per year, to charge a 500kWh battery overnight.

Country	Price with taxes [€/kWh]	Price without recoverable taxes [€/kWh]
France	0.17	0.14
Germany	0.25	0.20
Poland	0.22	0.17
Spain	0.14	0.11
Italy	0.21	0.16

Since depot charging does not usually fully meet daily energy requirements, the IRU AFEM model estimates the amount of charging that needs to occur at public stations. Using MILENCE data, the prices shared on the right are applied.

Country	Price without recoverable taxes
France	0.399 €/kWh + 1.99€
Germany	0.399 €/kWh + 1.99€
Poland	0.399 €/kWh + 1.99€
Spain	0.399 €/kWh + 1.99€
Italy	0.399 €/kWh + 1.99€

In this Intelligence Briefing, the pricing projection follows the same principle as diesel, with future values forecasted by indexing current prices to inflation. It is assumed that transport operators will find suitable public chargers available when needed, and it is also assumed that charging time does not count as drivers' working time. Considering the energy requirements at stations, derived from the IRU AFEM model, this assumption is reasonable as the battery does not need to be fully charged at public stations.

Hydrogen prices

Hydrogen remains an energy source in development, based on the current offer of fuelling stations and available trucks, with current prices likely higher than future forecasts. Hydrogen competes for investment with alternative sources of energy (notably electricity) and therefore still faces a “chicken and egg dilemma”: hydrogen suppliers are wating for a widespread adoption of FCEV trucks, while transport operators and original equipment manufacturers are waiting for favourable market conditions to invest and scale up the technology.

For the purpose of the TCO analysis, it is assumed that hydrogen prices will follow the inflation rate (section 2.3.) during the first ownership cycle of the truck.

Hydrogen prices

Source: Xavvy extracted on 2024-10-23

Country	Price with taxes [€/kg]	Price without recoverable taxes [€/kg]
France	15	12
Germany	16.7	13.5
Poland	16.7	12.9
Spain	10	7.9
Italy	10*	7.8

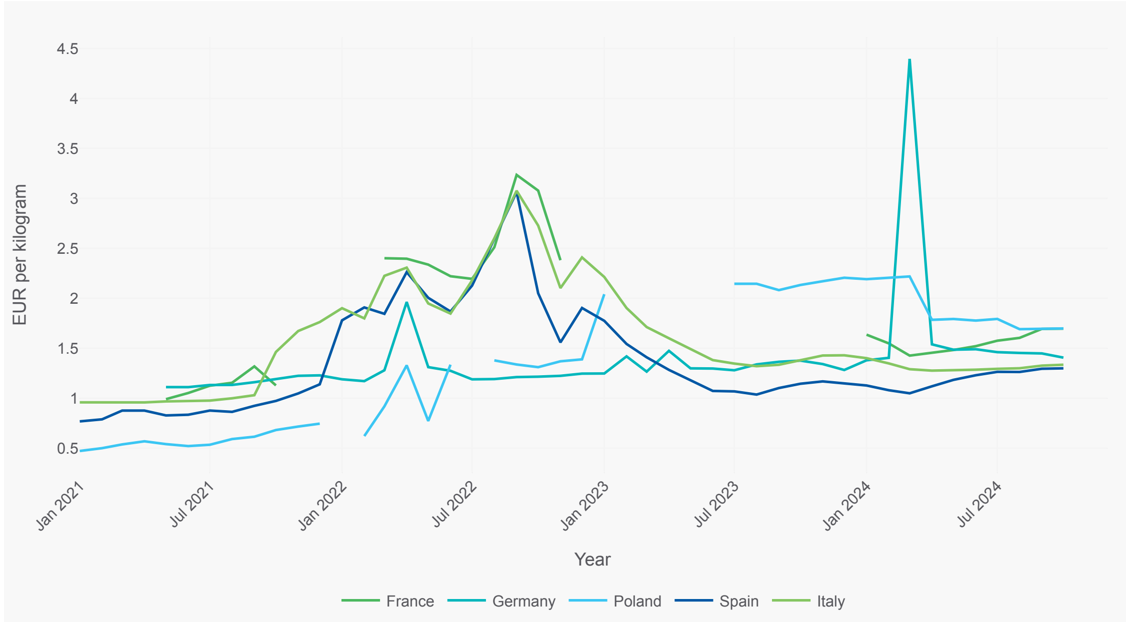
This Intelligence Briefing assumes that transport operators will find suitable filling stations for their vehicles when needed. The pricing projection follows the same principle as for diesel, with future values forecasted by indexing current prices to inflation.

CNG prices

CNG is the second most used alternative fuel among road transport operators in the EU (50% of alternative fuel trucks in 2023). Since 2013/2014, CNG-fuelled vehicles have grown in popularity, their engine power and torque level are comparable to diesel engines, as highlighted in the first section.

CNG, a derivative of natural gas, is stored onboard in cylinders at pressures between 200 and 250 bars. It can be distributed via pipelines or dedicated trucks. In 2022, CNG prices across the EU increased substantially due to the war in Ukraine, with Spain, France and Italy experiencing the highest prices. CNG prices have recently dropped by over 50% compared to 2022 levels, stabilising at a more consistent rate. However, their prices are still roughly double the prices observed before 2022.

CNG prices



Source: Xavvy extracted on 2024-10-23

This table shows the assumptions that were made in the calculation of CNG prices.

The pricing projection follows the same principle as for diesel, with future values forecasted by indexing current prices to inflation.

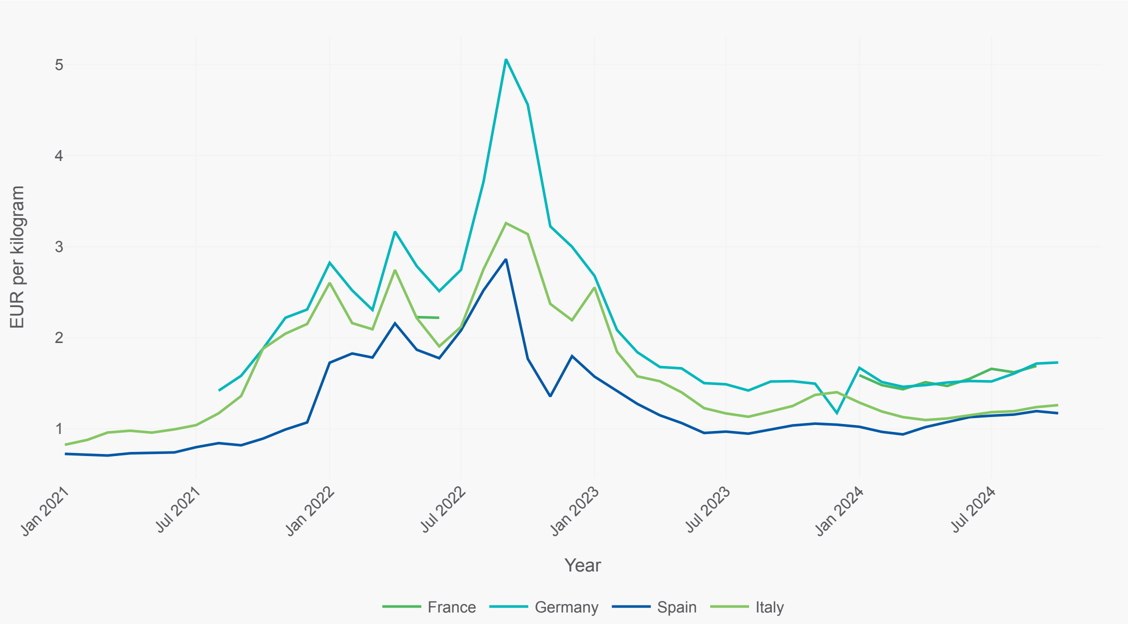
Country	Price with taxes [€/kg]	Price without recoverable taxes [€/kg]
France	1.69	1.35
Germany	1.45	1.17
Poland	1.69	1.30
Spain	1.29	1.02
Italy	1.33	1.04

LNG prices

LNG is natural gas cooled to a liquid state through a liquefaction process. Stored at -162°C, LNG has a higher energy density than CNG, giving tractor units a greater operational range. In the EU, LNG powertrains accounted for almost 20% of total trucks in 2023.

In 2022, both LNG and CNG prices surged across the EU (for instance, in Germany, LNG and CNG prices increased versus 2021 by 77% and 256%, respectively) due to the war in Ukraine. LNG experienced sharper spikes, especially in Germany and Italy. Although prices for both fuels have since decreased, they remain higher than their pre-2022 levels. LNG has shown more stability in recent years but is still more expensive than CNG in most markets.

LNG prices



Source: Xavvy extracted on 2024-10-23

Country	Price with taxes [€/kg]	Price without recoverable taxes [€/kg]
France	1.69	1.35
Germany	1.72	1.39
Poland	1.69	1.30
Spain	1.19	0.94
Italy	1.24	0.97

This table shows the assumptions that were considered in the calculation of LNG prices.

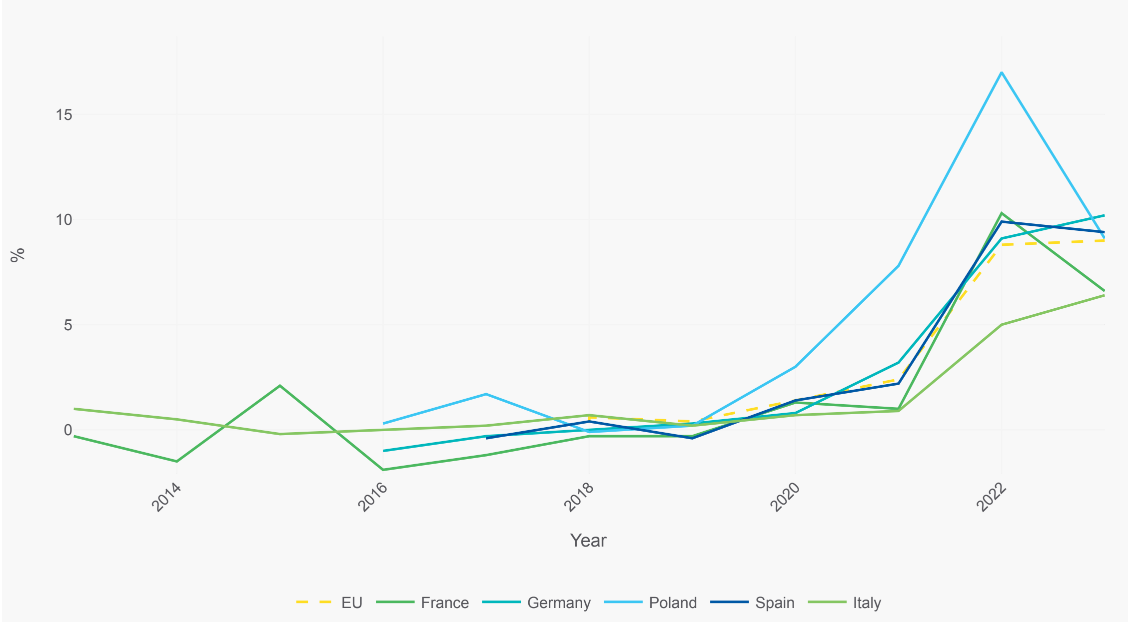
The pricing projection follows the same principle as for diesel, with future values forecasted by indexing current prices to inflation.

2.5. Tyre cost assumptions

Tyres impact TCO directly through their cost and use over a maximum mileage. They also impact TCO indirectly through their rolling resistance. The rolling resistance of tyres adds to other mechanical forces, such as aerodynamics, opposing the vehicle's movement. This resistance also affects energy consumption. The EU mandates various labels to inform transport operators, with rolling resistance being one grade given alongside wet adherence and noise.

Tyre costs have risen significantly in recent years (44% increase since 2016 in Poland). The rise can be attributed to increases in raw material prices and transport costs. Mandatory EU labelling introduced in 2021 might also explain this increase, as consumers were encouraged to purchase better performing products.

Tyre inflation



Source: Eurostat (prc_hcip_aind) extracted on 2024-10-23

These are the prices used in the analysis for premium C-grade tyres (size 315/70R22.5 for road tractors; and 385/55R22.5 for semi-trailers).

Country	Price without recoverable taxes [€]
France	700
Germany	510
Poland	470
Spain	650
Italy	600

On average, tyres' expected lifespan for diesel and HVO variants is 250,000km for the front axle, 200,000km for the drive axle, and 400,000km for the semi-trailer axle. For BEV and FCEV powertrains, the IRU AFEM model assesses how the energy recovered from braking affects the lifespan of tyres, reducing their durability.

In addition to these prices, the labour costs for rotating tyres should be accounted for. It is assumed that it accounts for 5% of the price of tyres.

2.6. Assumptions, maintenance and repair expenses

Maintenance includes both breakdown repairs and regular preventive maintenance. A general value is given for all powertrains. Even though electrical powertrains are supposed to require less maintenance, the lack of data and the fact that mechanics will need to be trained favours keeping a universal value for all powertrains. Only oil changes do not concern BEV and FCEV trucks, thus they need to be added to regular maintenance fees for diesel, HVO, CNG, and LNG road tractors.

The following maintenance cost assumptions are made, based on French data from CNR, indexed to the national median net income for 16 to 64-year-old employees and national company tax rates. Values are also indexed to inflation.

Maintenance [€/km]	2024	2025	2026	2027	2028	2029
France	0.095	0.097	0.099	0.101	0.103	0.105
Germany	0.114	0.117	0.119	0.121	0.124	0.126
Poland	0.035	0.036	0.037	0.038	0.039	0.040
Spain	0.071	0.074	0.076	0.078	0.080	0.083
Italy	0.085	0.087	0.089	0.090	0.092	0.094

Source: IRU modelling based on spare part costs and median income, already indexed to inflation

Country	Median net income [€]	Company tax rates [%]
France	27,833	25.0
Germany	30,533	29.9
Poland	11,691	19.0
Spain	20,963	25.0
Italy	23,375	24.0

Source: Eurostat (prc_hcip_aind) extracted on 2024-10-23

Country	Oil change cost [€]	Oil (without VAT) [€/L]
France	75	10
Germany	95	7
Poland	25	7
Spain	55	9
Italy	70	8

Source: IRU estimates

2.7. Registration fee and ownership tax assumptions

To operate a vehicle, transport operators must pay a registration fee when they purchase the vehicle, for both the road tractor and the semi-trailer, as well as an annual fee called ownership tax. These taxes depend sometimes on the powertrain, as governments might favour ZEVs.

Country	Registration tax	Ownership tax
France	850€ ZEV 320€	516€
Germany	26.3€	929€ ZEV 373€
Poland	290€	1,300€
Spain	100€	810€
Italy	1,250€	1,500€

Source: ACEA & Service Public & Ministry Transport of Spain extracted on 2024-10-23

2.8. Tolling assumptions

As articulated vehicles used for long-haul missions cover long distances every day, they spend most of their time on highways or similar long-stretch forms of roads. To fund the maintenance of such roads and account for externalities such as noise and air pollution, governments have set up tolling systems, which vary quite significantly from country to country in the EU. In the countries covered by this Intelligence Briefing, all tolling schemes are distance-based. However, France, Italy and Spain are using a gated distance toll scheme, with different fees depending on the road location, trip length on the toll network, and vehicle size. Whereas Germany and Poland are using digital tolls, with a harmonised fee at the national level and few local exceptions.

Transport operators' use of the toll network depends on the coverage of such networks and the alternative roads they can leverage to minimise this TCO component. For all countries except Germany and Spain (for Spain, according to the Ministry of Transport), the assumption taken is a toll intensity based on CNR data collection corrected by inflation values, resulting in the following table:

Country	Toll intensity [€/km]
France	0.100
Poland	0.100
Spain	0.190
Italy	0.160
Italy	70

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This toll already reflects the mix of toll and no-toll roads taken by transport operators. Since last December, Germany has applied a CO_2 component to its tolls, based to the Eurovignette directive, with a fee dependent on the CO_2 performance of the vehicle. A vehicle can fall into five classes:

- **Class 5** includes emission-free vehicles without an internal combustion engine (BEV or FCEV), and vehicles with an internal combustion engine whose CO_2 emissions are less than 1 g CO_2/kWh or less than 1 g CO_2/km.
- **Class 4** is for vehicles whose specific CO_2 emissions are more than 50% below the vehicle subgroup-specific CO_2 reference value.
- **Class 3** covers vehicles whose specific CO_2 emissions are more than 8% below the vehicle subgroup-specific CO_2 reference value at the time of initial registration. Vehicles in this class are retested and, if necessary, reclassified every six years.
- **Class 2** is for vehicles whose specific CO_2 emissions at the time of initial registration are more than 5% below the vehicle subgroup-specific CO_2 reference value. These vehicles are also retested and potentially reclassified every six years.
- **Class 1** includes vehicles that do not qualify for a higher CO_2 emission class. This may occur if the CO_2 emissions exceed the vehicle subgroup-specific CO_2 reference value, if no suitable verification documents are provided, or if no CO_2 reference value is available. Vehicles with a first registration date before 1 July 2019 are also automatically assigned to CO_2 emission Class 1.

Most diesel vehicles fall into Class 1. Some modern diesel vehicles can fall into Class 2, while some natural gas engines can fall into Class 3. The corresponding toll fees for Germany are given in the next table. (Please note that these values are not yet corrected for annual inflation, but they are for the calculations.)

Toll T2S3 [€/km] without VAT	2025	2026
Class 1	0.348	0.348
Class 2	0.340	0.340
Class 3	0.332	0.332
Class 4	0.269	0.269
Class 5	0	0.074

Source: Toll Collect DE extracted on 2024-10-23

It is assumed that a German truck covers 75% of its annual mileage on the toll network.

Chapter 3

TCO comparison

TCO is a crucial performance indicator for transport operators and shippers, but it is complex to handle as a single value does not provide the full picture. Despite the extensive research in this Intelligence Briefing, the TCO values should be considered in the stated use case and assumptions used based on the time period considered. For example, the Intelligence Briefing assumes a constant workload, payload and external conditions for vehicles over their first six years. As a result, the values do not factor in the effects of weather or empty trips. Moreover, the TCO values do not fully reflect the risk transport operators face with greater capital investment in their fleets, particularly in cases of major breakdowns or low transport activity. New powertrains tend to offset their higher capital expenditure (CapEx) through lower operational expenditures (OpEx). Nevertheless, a TCO analysis remains relevant as it illuminates the current standing of technologies in today's market conditions.

This Intelligence Briefing assumes that the enabling conditions exist for all fuels, giving transport operators access to HVO, CNG, LNG, H2 and electric chargers suitable for articulated vehicles. However, these enabling conditions are not yet in place for LNG, H2 and electric charging. Regarding HVO, it is important to note that production levels will be limited compared to the needs of road transport (including cars and vans), maritime and aviation. To put it in perspective, the total HVO production forecast for 2050 would cover less than a third of truck and bus needs, and only if all European production was consumed.

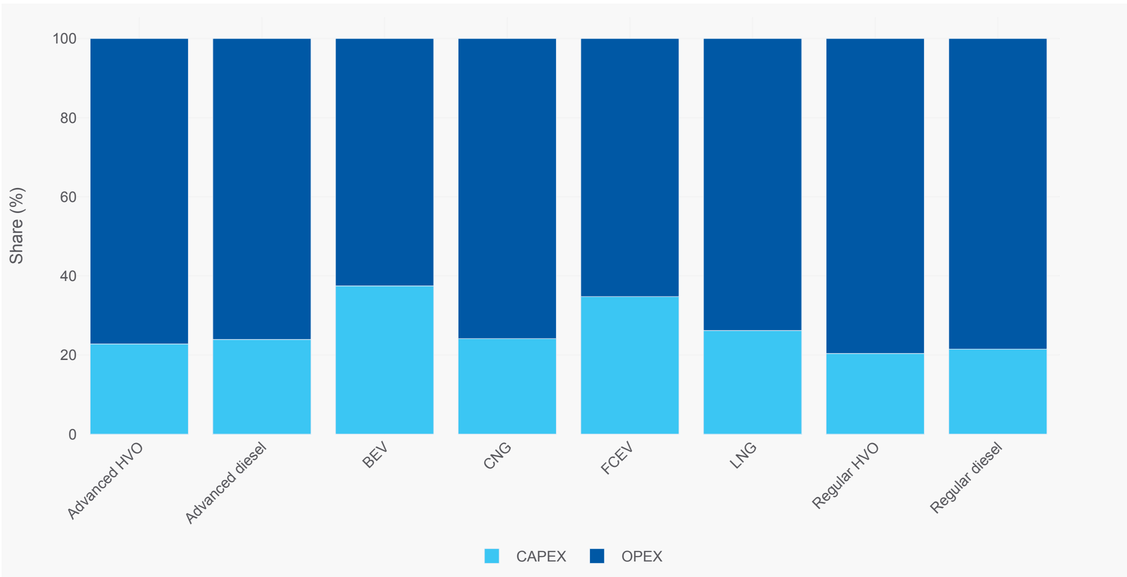
TCO will be presented in two units: EUR per kilometre for a given payload, and EUR per tonne-kilometre.

3.1. TCO decomposition (CapEx and OpEx) for a given payload

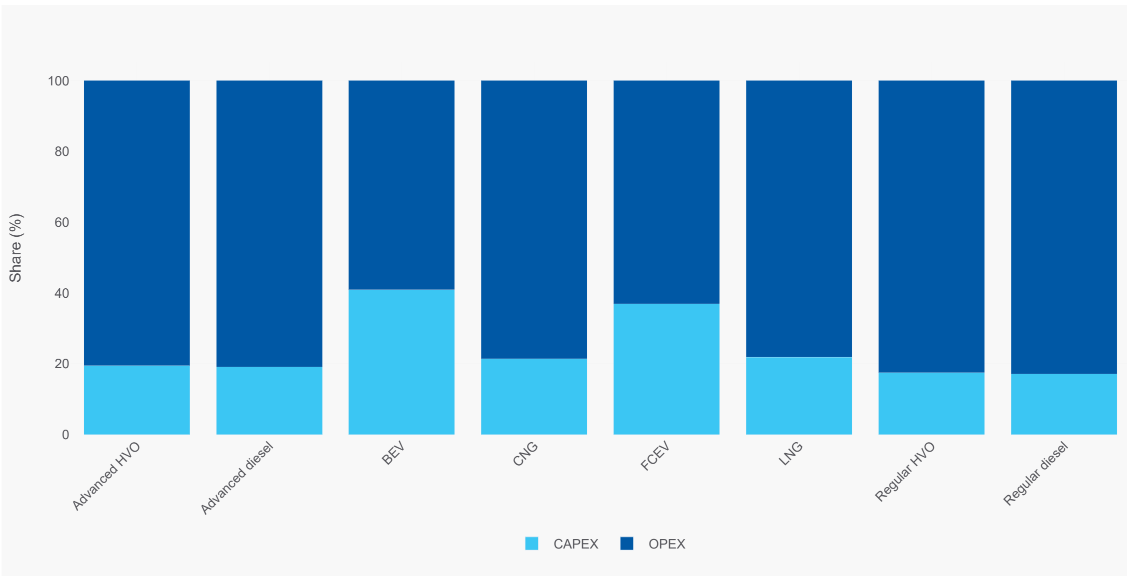
This section breaks downs TCO's cost structure by powertrain and country for a given payload. The payload is assumed to be 15 tonnes for long-haul operations (EU average payload for articulated vehicles).

Starting by looking at the weight of CapEx and OpEx in the TCO, it should be noted that the regular diesel truck (class 1 on CO_2 emissions) is the least CapEx-intensive powertrain. BEV and FCEV trucks have a more CapEx-intensive TCO, with FCEV being the most CapEx-intense on average, apart from Germany, Poland and France, where the weight of CapEx is greater for battery, since FCEVs' OpEx are significantly higher than that of BEVs. OpEx are the main TCO cost component (more than 60-80% on average) for all powertrains and all countries.

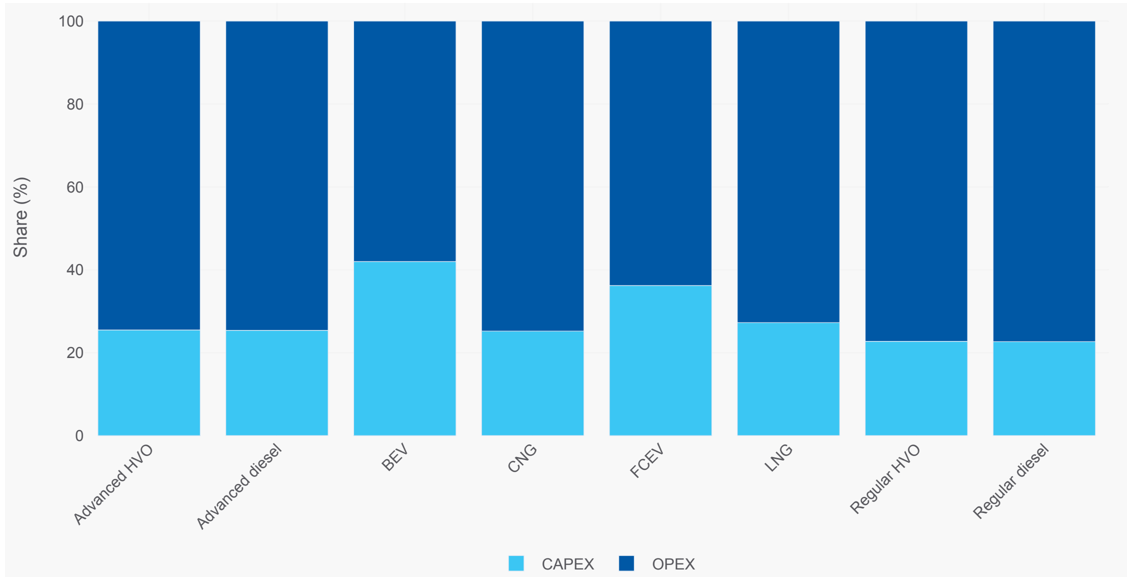
Cost structure by powertrain for 15-tonne payload in France



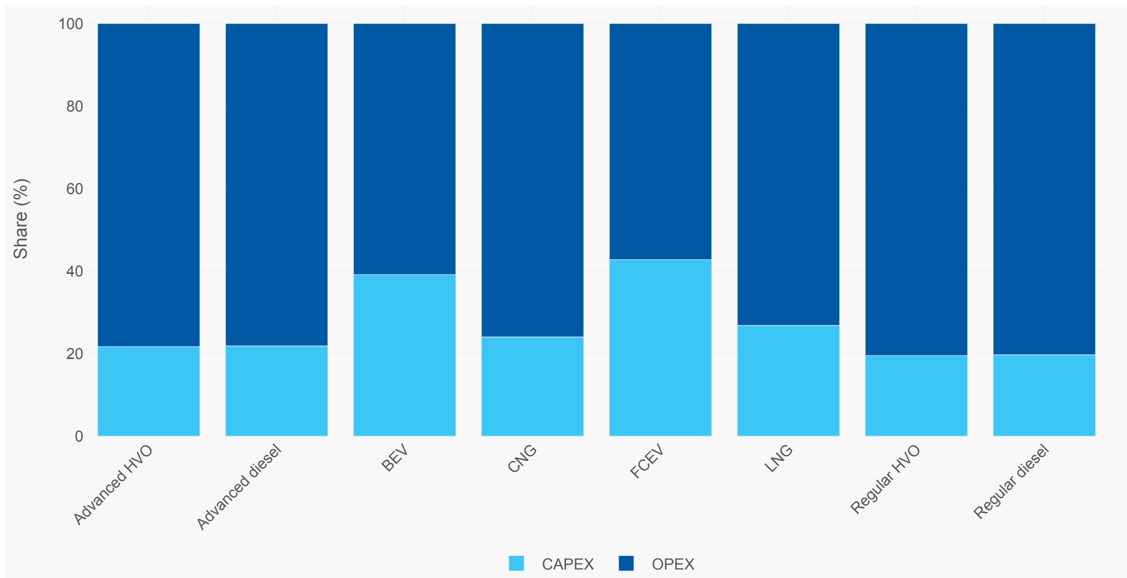
Cost structure by powertrain for 15-tonne payload in Germany



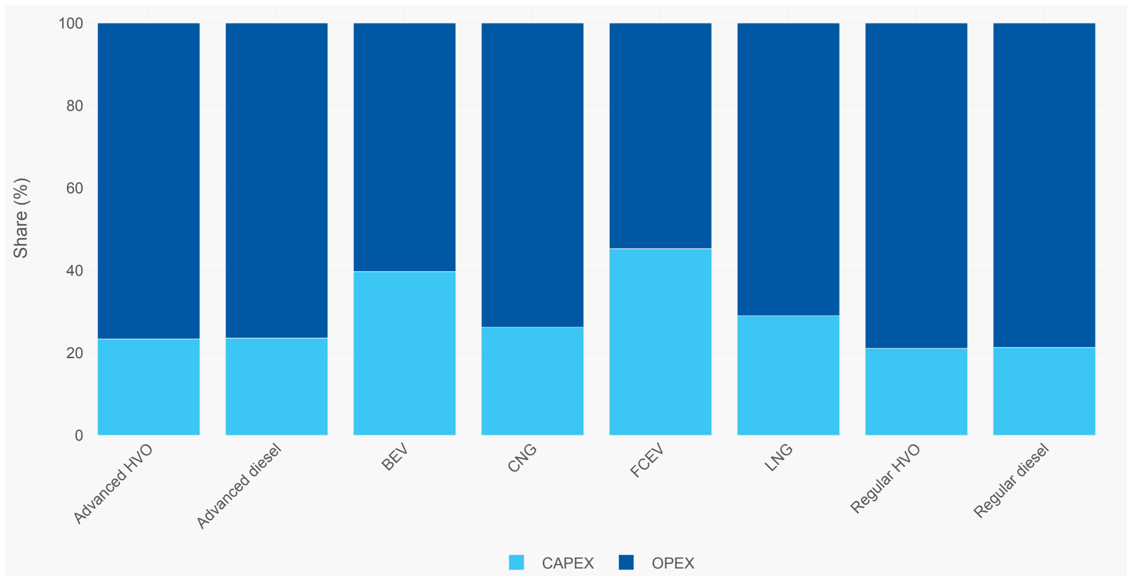
Cost structure by powertrain for 15-tonne payload in Poland



Cost structure by powertrain for 15-tonne payload in Spain

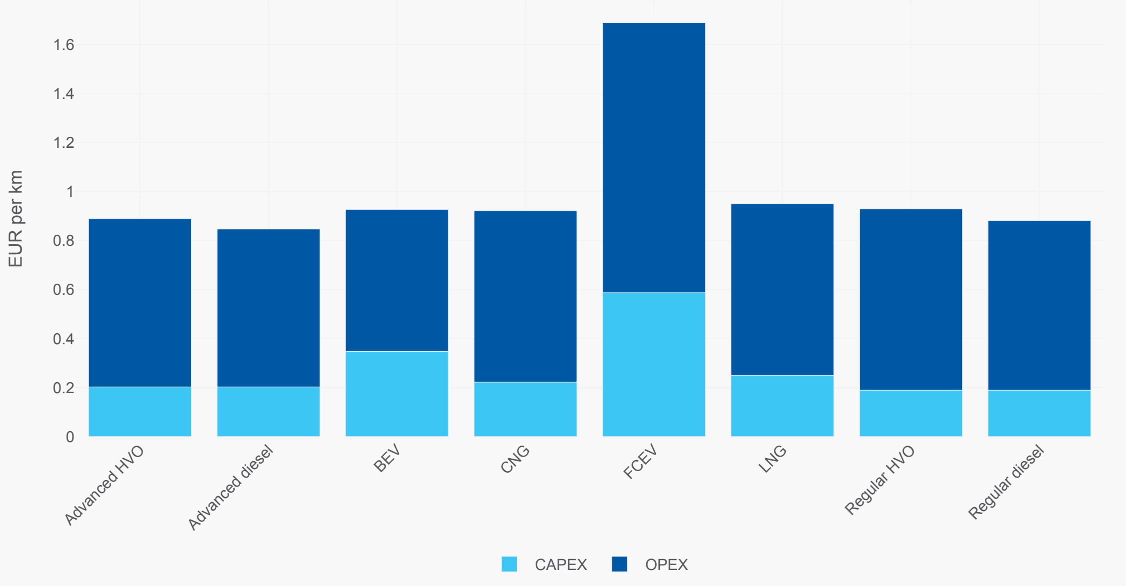


Cost structure by powertrain for 15-tonne payload in Italy

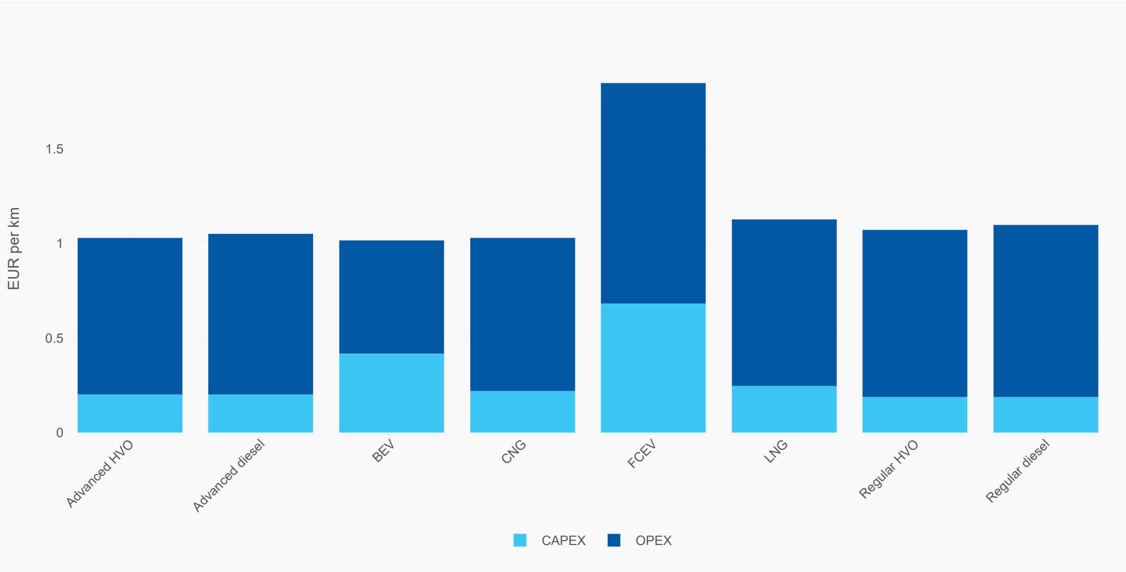


Looking at TCO in absolute value (EUR per km), the situation differs greatly between countries. However, for all of them, FCEV powertrains are the most expensive to operate, costing about EUR 1.6 per kilometre, 1.5 times more expensive than other powertrains.

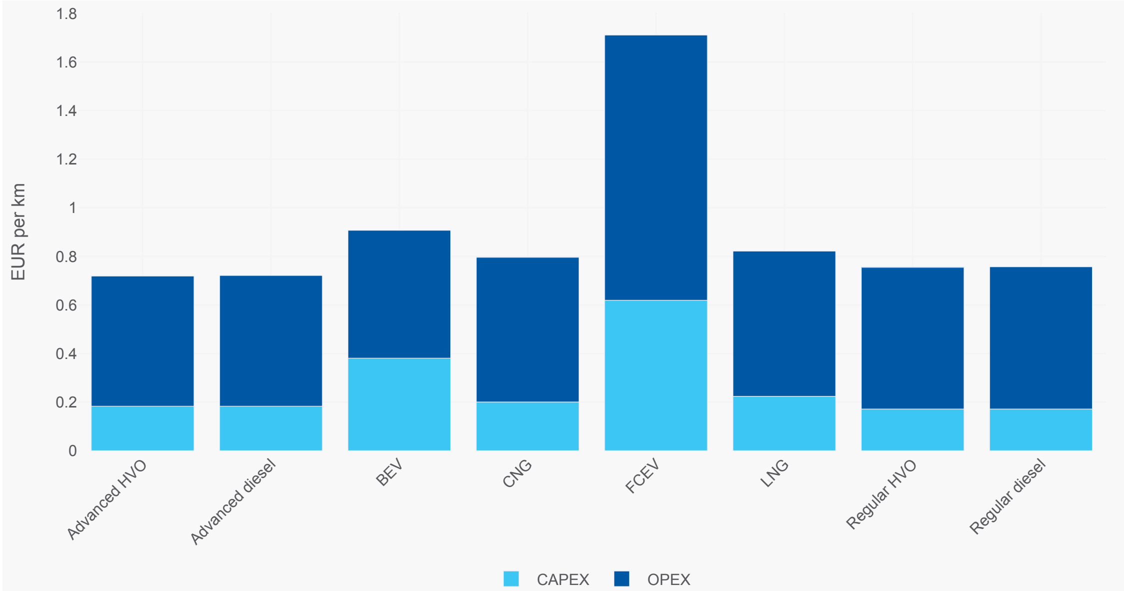
Cost structure by powertrain for 15-tonne payload in France



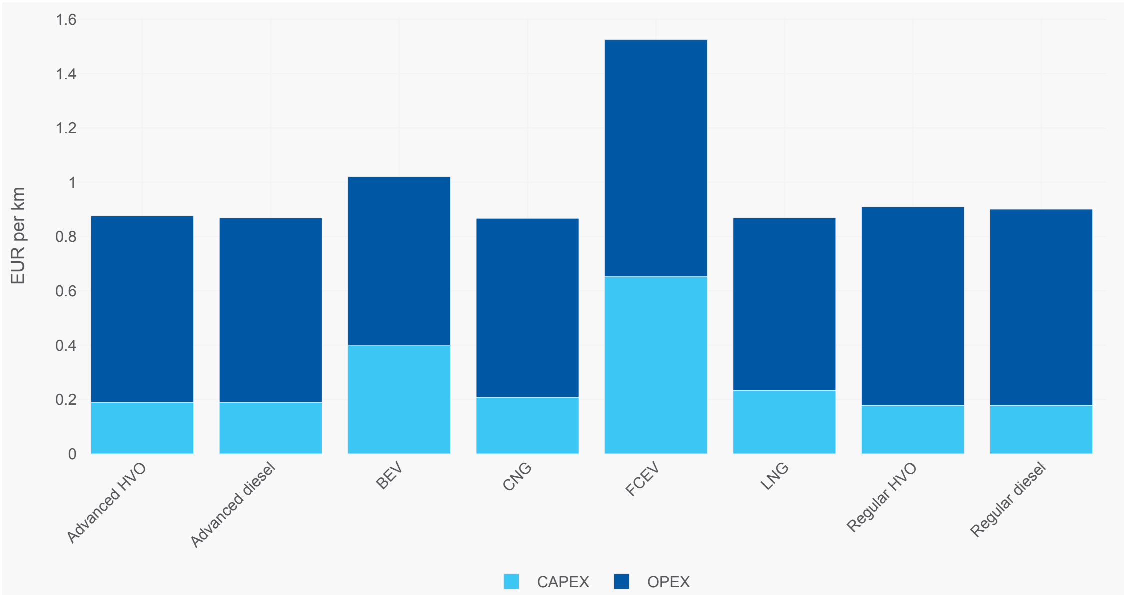
Cost structure by powertrain for 15-tonne payload in Germany



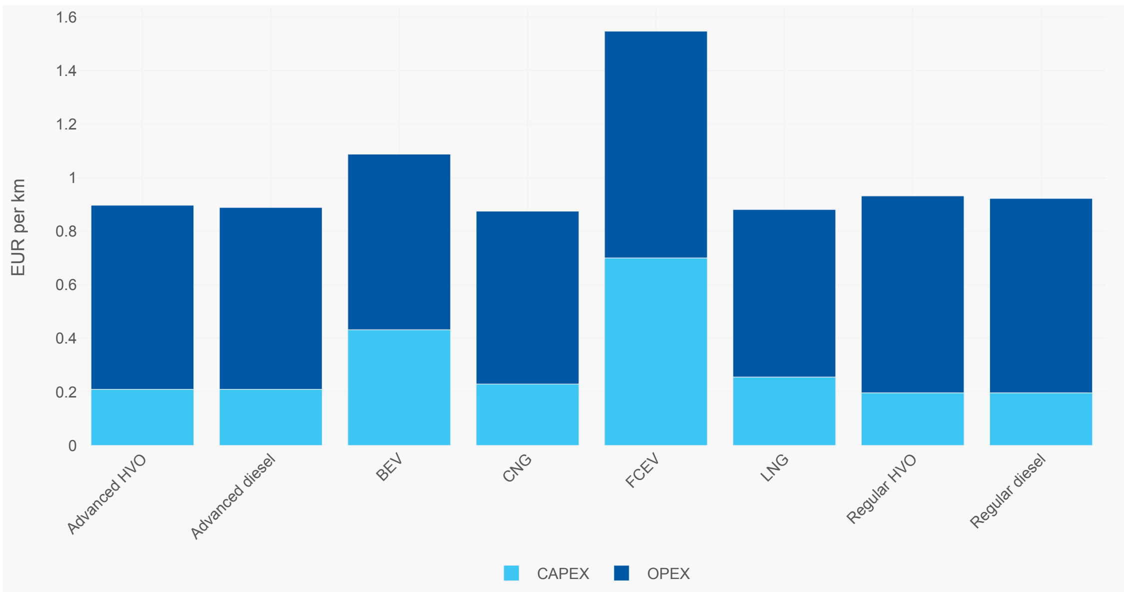
Cost structure by powertrain for 15-tonne payload in Poland



Cost structure by powertrain for 15-tonne payload in Spain

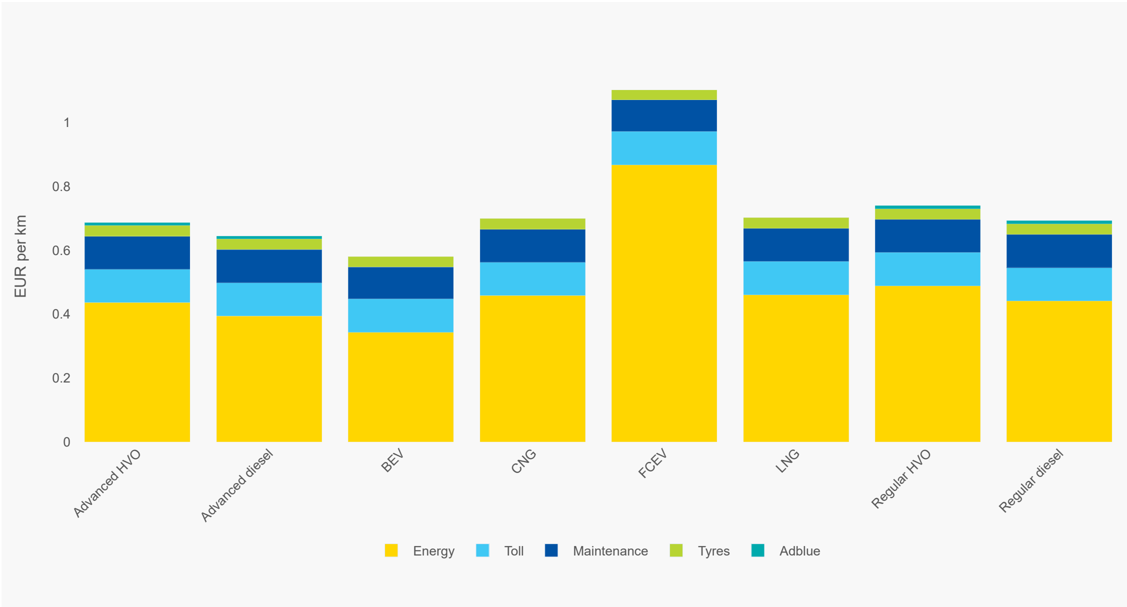


Cost structure by powertrain for 15-tonne payload in Italy

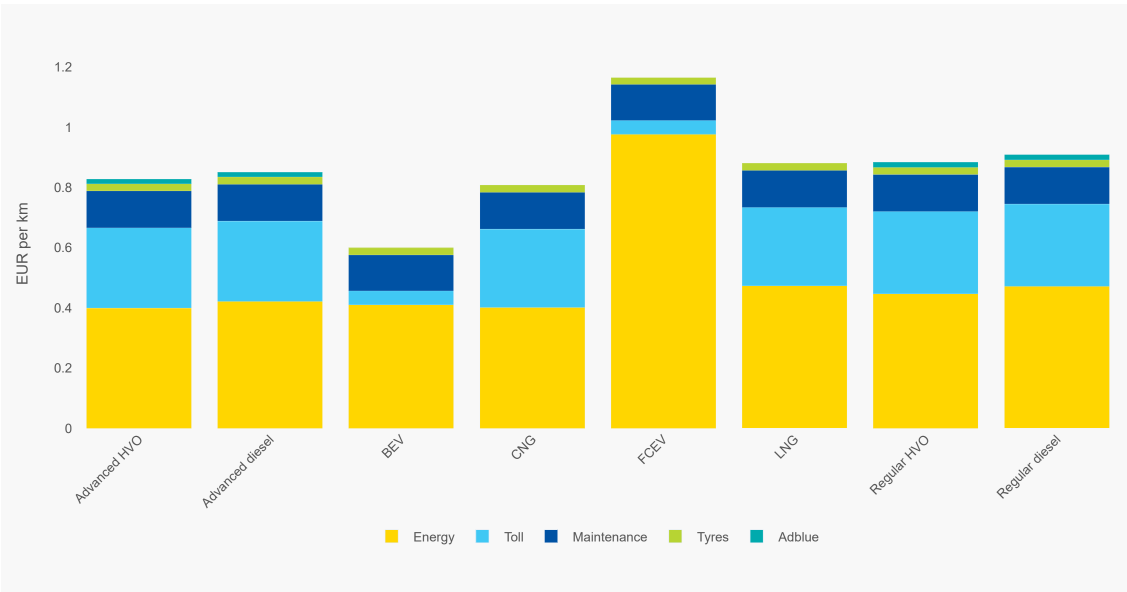


The least expensive powertrain depends on the country. In France and Poland, the most advantageous TCO is brought by the advanced diesel engine. In Italy, CNG is the most interesting option, in Spain, it is LNG, and in Germany, BEV is the best option at equal values. Energy costs and tolls are the primary factors explaining such rankings, as shown by the next graphs depicting the OpEx decomposition.

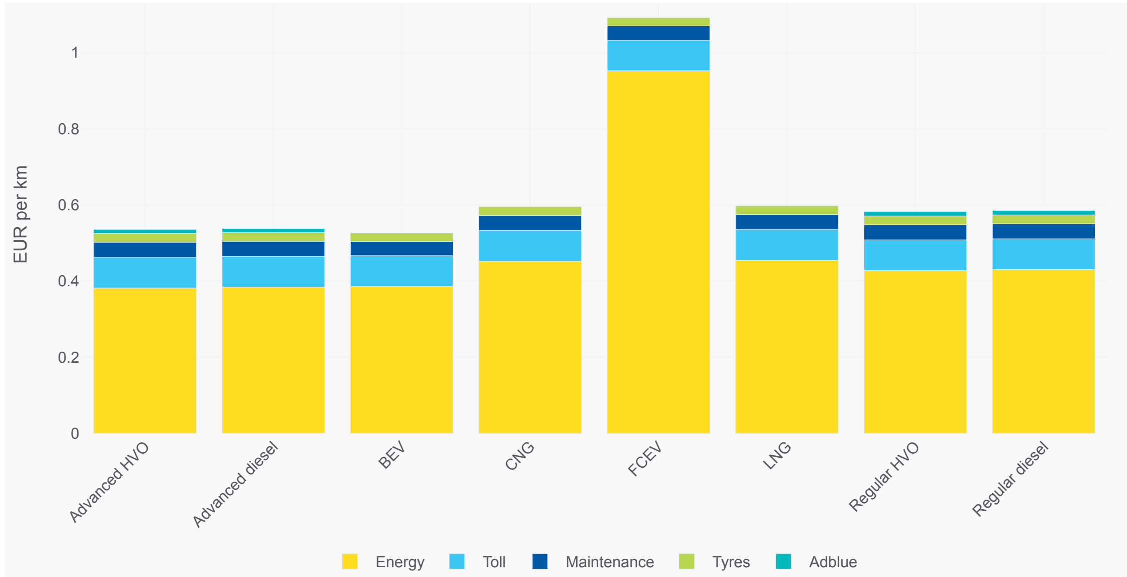
OpEx structure by powertrain for 15-tonne payload in France



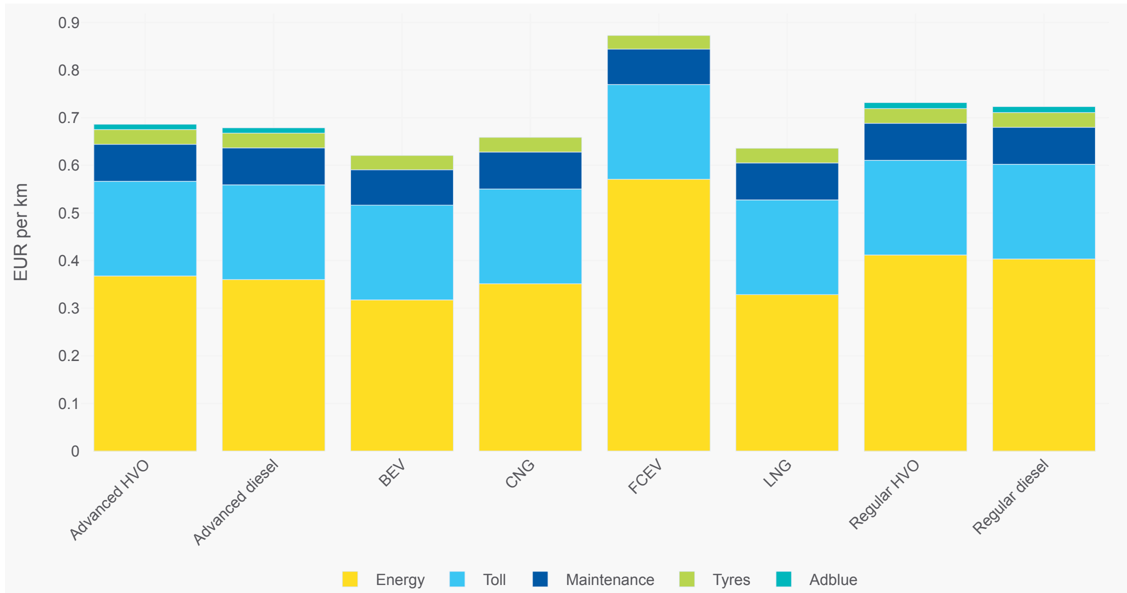
OpEx structure by powertrain for 15-tonne payload in Germany



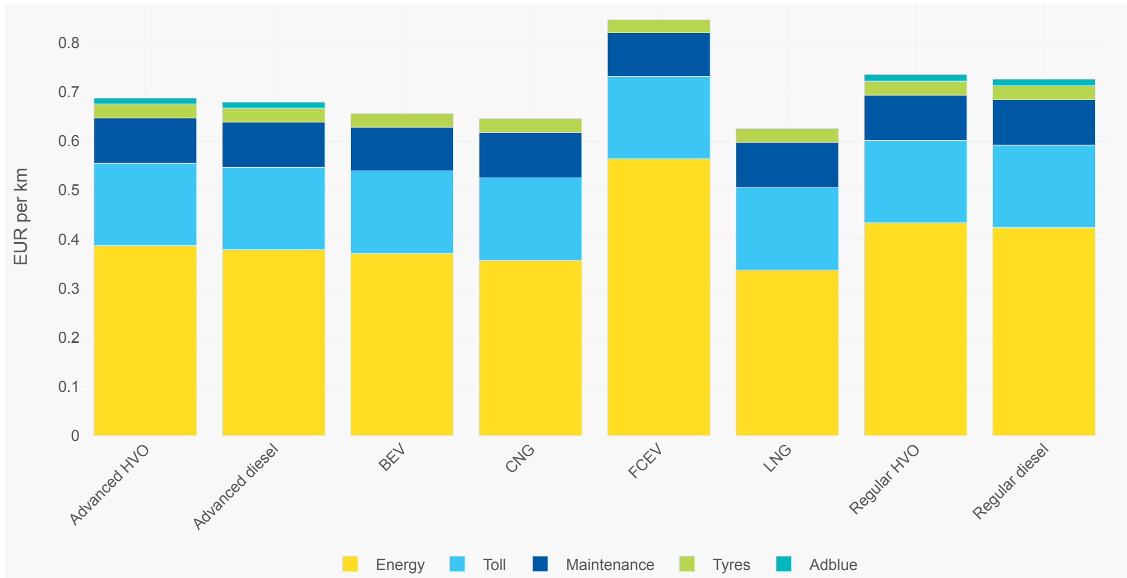
OpEx structure by powertrain for 15-tonne payload in Poland



OpEx structure by powertrain for 15-tonne payload in Spain



OpEx structure by powertrain for 15-tonne payload in Italy

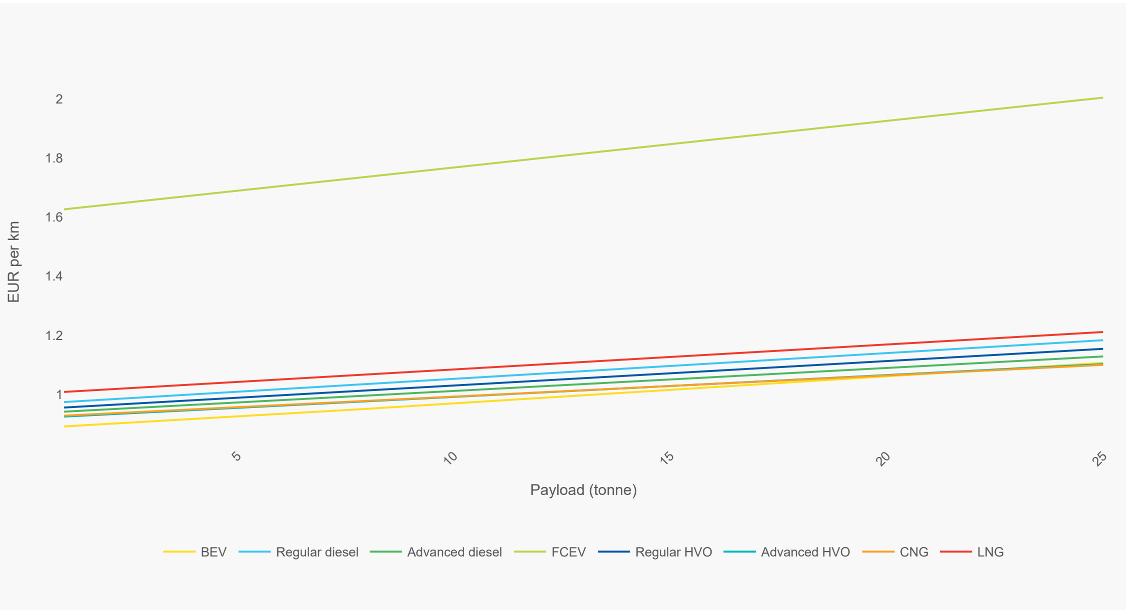


Interestingly, BEVs have the lowest operational costs in all countries. However, only Germany offers a lower TCO for BEVs due to reduced tolling fees for zero-emission powertrains. It is worth noting that BEVs' TCO is lower now primarily because of the rising TCO of fossil-fuel vehicles, rather than a decrease in BEVs' own TCO.

3.2. TCO comparison per country

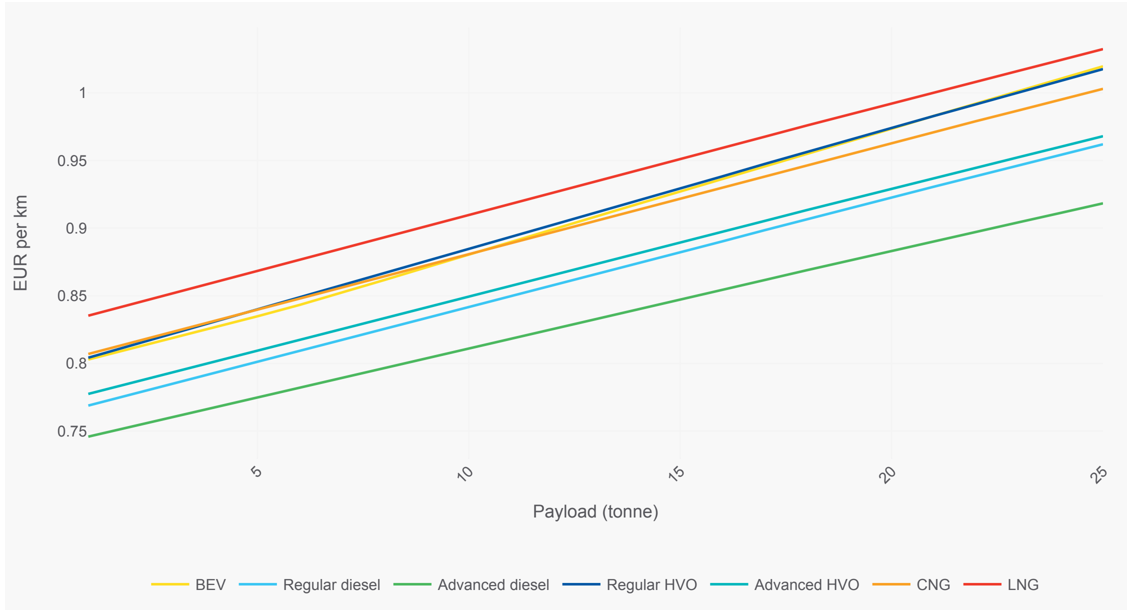
The analysis continues by removing the 15-tonne payload hypothesis, bringing more complexity to the TCO analysis as TCO increases with payload, but at different rates, changing the ranking of powertrains. TCO in EUR per km is given for Germany with the following graph.

TCO in Germany (including FCEV)

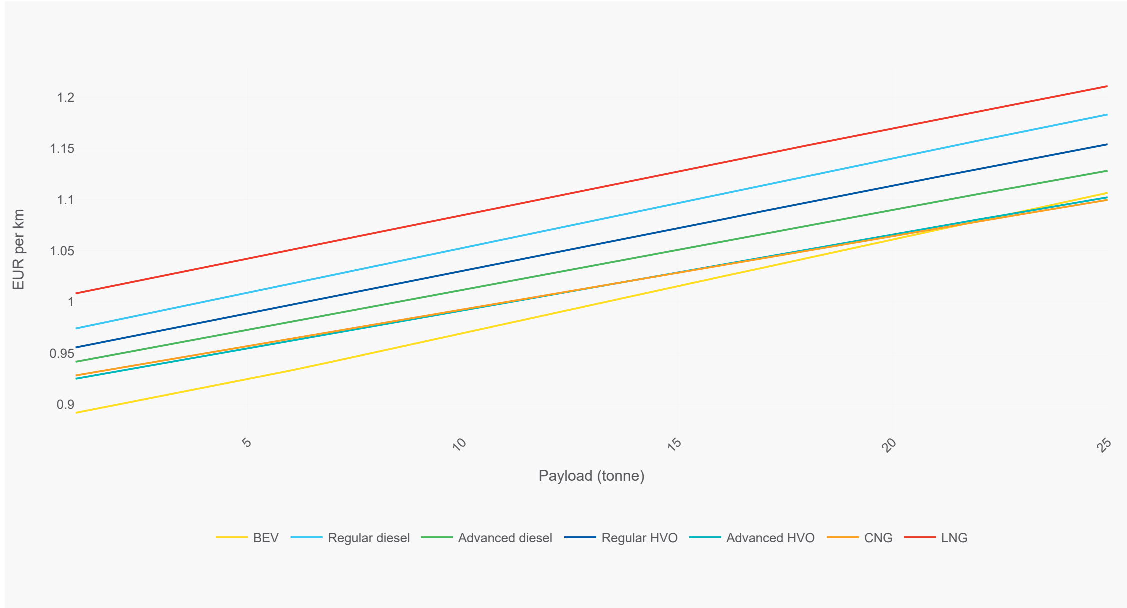


As FCEV is the most expensive technology in all the countries covered, it will be removed from the next graphs in order to zero in on the competition between other powertrains, as, despite having different values, they are all close to each other.

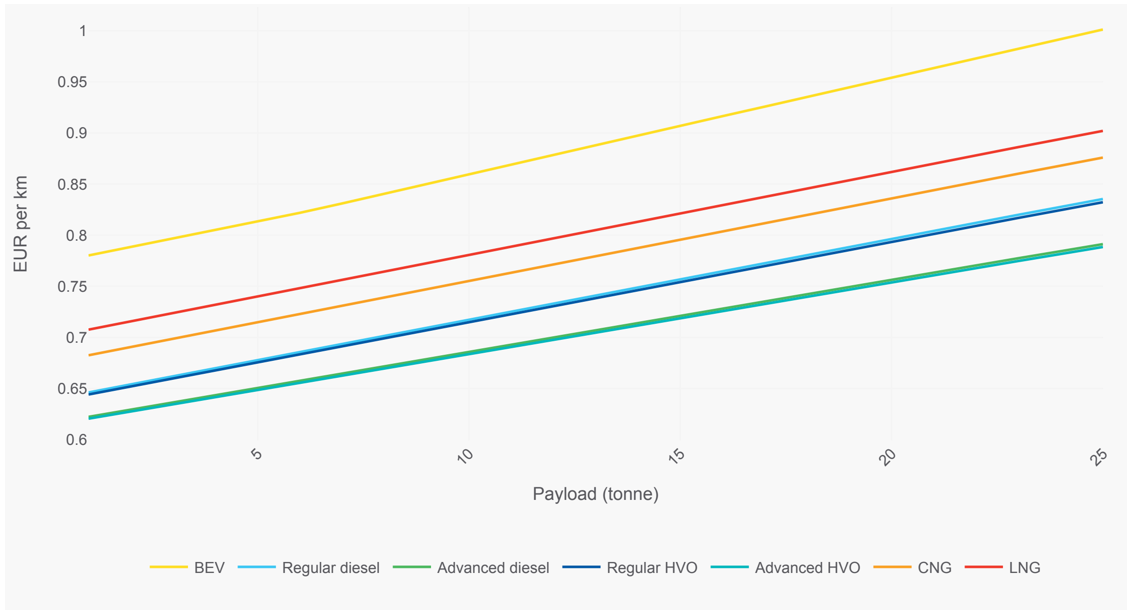
TCO in France



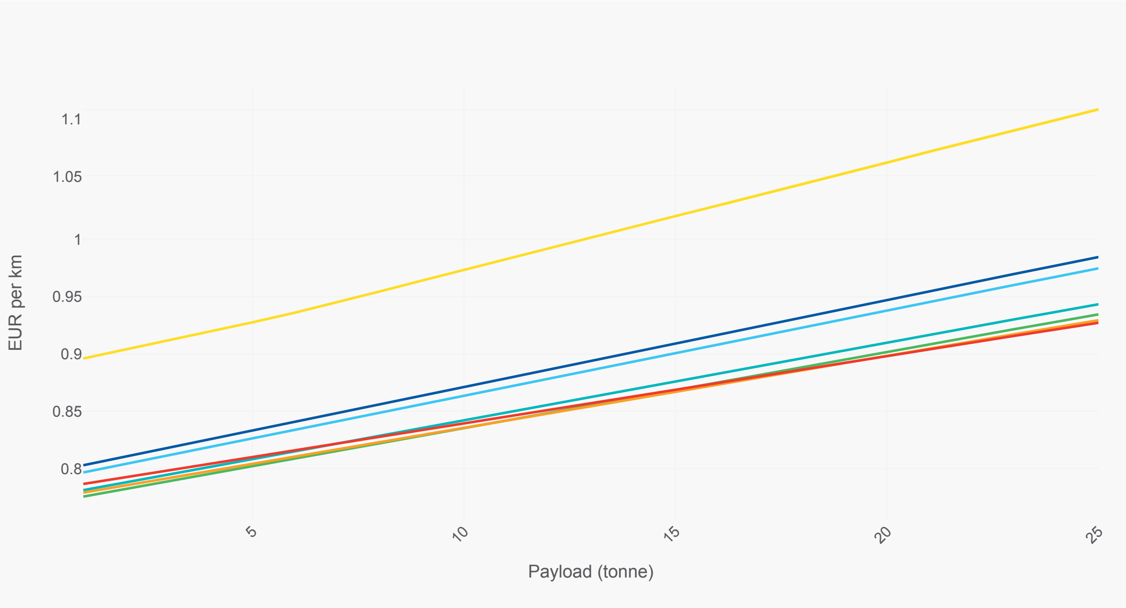
TCO in Germany



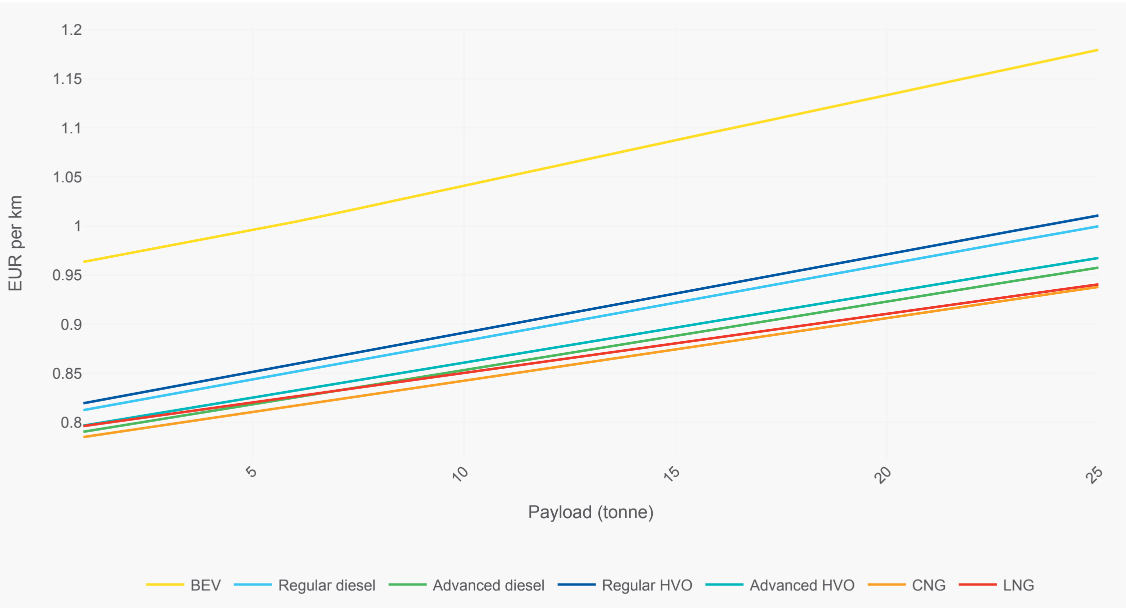
TCO in Poland



TCO in Spain



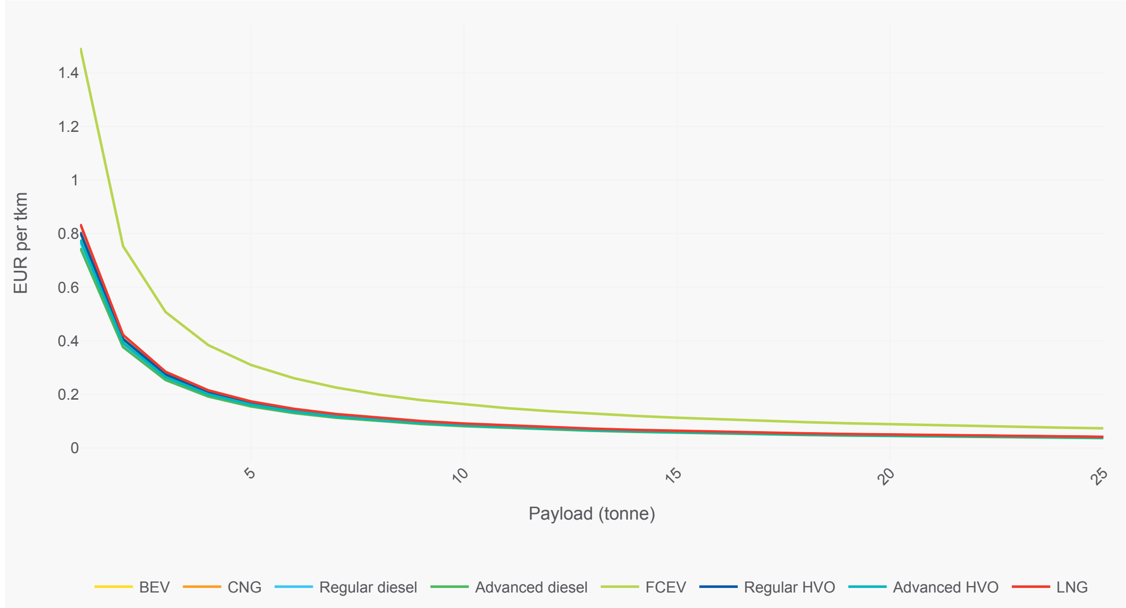
TCO in Italy



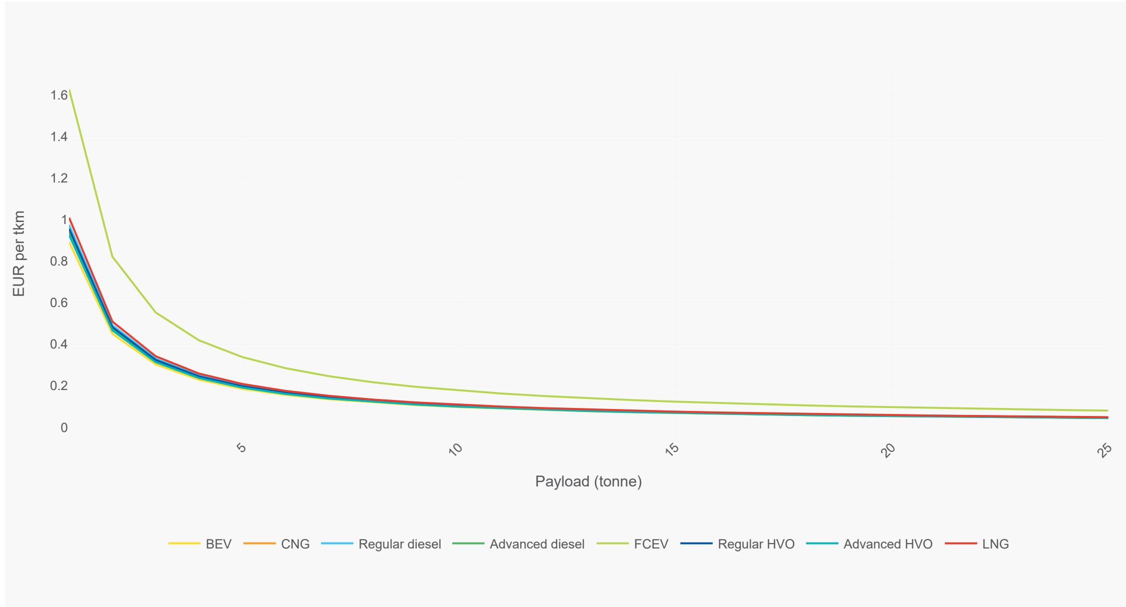
It is apparent that the BEV powertrain is the most expensive in all countries except Germany and France, due to lower electricity costs, and lower toll fees for BEVs in Germany. In France, the ranking, in EUR per kilometre, between powertrains evolves according to payload increases. The higher the payload, the more efficient the internal combustion engines are on average compared to BEVs. Excluding BEVs, the TCO of different powertrains are almost equally spread in Spain and Italy, while other countries have substantial differences due to variations in cost structures, as previously demonstrated.

Another perspective emerges when examining the TCO in EUR per tonne-kilometre rather than just per kilometre. This view reveals that TCO variations between powertrains become less significant compared to TCO variations across payload values (except for FCEVs). This TCO intensity demonstrates that, regardless of the powertrain, increasing payload is a powerful lever for minimising transport costs.

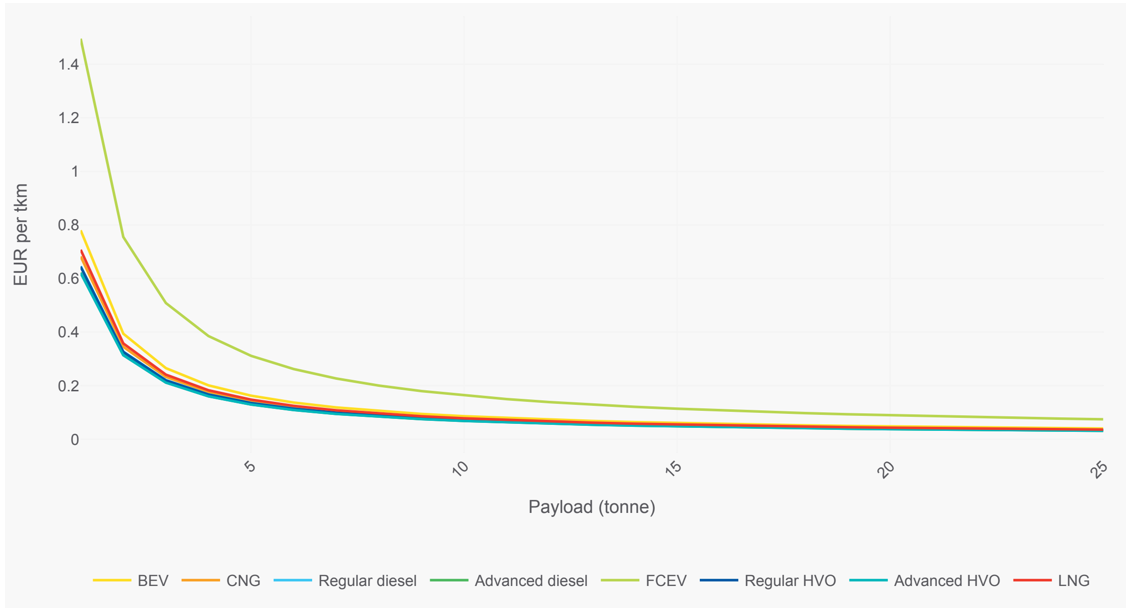
TCO in France



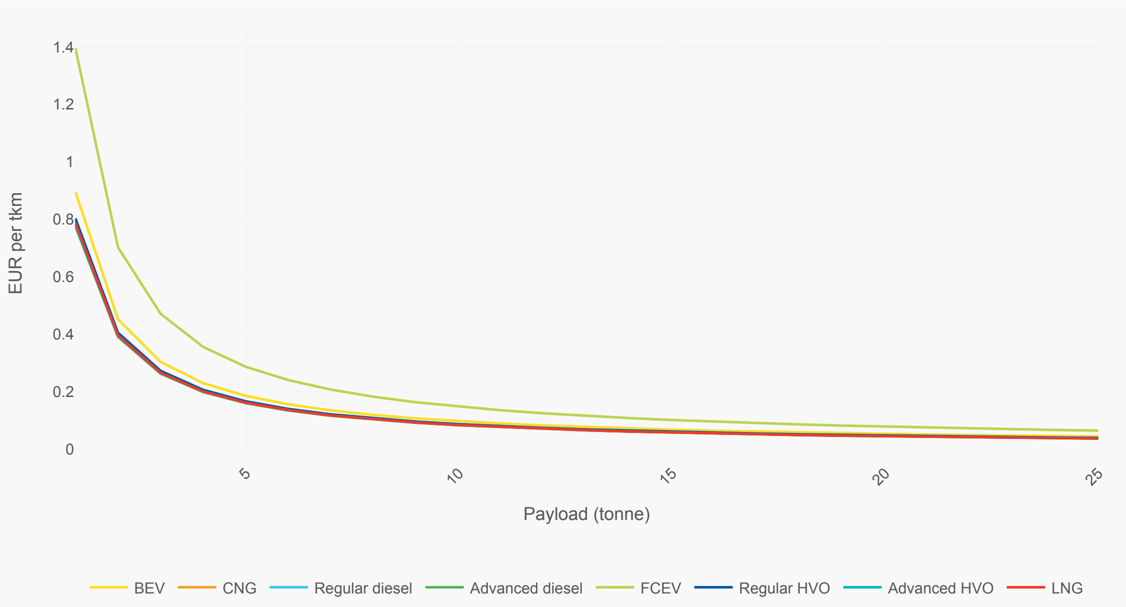
TCO in Germany



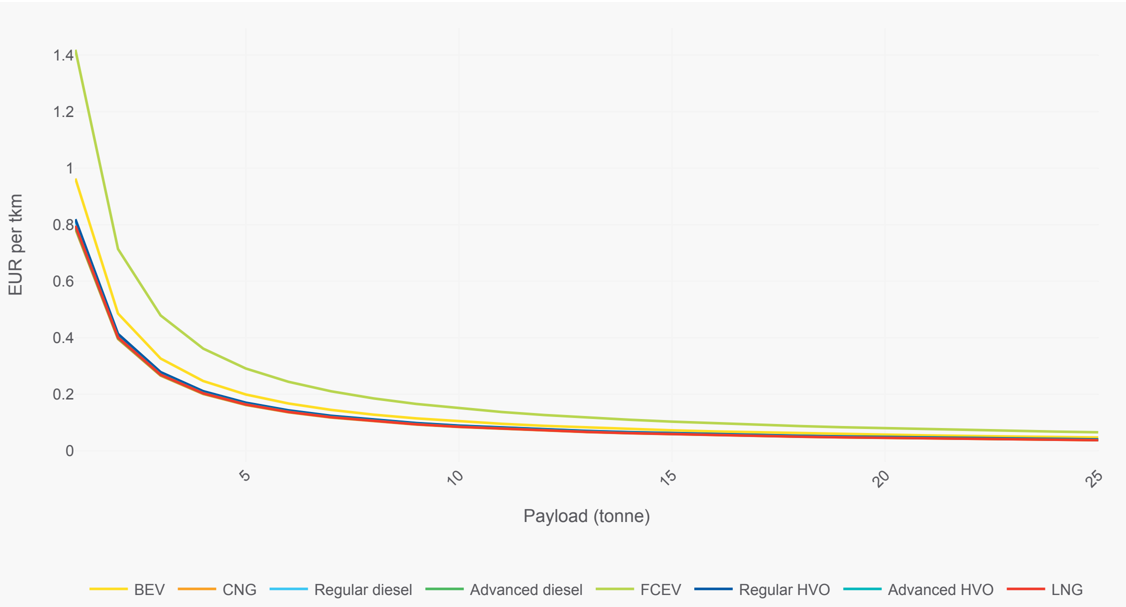
TCO in Poland



TCO in Spain



TCO in Italy

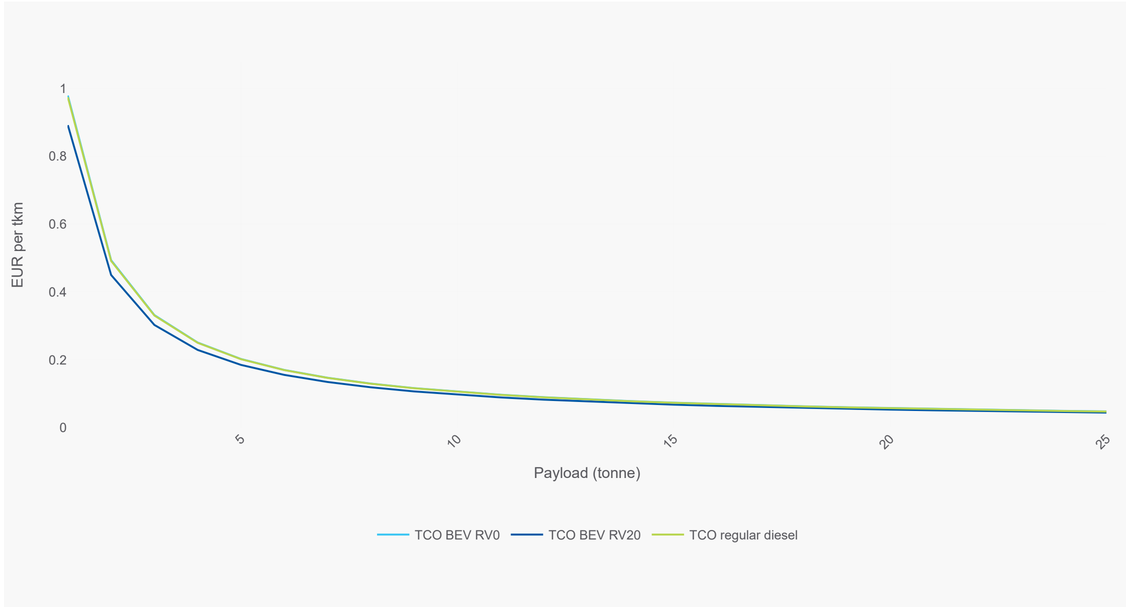


3.3. TCO variation assumptions

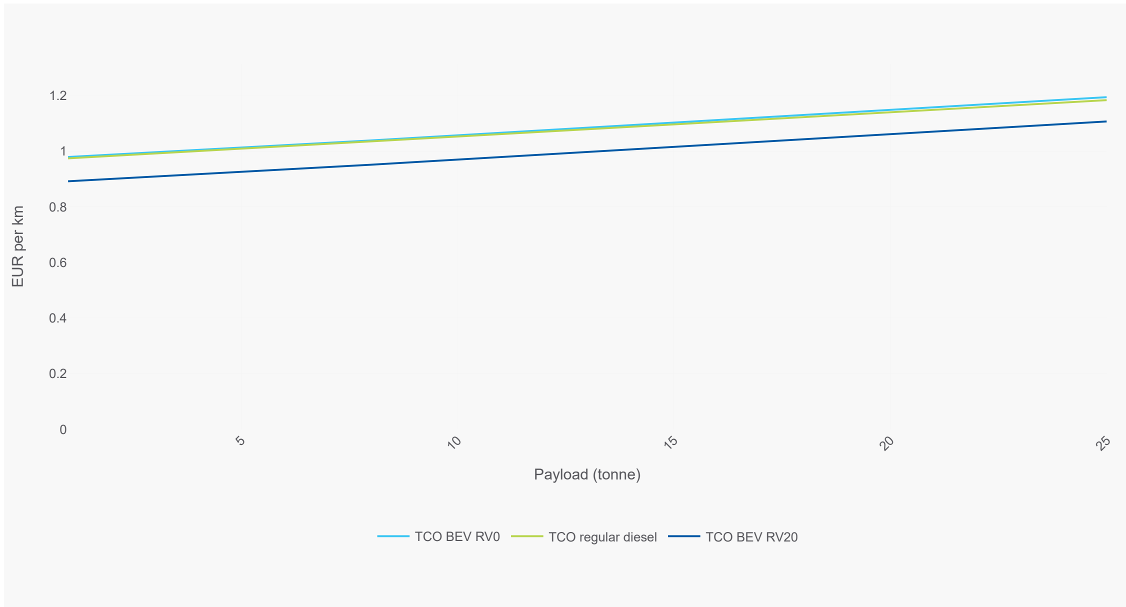
Residual value equals to zero

A variation has been simulated where the residual value of the BEVs is not 20% but rather 0% after six years. The comparison between regular diesel trucks and BEVs with a residual value of 20% are given in the following graphs.

Sensitivity of TCO to residual value



Sensitivity of TCO to residual value

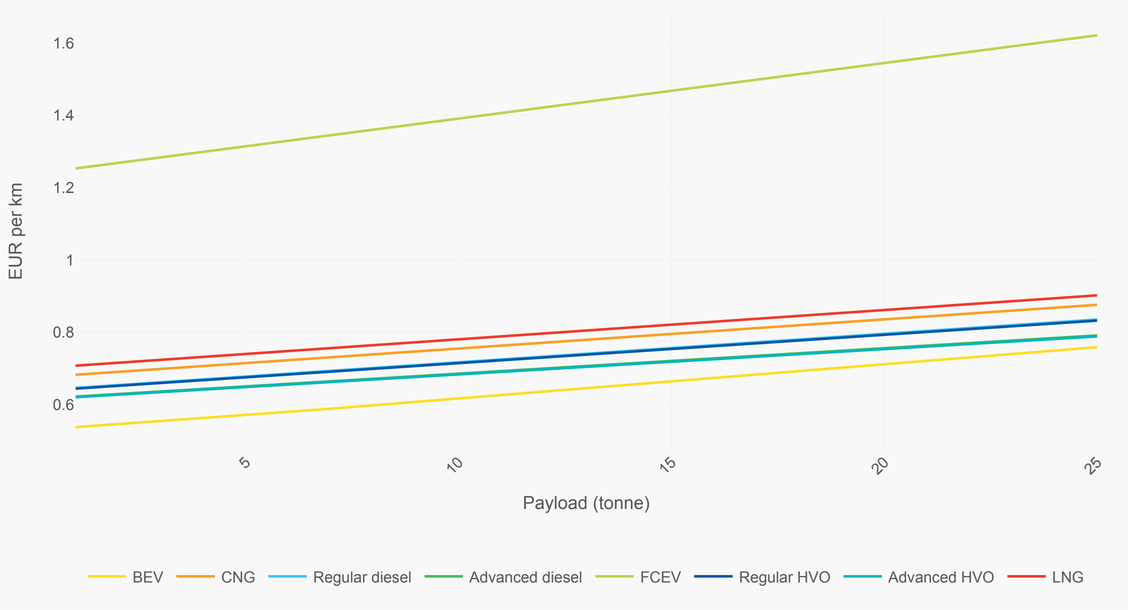


The cancellation of the residual value did significantly increase the TCO for the BEV combination (9% increase at 15-tonne payload), with the TCO now being slightly higher than a regular diesel truck (0.6% higher at 15 tonnes), demonstrating the sensitivity of TCO to residual values.

Polish subsidies

The Polish authorities are working on a project (according to the Government of Poland) to implement purchase incentives for zero-emission N2 and N3 vehicles. In the case of the combination studied here, the incentive could reach up to EUR 174,000. This incentive was not considered in the previous calculation, as it is not yet in place. Here are the TCO simulations when considering this governmental support.

TCO in Poland with subsidies



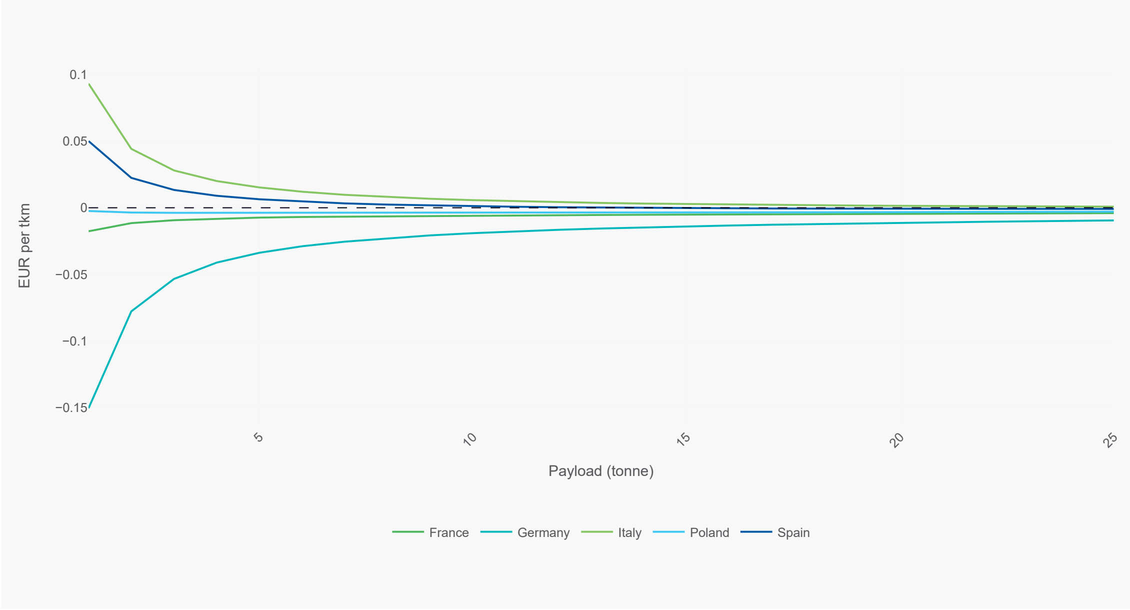
This incentive will help bring the TCO of the BEV configuration under that of other powertrains. However, caution is needed when looking at this figure as the incentive is not yet finalised and could differ according to the size of the company.

3.4. TCO for a more efficient setup

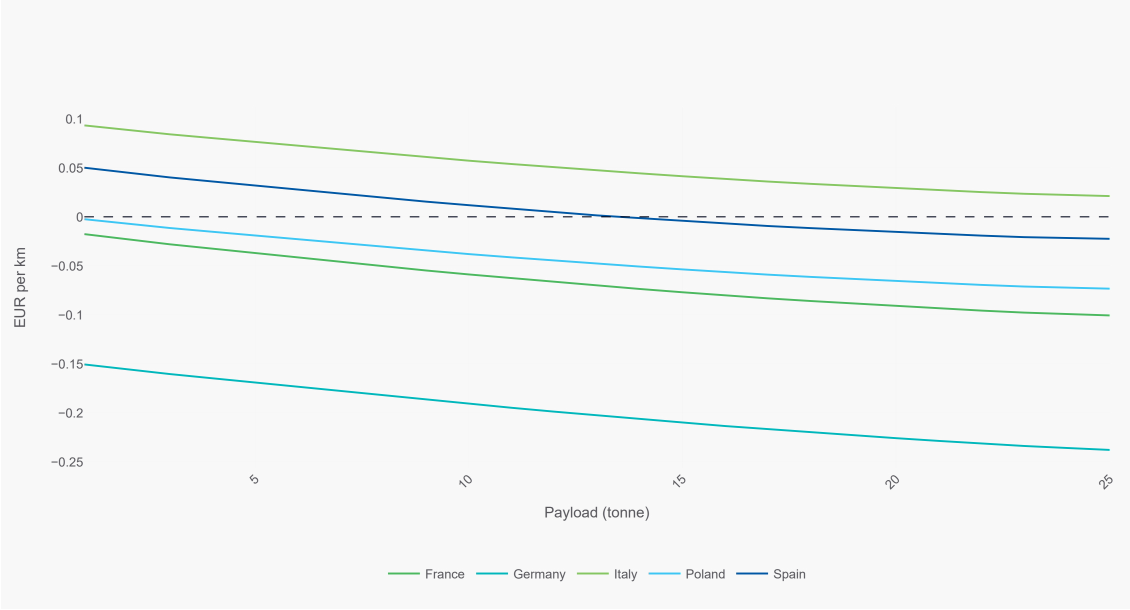
A key insight from the IRU Green Compact is that a dual approach can facilitate the transition towards alternative powertrains. This dual approach consists of leveraging more efficient drivers, vehicles and logistics to mitigate TCO increase and facilitate the decarbonisation of road transport.

Another simulation was conducted using an articulated vehicle fitted with grade-A rolling resistance tyres (3.5kg/tonne but 10% less mileage), a lighter semi-trailer (6,500kg instead of 7,500kg), and a more aerodynamic cab (A14 to A10). These improvements added EUR 15,000 to the price of articulated vehicles.

TCO difference: Super efficient vehicles vs efficient vehicles



TCO difference: Super efficient vehicles vs efficient vehicles



Comparing this new optimised BEV with a regular diesel engine reveals that it brings BEVs' TCO below the diesel reference, despite the greater initial investment. The more efficient BEV variant has a lower TCO than the reference in France, Poland and Germany. It could potentially achieve this in Spain for payloads greater than 14 tonnes. However, this improvement will not be sufficient to make it cost-effective in Italy.

Chapter 4

CO_2 emissions and TCO trade-off comparison

TCO is not the only indicator to consider. Diesel trucks already offer a competitive TCO compared to other powertrains. However, the need to leverage new engine technologies arises from the necessity to reduce greenhouse gas emissions. With the road freight industry's commitment to reach carbon neutrality by 2050, it is crucial to explore and compare how different powertrains reduce carbon emissions and to explicitly outline their associated costs.

4.1. Carbon emission factor assumptions

Carbon emission factor (CEF) is used to link energy consumption to CO_2 emissions. The CEF used here follows a well-to-wheel perspective, meaning it already includes the production or capture of CO_2 molecules during the production process of the energy. Beginning with electricity, countries produce electrical energy either from renewable sources such as solar or wind, low-emissions sources such as nuclear, or from fossil fuels, generally coal and natural gas. As a result, the carbon intensity differs between countries, depending on their energy planning strategy:

Country	2023 CEF electricity [gCO_2/kWh]
France	56
Germany	381
Poland	662
Spain	174
Italy	331

Source: Our World in Data (carbon intensity of electricity generation) extracted on 2024-10-23

The carbon intensity of electricity production is falling over time with the introduction of cleaner production sources such as renewables or nuclear. To anticipate this emission reduction, a linear extrapolation of the reduction rate is used to forecast the CEF of electricity production for these countries.

The following values are included into the next calculations:

gCO_2/kWh	2024	2025	2026	2027	2028	2029
France	55	54	53	52	51	50
Germany	360	347	333	319	305	291
Poland	662	647	631	616	601	586
Spain	169	158	147	136	124	113
Italy	322	314	306	297	289	280

Source: IRU estimates

For diesel, HVO and natural gas (both CNG and LNG), the European Environment Information and Observation Network conducts regular analyses. The resulting CEF are applied uniformly across all countries. Regarding AdBlue's CEF, the value is derived from IRU's analysis.

	Energy content	Density	CEF
Diesel	44 MJ/kg	0.82	3.4 kg/L
HVO (ex. ILUC)	44 MJ/kg	0.77	0.4 kg/L
CNG	45 MJ/kg	-	3.1 kg/L
LNG	45 MJ/kg	-	3.4 kg/L
AdBlue	-	1.09	0.3 kg/L

Source: ETC CM report 2023/03 extracted on 2024-10-23

Finally, obtaining the CEF for hydrogen is complex due to unclear production processes at the pump. To address this, a theoretical maximum CEF is calculated using the national electricity CEF. This calculation considers production efficiency (75%), transport efficiency (90%) and hydrogen's energy content (33.4 kWh/kg). When this calculated CEF exceeds the CEF of grey hydrogen (13kgCO_2/kg, derived from natural gas, currently the most common form), grey hydrogen's CEF is used instead. The following table presents hydrogen's CEF values for each country.

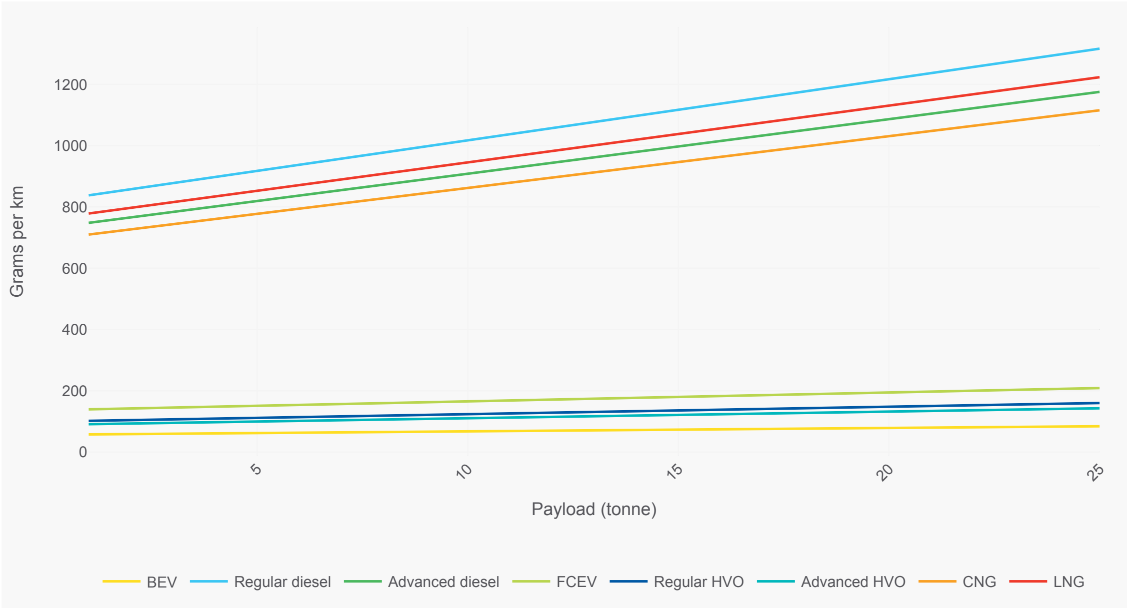
It is worth noting that, like electrical energy, if renewable sources are used to power the tractor, its CEF will be zero from a well-to-wheel perspective.

Country	CEF electric[kgCO_2/kg]
France	2.8
Germany	13.0
Poland	13.0
Spain	8.6
Italy	13.0

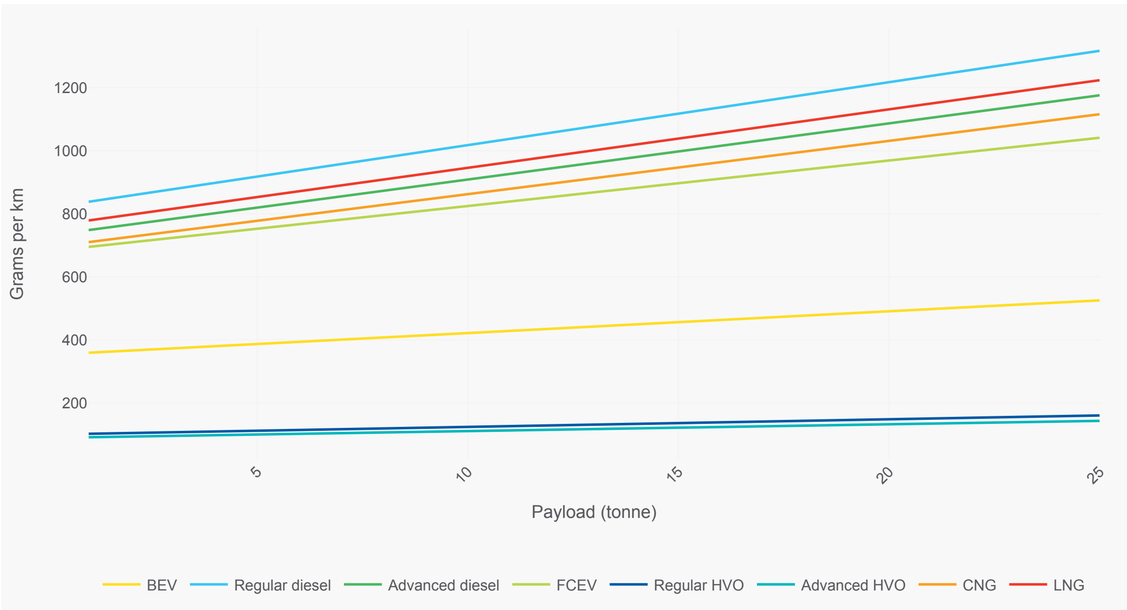
4.2. CO_2 results

Combining the previous CEF to the energy consumption results derived from the IRU AFEM model, it is possible to estimate the CO_2 emissions for each powertrain within all countries. As for TCO, CO_2 emissions could be looked at gCO_2/km or at gCO_2/tkm. Starting with the first unit, the following graphs illustrate the CO_2 emissions intensity for all five countries.

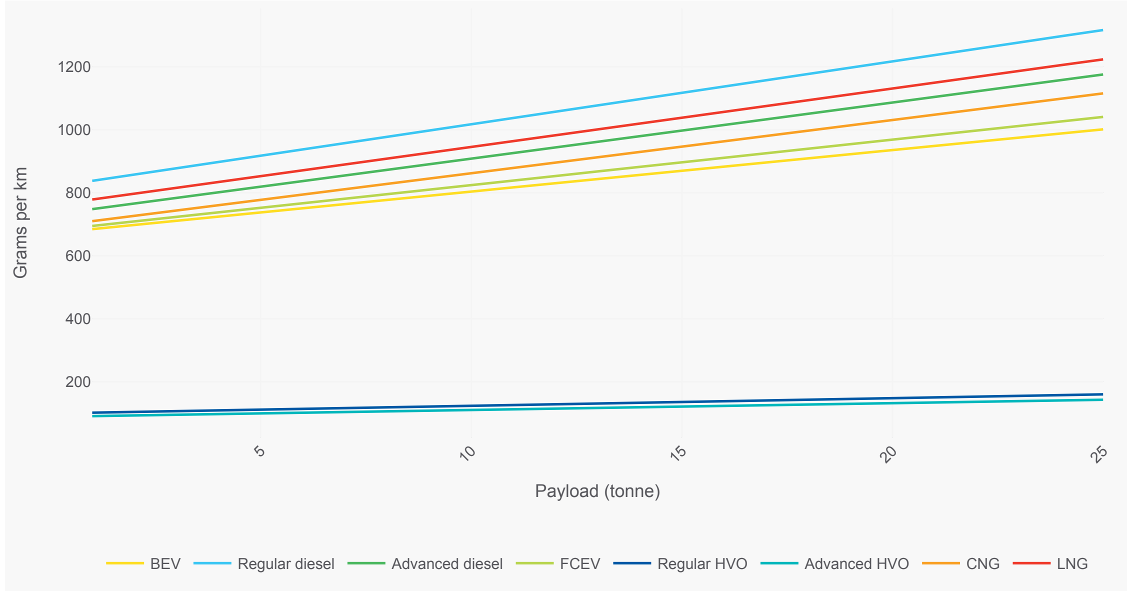
Carbon emissions in France



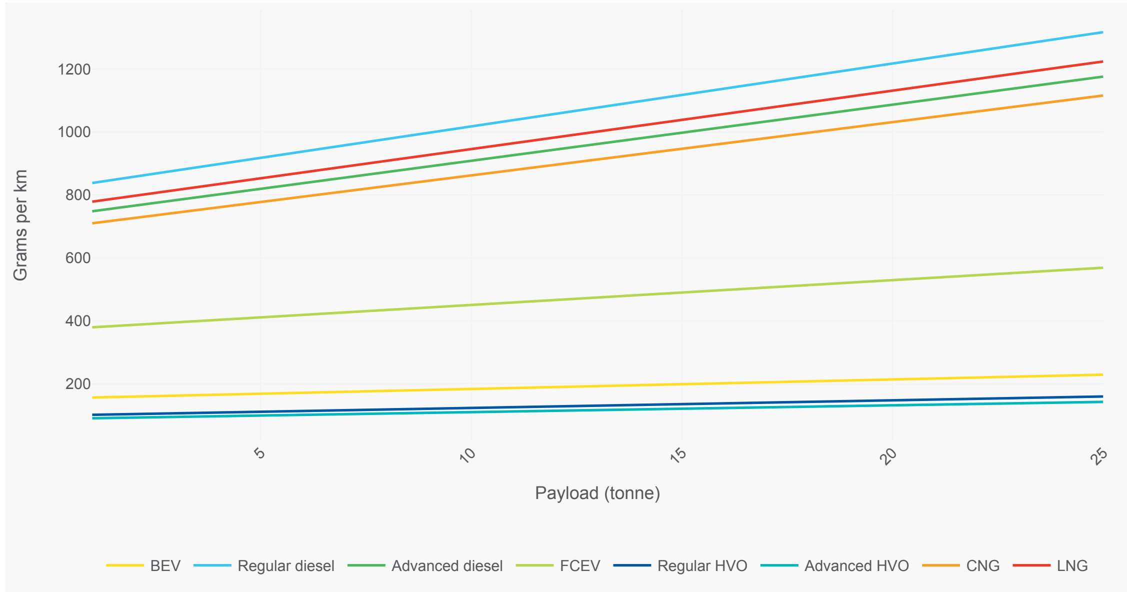
Carbon emissions in Germany



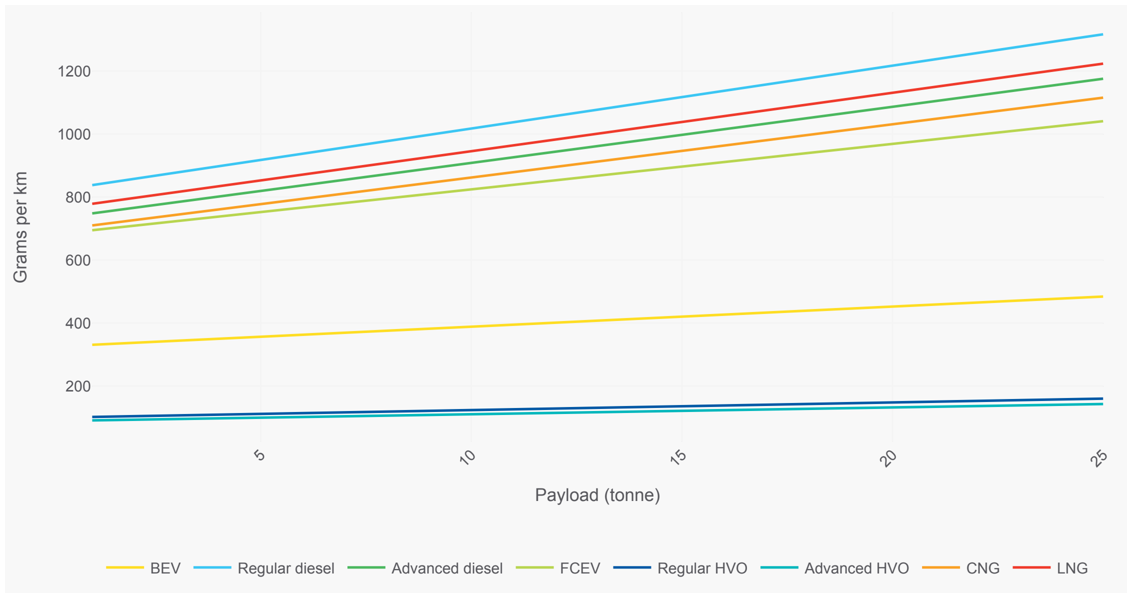
Carbon emissions in Poland



Carbon emissions in Spain



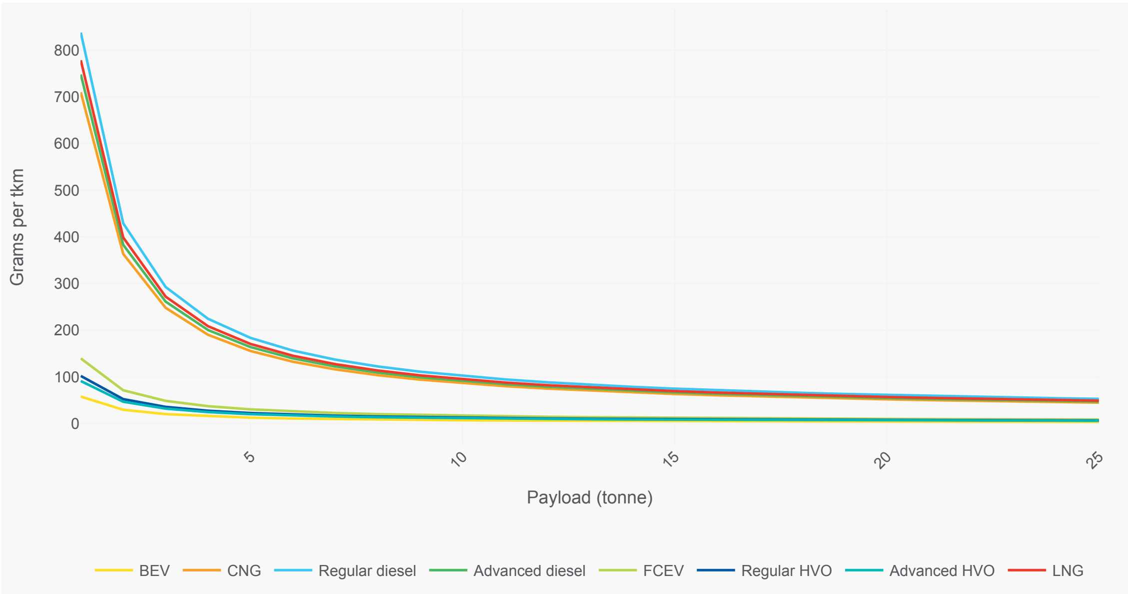
Carbon emissions in Italy



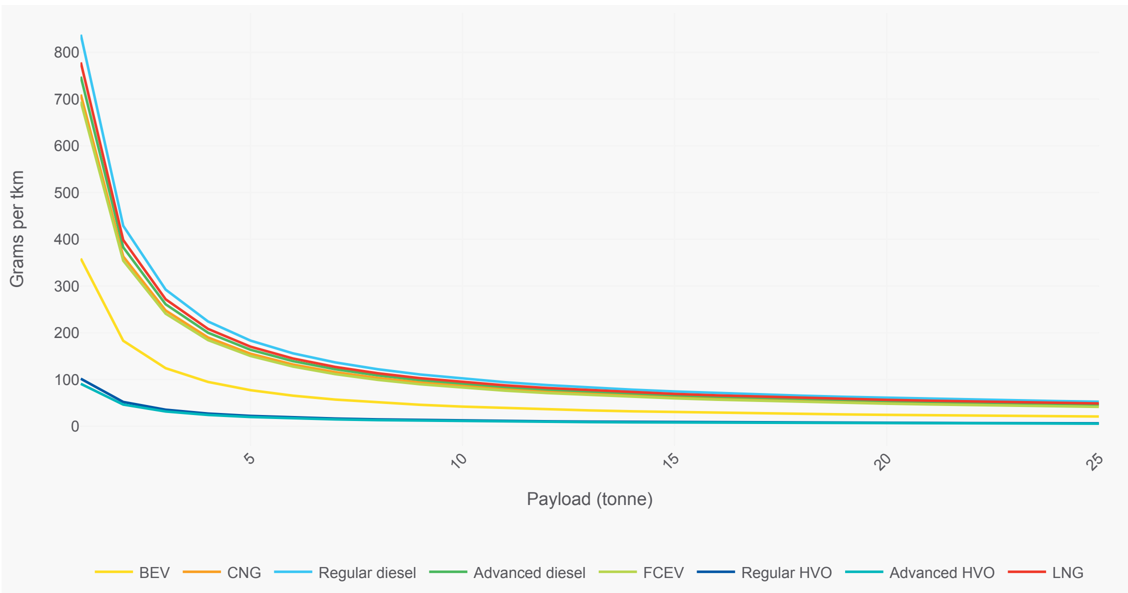
The previous graphs showcase CO_2 emissions (grams per km) across payloads, using a WTW approach. A cross-country analysis shows that diesel has the highest emissions, indicating that all other powertrains effectively reduce greenhouse gases. The most powerful option is HVO, used in both regular and advanced diesel engines. BEV also reduces CO_2 emissions, but its effectiveness varies depending on the carbon intensity of the electricity production. In most countries, BEVs offer a significant fall in CO_2 emissions, even surpassing HVO in France. However, in countries like Poland, BEV emissions can fall within the range of fossil fuels, due to more than 70% of the production coming from fossil energy. FCEVs emit more CO_2 than BEVs in all countries, highlighting that transport operators alone cannot fully decarbonise without adequate energy production methods.

When examining CO_2 emissions in grams per tonne-kilometre, trends similar to those of TCO emerge, highlighting the importance of payload optimisation in minimising emission intensity. In this context, the technological differences become more pronounced.

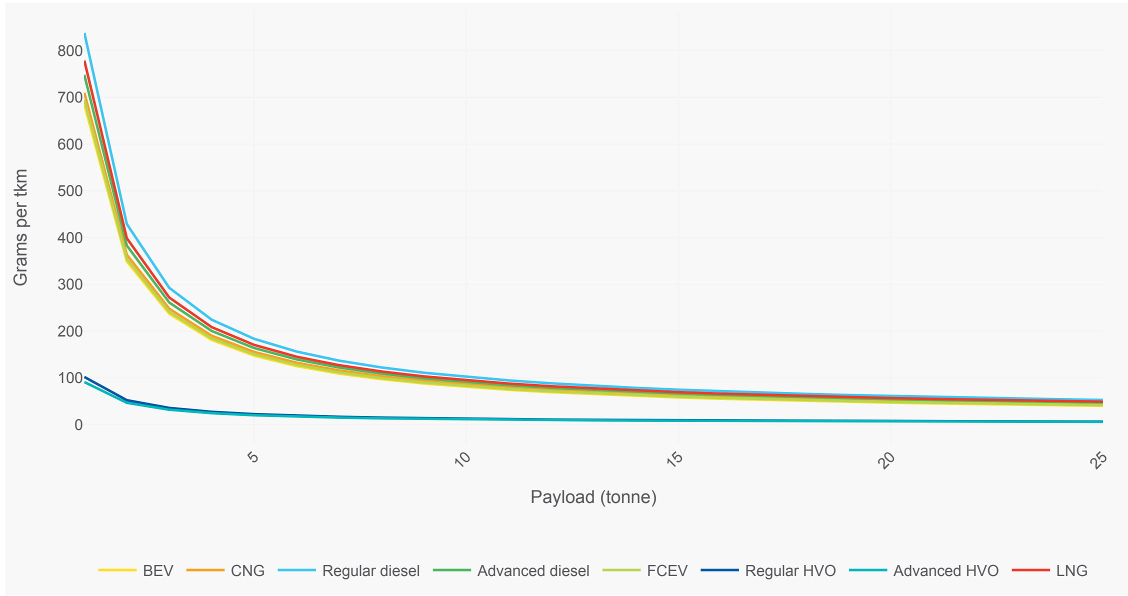
Carbon emissions in France



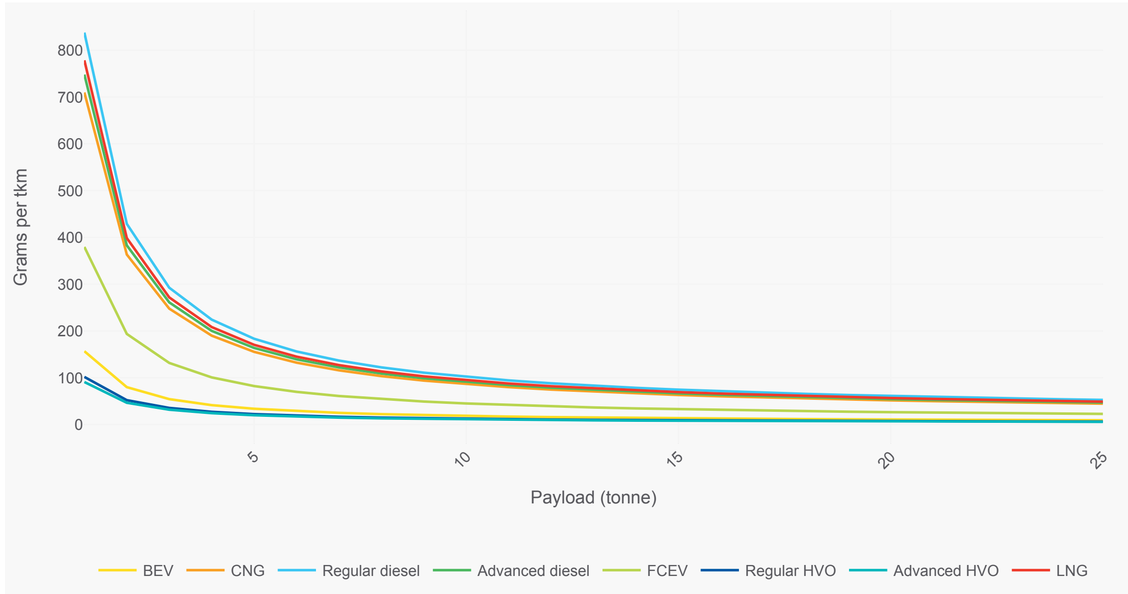
Carbon emissions in Germany



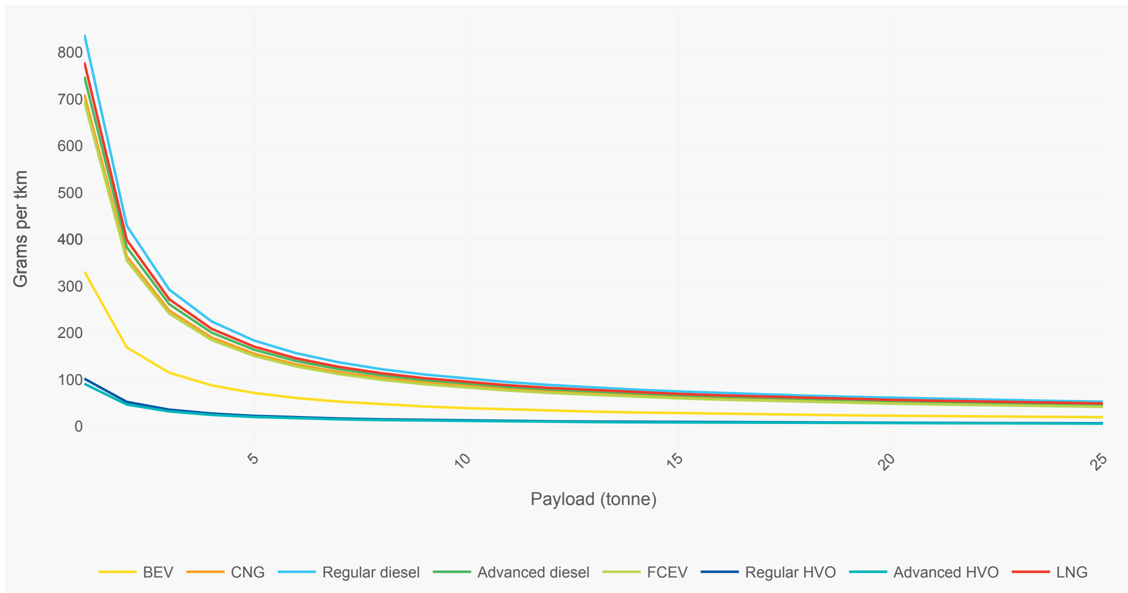
Carbon emissions in Poland



Carbon emissions in Spain



Carbon emissions in Italy



4.3. The TCO/CO_2 trade-off

After examining the TCO and CO_2 emissions for selected powertrains across five countries, it is now time to consider the cost of CO_2 removal per country and powertrain.

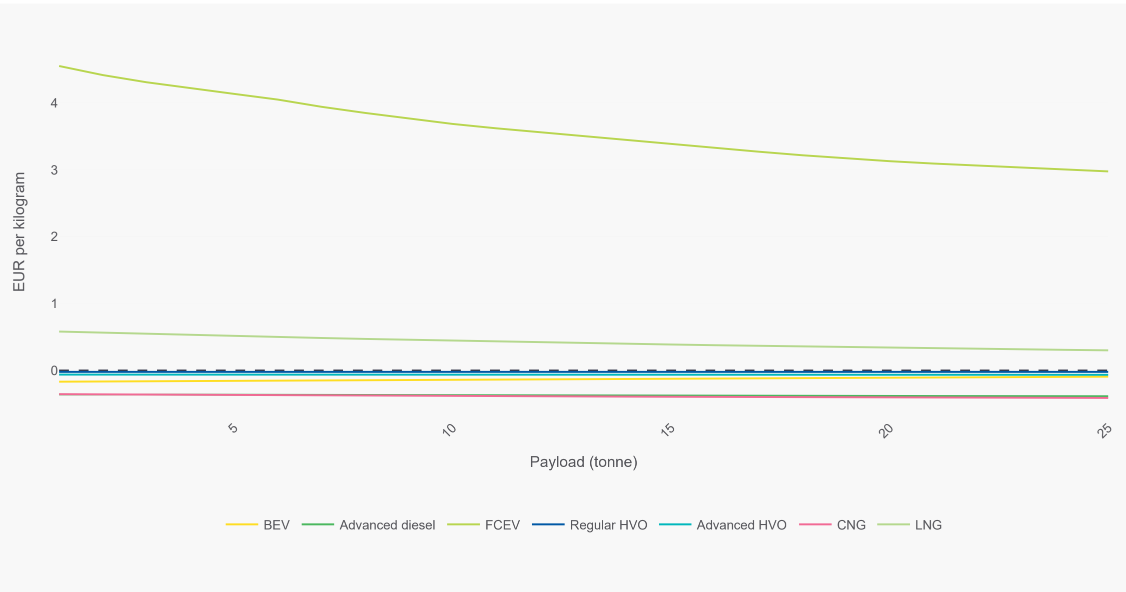
Using regular diesel trucks as a reference (ref) for all countries, we can calculate the cost for each powertrain (po) using the following equation:

$$\text{Cost} = \text{sign}\left(\text{TCO}_{\text{po}} - \text{TCO}_{\text{ref}}\right) \times \left(\frac{|\text{TCO}_{\text{po}} - \text{TCO}_{\text{ref}}|}{|\text{CO}_{2,\text{po}} - \text{CO}_{2,\text{ref}}|}\right)$$

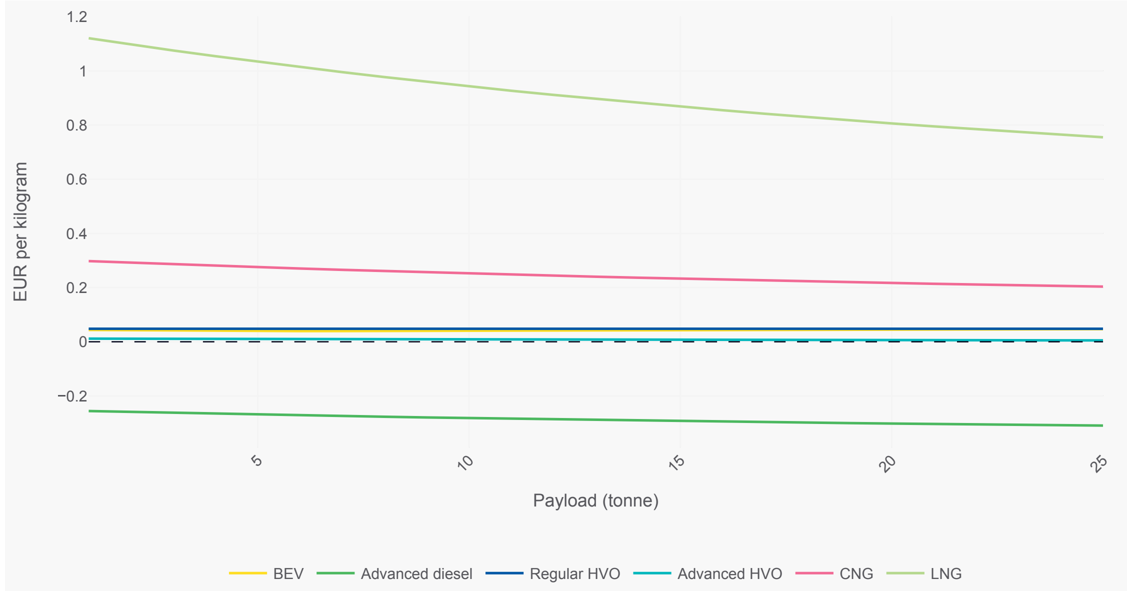
The graphs below present these costs in EUR per kilogram reduction of CO_2. These figures help to summarise and visualise the TCO and carbon emissions of each powertrain in contrast to regular diesel (black dotted line). The most expensive powertrain to reduce CO_2 emissions is FCEV, due to the source of fuel (mostly grey hydrogen) and higher cost of the vehicle. This powertrain is then removed to provide a clearer view of the following figures.

On average, changing to an advanced diesel powertrain is the cheapest and most effective way to reduce CO_2 emissions, resulting in savings of EUR 0.3 per kilometre. In Italy and Spain, LNG tends to be the best alternative, offering a reduction of almost EUR 0.5 per kilometre (at 15 tonnes) due to lower energy costs.

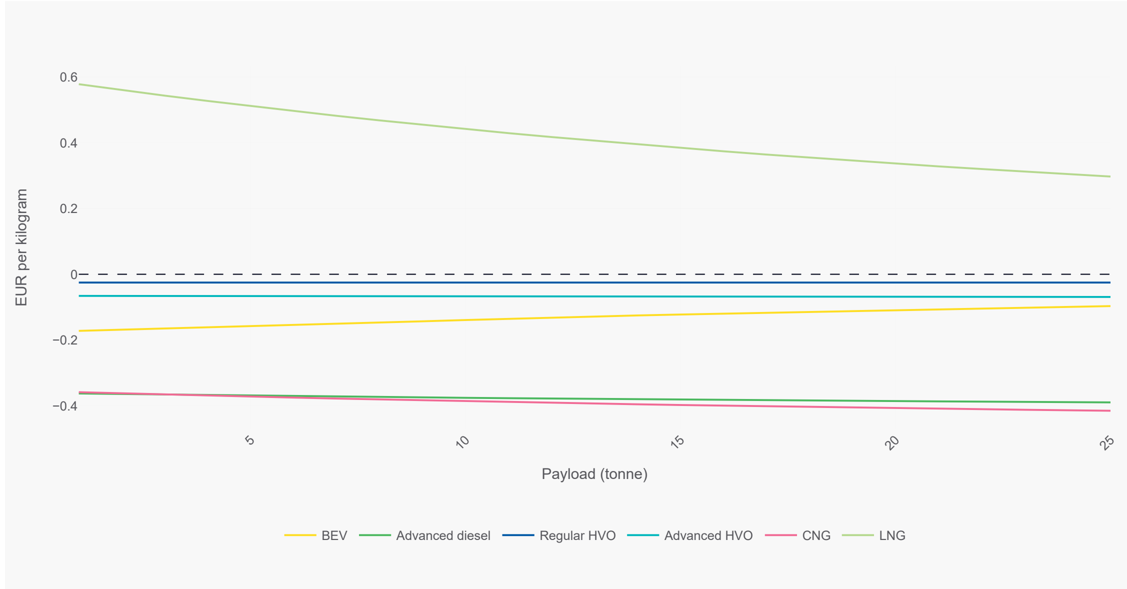
Cost of reducing 1kg of CO_2 per km in constrast to regular diesel for Germany (including FCEV)



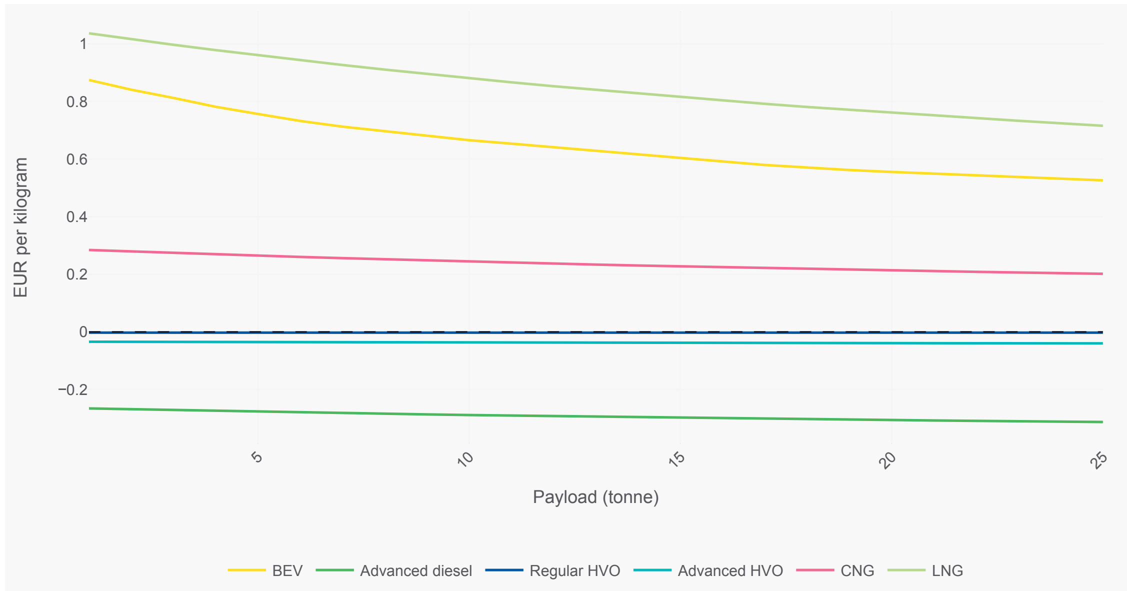
Cost of reducing 1kg of CO_2 per km in constrast to regular diesel for France



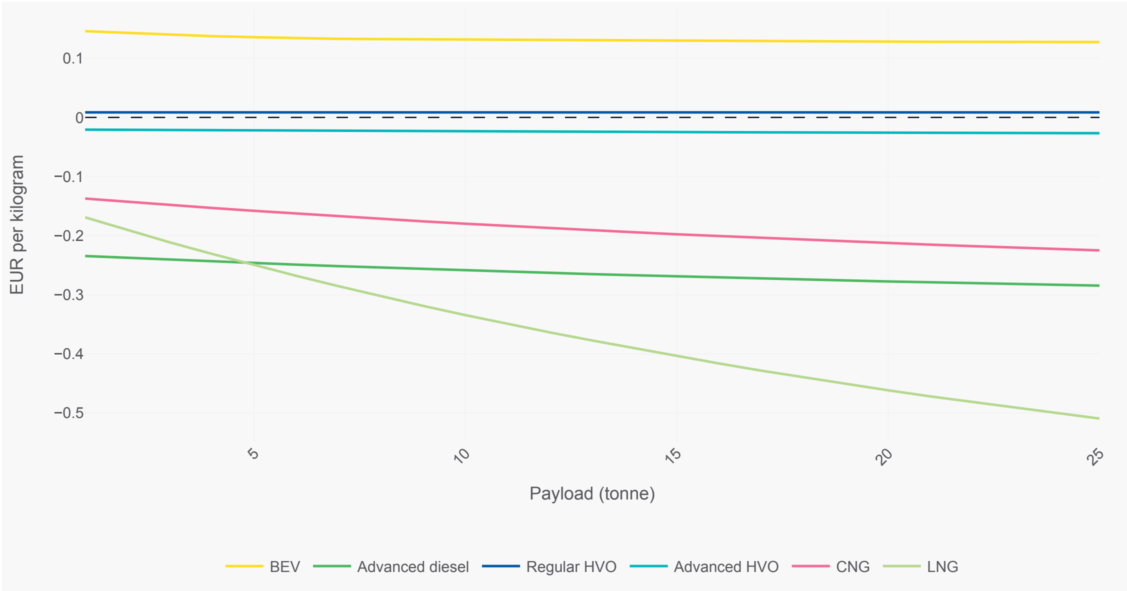
Cost of reducing 1kg of CO_2 per km in constrast to regular diesel for Germany



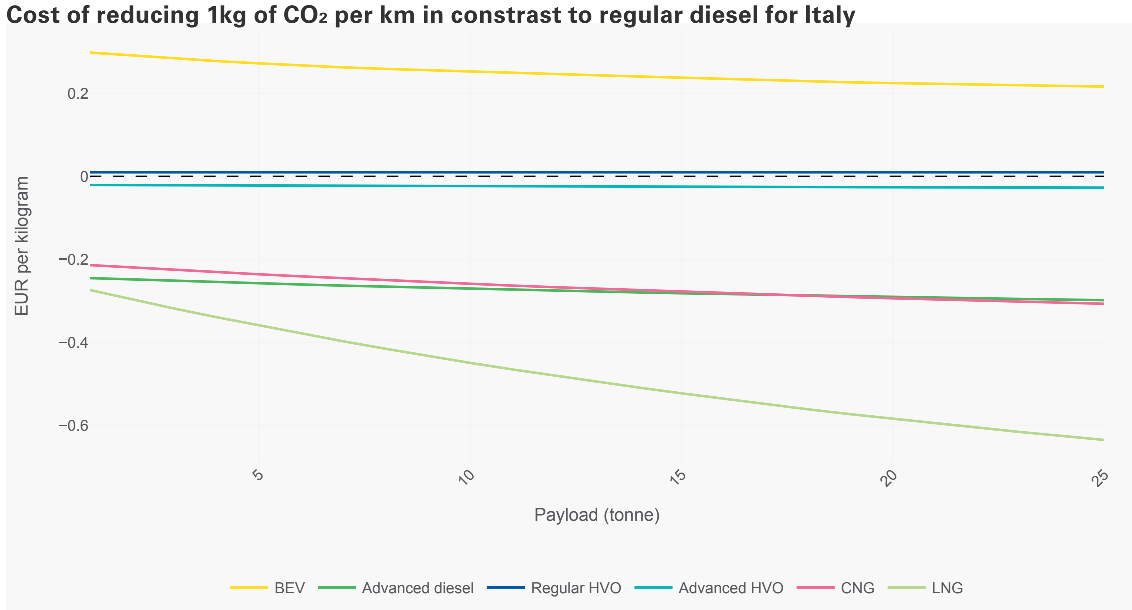
Cost of reducing 1kg of CO_2 per km in constrast to regular diesel for Poland



Cost of reducing 1kg of CO_2 per km in constrast to regular diesel for Spain



Cost of reducing 1kg of CO_2 per km in constrast to regular diesel for Italy



All solutions having negative values offer a win-win solution, saving both on TCO and CO_2 emissions. However, it must be considered how much CO_2 savings could be achieved.

For instance, in Italy, LNG has a win-win value, but the CO_2 reduction potential is more limited than for BEVs.

Key takeaways

This IRU Intelligence Briefing compares the TCO and CO_2 emissions of alternative powertrains (CNG, LNG, HVO, BEV and FCEV) with those of traditional diesel powertrains. It considers various factors affecting TCO and emissions, including vehicle prices, subsidies, residual values, insurance, interest rates, energy consumption and costs, maintenance, and tolls, all indexed to inflation.

The analysis focuses on the first six years of registration (which is the average duration a heavy-duty vehicle remains with its first owner) for a two-axle road tractor with a three-axle semi-trailer, which transports almost 65% of the total EU road freight volume (in tonne-kilometres). The usage covered is long-haul, characterised by high annual mileage completed mainly on highways.

The geographical scope of this Intelligence Briefing encompasses the five biggest EU road freight countries (France, Germany, Poland, Spain and Italy), which are also the five biggest in terms of alternative fuel vehicle registrations. The CO_2 emissions analysis uses a well-to-wheel perspective, considering the carbon intensity of different energy sources in each of the five countries. This approach reveals that while all alternative powertrains reduce greenhouse gas emissions compared to regular diesel engines, the extent of the reduction varies significantly based on local energy production methods and efficiencies.

So, which powertrain has the lowest TCO, and which one reduces CO_2 emissions the most?

Operating costs (OpEx) typically account for 60-80% of the TCO, with energy costs being the major operating expense. BEVs and FCEVs have the highest capital expenditures (CapEx) due to their higher purchase prices.

National conditions significantly impact both economic and environmental indicators, leading to varying optimal solutions in different countries. However, TCO variations between powertrains are more limited than TCO variations for different payloads. Maximising payload capacity is key to getting the most out of a truck. Advanced diesel engines, which are more fuel-efficient than regular diesel road tractors, offer a common cost-effective solution. However, the most economical option varies by country.

In Italy, CNG trucks have the lowest TCO, while being more expensive than diesel in France and Poland. In Germany, BEVs have the lowest TCO following the increase in diesel toll fees in 2023. In Italy and Poland, BEVs have the second highest TCO. FCEVs have the highest TCO across the five countries. These results are mostly linked to energy prices.

In terms of emissions reduction, the effectiveness of different powertrains varies based on local conditions. BEVs emit the least amount of CO_2 in France, where the electricity grid relies heavily on renewable and nuclear power, an electric truck emits less than 100g of CO_2 per kilometre (15-tonne payload), whereas they emit ten times more CO_2 in Poland. In other countries, HVO offers the most significant CO_2 emissions reduction, especially when combined with advanced diesel engines. This combination currently provides the best balance between TCO and CO_2 emissions in Germany, Spain and Italy.

There are uncertainties regarding the residual value of alternative fuel trucks, as they are new technologies which have only recently entered the market. Currently, 99% of EU-registered trucks have a diesel powertrain. It was assumed that these new technologies' residual values would be similar to current diesel values. A sensitivity analysis done in Germany found that reducing the residual value significantly increases the TCO, closing the gap between diesel and electric powertrains.

Subsidies, on the other hand, significantly lower zero-emission vehicles' TCO without penalising other powertrains or leading to higher transport costs. Another solution to reduce the TCO for all powertrains is to use more efficient vehicles and technologies, such as lighter semi-trailers and more efficient tyres, which, despite higher retail prices, lower the TCO.

Enabling conditions such as cleaner electricity production, numerous recharging/refuelling stations, and sustained transport volumes will be key to meeting these TCO estimations while lowering CO_2 emissions. The calculations assume that all trucks can find recharging/refuelling stations when needed, which is currently not the case. Lastly, this Intelligence Briefing's TCO calculations are based on national average values, average vehicle characteristics, and average long-haul usage. Road transport stakeholders can contact IRU to use the same methodology but with their own datasets.

More information and insights are available on the IRU Intelligence Platform.

Methodology

TCO is the combination of a CapEx and OpEx component, both including sub-components. The TCO given in this Intelligence Briefing covers all the costs occurring during the first six years of use, ventilated on the total mileage done on this period. This value does not reflect the TCO variation between each individual year, and a constant payload is assumed for every day of operation. In the following, the payload is supposed to be different from zero.

Regarding CapEx, it includes here the price of vehicles, interest rate, registration and ownership taxes, as well as insurance fees.
In tonne-kilometres, the formula is:

$$\text{CAPEX} = \frac{\sum_{6\text{ years}}(\text{ownership} + \text{registration} + (1+\beta_{\text{interest}}) \times (\text{€tractor} + \text{€trailer} - \text{subside}) + \beta_{\text{insurance}} \times (\text{price tractor} + \text{price trailer}))}{\text{Payload} \times \sum_{6\text{ years}} \text{mileage}}$$

Regarding OpEx, the calculation involves an energy consumption assessment for all types of powertrains and all payload values. IRU has developed a vehicle model called the IRU AFEM model, which uses longitudinal dynamics to assess mechanical energy consumption, engine torque and speed, based on vehicle characteristics, from a usage characterised by a speed and altitude profile. The engine torque and speed points are then used in combination with a fuel engine map to assess final fuel consumption for diesel and gas combustion engines. For BEVs and FCEVs, constant efficiency terms are used to estimate energy consumption at the battery and H2 tank levels. For BEVs, a constant charging efficiency of 0.95 is used to estimate energy consumption at the pump level. For the articulated vehicle covered in this Intelligence Briefing, results have shown a 95% coherence with the VECTO tools regarding energy consumption.

In the case of a diesel or HVO truck, AdBlue consumption is correlated to fuel consumption, (AdBlue consumption equals 5% of the fuel consumption).

In the case of BEVs and FCEVs, a tyre wear indicator is calculated based on the absolute value of torque at the drive axle, and then compared to the diesel value used as a baseline. This wear indicator is then used to modulate drive axle tyre lifespans for both BEVs and FCEVs.

In the case of BEVs, a daily energy consumption is estimated with results coming from the IRU AFEM model. The IRU AFEM model assesses a total daily energy consumption. Battery capacity is reduced from this value, as it is assumed that the battery was charged at the depot overnight (with the cost of depot charging). The leftover, if any, needs to be compensated by public charging, and it is supposed to add 10% to this leftover, resulting in the end in the amount of energy to be charged at a public charging station.

All energy prices, tyres, toll, lubricants, maintenance, labour, and ETS2 are indexed to inflation.

OpEx is then calculated with the following equations (given in tkm):

$$OpEx = \frac{Energy + AdBlue + Toll + Maintenance + Tyres}{Payload}$$

$$Energy = \frac{\sum_{y=1}^{6} consumption \times energy\ price_y \times mileage_y}{\sum_{6\ years} mileage}$$

except for BEVs which uses:

$$Energy_{electric} = \frac{\sum_{y=1}^{6} consumption \times mileage_y \times (ratio_{depot}.price\ depot_y + ratio_{public}.price\ public_y + n_{public} \times \beta)}{\sum_{6\ years} mileage}$$

where n_public×β is the number of transactions done at a public station times the fee per transaction.

$$AdBlue = \frac{\sum_{y=1}^{6} consumption \times 0.05 \times AdBlue\ price_y \times mileage_y}{\sum_{6\ years} mileage}$$

$$Toll = \frac{\sum_{y=1}^{6} toll\ intensity_y \times mileage_y \times split\ highway}{\sum_{6\ years} mileage}$$

where toll intensity is in €/km, considering vehicle classes for Germany, and a split highway of 0.75, whereas for other countries, the split highway is equal to 1 and the toll intensity is given on average for the considered usage.

$$Maintenance = \frac{\sum_{y=1}^{6} maintenance\ intensity_y \times mileage_y + oil_{volume} \times oil\ price_y + labour\ oil_y}{\sum_{6\ years} mileage}$$

Obviously, oil change costs are not considered for BEV and FCEV trucks.

$$Tyre = \frac{\sum_{y=1}^{6} tyre\ intensity_y \times mileage_y}{\sum_{6\ years} mileage}$$

Vehicles characteristics

The vehicle combination used for the calculations is an articulated vehicle composed of a two-axle road tractor with a three-axle semi-trailer for a GCW of 40 tonnes.

	Diesel - HVO	CNG - LNG	BEV	FCEV
Kerb weight with fuel [tonnes]	15.4	15.4	19.1	16.0
GCW [tonnes]	40.0	40.0	41.0	40.0
Aerodynamic performance	A14	A14	A14	A14
Engine maximum torque [N.m]	2,100	2,100	2,100	2,100
Engine maximum power [kW]	350	350	400 (continuous)	400 (continuous)
Gearbox ratios	[14.931-1]	[14.931-1]	[14.931-1]	[14.931-1]
Drive axle ratio	2.412	2.412	2.412	2.412
Tyres dimension	315/70R22.5 + 385/55R22.5	315/70R22.5 + 385/55R22.5	315/70R22.5 + 385/55R22.5	315/70R22.5 + 385/55R22.5
Tyres Crr [kg/tonnes]	Front: 5.5 Drive: 6 Trailer: 5.5	Front: 5.5 Drive: 6 Trailer: 5.5	Front: 5.5 Drive: 6 Trailer: 5.5	Front: 5.5 Drive: 6 Trailer: 5.5
Drivetrain friction [%]	15	15	0	0
Cooling power [kW]	0	0	0	0
PTO [kW]	0	0	0	0
Energy recovery [% of engine max power]	0	0	75	75
Engine top efficiency class 1 (but engine map considered)	43.5%	40%	90%	90% (electric engine) 55% (fuel cell)
Engine top efficiency class 2 (but engine map considered)	48.6%	-	-	-
Oil volume [L]	35	35	0	0

As there is still no public information available on the eAxle for the BEVs and FCEVs, it was decided to virtually electrify the classic diesel powertrain, thus using the same value of torque, and gearbox and drive axle ratios, but removing the diesel engine map in favour of a constant value of electric powertrain efficiency at 90%.

FCEV is a BEV twin, removing battery weight (621 kWh at 155 Wh/kg) of four tonnes, adding 100 kWh battery Li-Ion at 250 Wh/kg, plus 80kg H2 (2m3), plus 115kg/m3 tank (230kg) and three TOYOTA Mirai FC (300 kW, 114kW 56kg for Mirai, so 150kg here).

About IRU

IRU, the world road transport organisation, has more than 75 years of on-the-ground experience with a network of over 170 members from around the world. We represent the entire industry – bus, coach, truck and taxi, and strive for the sustainable mobility of people and goods across the planet.

As the voice of more than 3.5 million companies operating mobility and logistics services in over 100 countries, IRU fosters impactful solutions to help the world move better. We bring a unique perspective, bridging the public and private sectors to support trade, economic growth, jobs, safety, the environment and communities.

IRU provides concrete services to transport and logistics companies, ranging from representation at the European and global level, trade and transit tools, driver skills assessments (including eco-driving), comprehensive research and insights with thematic workshops and roundtables on decarbonisation, driver shortages and digitalisation.

Join us

Interested in joining a network of over 170 members to shape the future of road transport?

Looking for a tailored partnership to boost your company's footprint in the industry?

Need advice to better understand market trends to support your decision-making and better address regulatory, business and operational opportunities or issues?

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