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LNG trucks: a dead end bridge

Emissions testing of a diesel- and a gas-powered long-haul truck

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Executive Summary

The gas industry claims that gas-powered heavy-goods vehicles (HGVs) offer a green alternative to conventional diesel trucks. Truck makers and fuel suppliers alike claim that running on both fossil-derived or renewable methane delivers meaningful greenhouse gas (GHG) and air pollutant emission reductions. Notably trucks running on liquefied natural gas (LNG) are often presented as the only widely available technology today to reduce GHG emissions in the long-haul segment.

IVECO, which of the European truck makers is most heavily invested in gas engines, is also a strong advocate of LNG trucks. The truck maker claims that its most recent spark ignition (SI) gas engine reduces tank-to-wheel (TTW) CO_2 emissions by 15% with fossil-derived methane. In terms of air pollutant benefits, IVECO states savings of nitrogen dioxide (NO_2) emissions by 90%, and particulate matter (PM) by 95% compared to diesel.

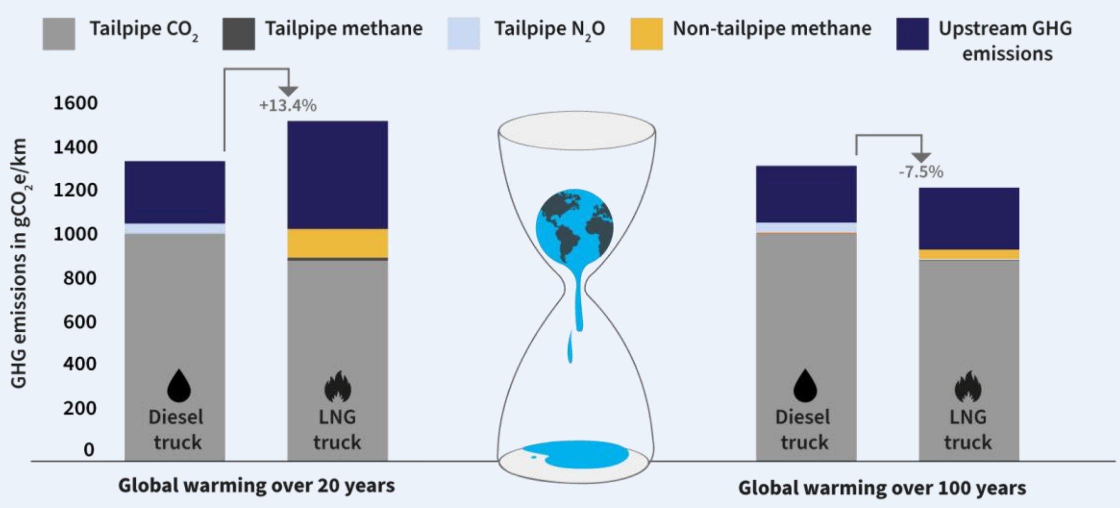
To determine whether the suggested emissions savings can be achieved in the real world, T&E commissioned the Graz University of Technology to undertake testing of a conventional diesel truck and a gas-powered LNG truck, both manufactured by IVECO.

This report presents the TTW GHG and air pollutant emissions performance of the two vehicles on real-world driving cycles as well as the expected well-to-tank (WTT) and well-to-wheel (WTW) GHG emissions. In addition, the report also examines the cost, availability and scalability challenges of sustainably sourced biomethane and renewables-based synthetic methane. The report finds that gas trucks are not a viable solution to reduce emissions, neither in terms of GHGs nor air pollutants.

LNG truck fails to reduce GHG emissions

In terms of the WTW GHG performance, the tested LNG truck delivered much lower emissions savings than claimed by IVECO. Over a 100-year global warming potential (GWP), the LNG truck achieved a GHG reduction of 7.5% compared to the tested diesel truck. When looking at a 20-year GWP time frame, the LNG truck had higher emissions than the diesel truck, resulting in 13.4% higher GHGs.

LNG truck worse for the climate over 20-year timeframe



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Sources: Tests by Technical University of Graz, and T&E calculations based on Prussi et al. (2020), IPCC (2007), IPCC (2013), Mottschall et al. (2020).

These findings run contrary to the industry's claims that gas-powered trucks constitute a viable 'bridge technology' which could deliver meaningful GHG reductions both in the short- and long-term. As the results of this testing project highlight, betting on LNG trucks is counterproductive. The significantly higher global warming potential of methane over 20 years, compared to a 100-year timeframe, means that increasing the number of LNG trucks on European roads today would actually lead to an increase in global warming over the next few decades compared to the alternatives.

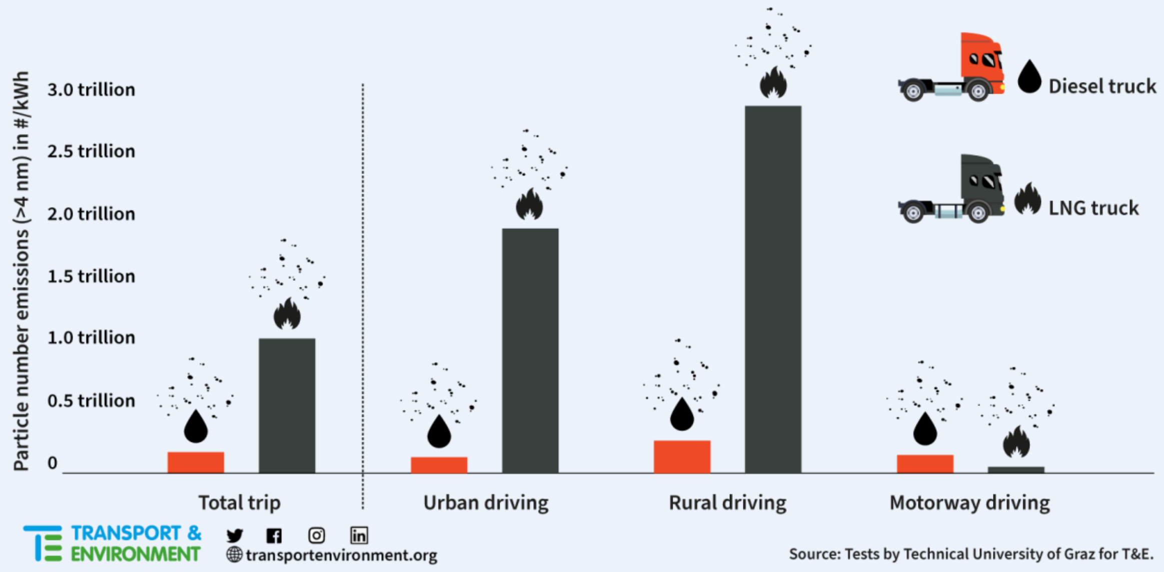
Renewable methane: neither scalable nor affordable

Neither sustainable biomethane nor synthetic methane produced from renewable electricity will be sufficiently scalable or affordable to be a viable solution for decarbonising trucking. Even with extremely high subsidies, up to six times the retail price of fossil gas, the available biomethane feedstock in the six biggest European countries would only meet 4% to 28% of the expected road freight energy consumption in 2050. It is therefore not credible to take into account any hypothetical GHG savings from renewable methane when quantifying the emissions performance of gas-powered trucks today or in the future.

LNG truck worsens air pollution

Gas trucks are not a credible solution for reducing air pollutant emissions and improving air quality either. Contrary to IVECO’s claims that the LNG truck can deliver large reductions in PM emissions, the testing results are showing that particle emissions from LNG trucks, both particle mass and particle number, can be higher than those from diesel trucks. The tested LNG truck emitted particularly large amounts of very small particles – 37 times more than the diesel truck – which are increasingly considered as the most harmful to human health.

LNG truck emits more cancer-causing particles



Source: Tests by Technical University of Graz for T&E.

While overall NO_x emissions were reduced compared to diesel, emissions during urban operation were close to the legal limits. This provides further evidence that gas-powered trucks are not a low-emission option and will not improve air quality in cities and urban areas, where pollution has the biggest adverse impact on human health.

Conclusion: focus on zero-emission trucking

Continuing the investment in LNG trucks and infrastructure carries a high risk of stranded assets and would create a fossil fuel lock-in due to the lack of renewable alternatives. As long as some vehicle manufacturers, hauliers and infrastructure operators continue to invest in this technology, they will have a vested interest to protect those investments. Since there will not be enough renewable methane available at competitive costs, even by 2050, the industry would instead need to rely on fossil gas in order to meet increasing fuel demand from gas-powered trucks.

Spending time and money on a technology which can deliver little climate benefit and actually increases emissions over the coming decades is not compatible with the European Green Deal or the

Paris Agreement. Instead, the EU and its Member States should end their harmful subsidies for gas trucks and focus exclusively on zero-emission vehicles.

Policy recommendations

Alternative Fuels Infrastructure Regulation (AFIR)

The EU should aim for an ambitious AFIR that focuses exclusively on electricity and renewable hydrogen, effectively removing gas refuelling (both CNG and LNG) from the scope and turning it into a Zero Emission Infrastructure Regulation (ZEIR). This will ensure that infrastructure investment in the EU is made ready for zero-emission trucks.

Energy Taxation Directive (ETD)

Many Member States still give tax breaks to fossil gas used in transport despite the lack of environmental benefits. It is welcomed that, as part of the revision of the ETD, the European Commission has proposed to remove the possibility of tax exemptions or reductions for fossil gas used as a transport fuel. The proposed minimum excise duty rate for both fossil gas and 'non-sustainable' biogas should be set at the same level as petrol and diesel right from the start of the transitional period.

EURO VII emission standards

The European Commission is set to put forward a proposal for a EURO VII Regulation in order to reduce toxic pollution from ICE trucks. As a priority, the upcoming proposal should include:

- A reduction of the emission limits for all regulated pollutants to the lowest levels that are technically feasible. This should include a reduction of the PM number emissions limit to levels which require the fitting of particle filters to gas-powered trucks. A reduction in the methane (CH_4) emissions limit for all trucks is also needed.

- The introduction of limits for all pollutants that are harmful to health or the environment and can be effectively regulated at the tailpipe. This should include limits for currently unregulated pollutants such as smaller than 23 nanometer particles and the potent greenhouse gas nitrous oxide (N_2O).

- Emission tests which fully cover all driving conditions including cold start (when the engine is first started) and low-speed, low-load urban driving to ensure that emission limits are respected under all possible driving conditions.

CO_2 standards

Neither more efficient diesel nor gas trucks are a solution for decarbonising trucking or improving air quality. This will require a rapid increase in the supply of zero-emission trucks beyond what truck manufacturers have to deliver under the current European CO_2 standards for new HDVs.

The review of the CO_2 standards, which is planned for 2022, needs to ensure at least 50% zero-emission truck sales by 2030. This is in line with recent public announcements by European truck manufacturers, which already aim for ZEV sales shares between 40% and 50% by the same date. The EU should also adopt a 100% CO_2 reduction target by 2035 for the vast majority of trucks.

National level

EU Member States should end fleet renewal, special depreciation and purchase incentives for gas-powered trucks. Other subsidies such as road charge exemptions and fuel duty reductions should also be phased out.

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List of acronyms

CCS	Carbon capture and storage
CH_4	Methane
CI	Compressed ignition
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DAC	Direct air-capture
E-fuels	Electrofuels
gCO_2e	Grams of carbon dioxide equivalent
GHG	Greenhouse gas
GVW	Gross vehicle weight
GWP	Global warming potential
HC	Hydrocarbons
HDV	Heavy-duty vehicle
HGV	Heavy-goods vehicle
HPDI	High-pressure direct injection
ISC	In-service conformity
LNG	Liquefied natural gas
NO	Nitrogen oxide
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
N_2O	Nitrous oxide
PEMS	Portable emissions measurement system
PM	Particle mass
PN	Particle number
SCR	Selective catalyst reduction
SI	Spark ignition
SMR	Steam methane reforming
TTW	Tank-to-wheel
VECTO	Vehicle Energy Consumption Calculation Tool
WTT	Well-to-tank
WTW	Well-to-wheel
ZEV	Zero-emission vehicle
ZLEV	Zero- and low-emission vehicle

1. Introduction

The European Union has adopted its first-ever CO_2 emission performance standards for new heavy-duty vehicles (HDVs) in 2019, requiring European truck manufacturers to reduce their average fleet emissions by 15% by 2025 and 30% by 2030.[1] To enable the EU to meet its climate target of reducing greenhouse gas (GHG) emissions by at least 55% in 2030 and to fully decarbonise the road freight sector in the long-term, these reduction targets will need to be considerably increased as part of the upcoming review in 2022. The European Commission will also bring forward a legislative proposal this year for more stringent air pollutant emissions standards for trucks to replace the current EURO VI Regulation.[2,3]

The urgency to achieve quick and deep emission cuts and offer a viable decarbonisation pathway by mid-decade poses challenges to the road freight sector in Europe. The gas industry claims that gas-powered heavy-goods vehicles (HGVs) offer a green alternative to conventional diesel trucks. Truck manufacturers and fuel suppliers alike claim that running on both fossil-derived or renewable methane delivers meaningful GHG and air pollutant emission reductions. What's more, trucks running on liquefied natural gas (LNG) are often presented as the only widely available technology today to reduce GHG emissions in the long-haul segment.[i]

A key defence of gas technology by the industry continues to be the argument that gas-powered trucks constitute a 'bridge technology', which could deliver swift emissions reductions in the short-term and, based on renewable-based methane, provide a viable decarbonisation pathway to zero emissions in the long-term. Notably IVECO, which of the European truck makers is most heavily invested in gas engines, is also a strong advocate of the 'bridge technology' approach: '[Our] path to carbon neutrality starts with natural gas and proceeds through LNG, the bridge to hydrogen, and Bio-LNG, the rocket launcher to the final destination: a full choice of solutions for a green mobility'.[4]

This position is rooted in IVECO’s claims that its most recent spark ignition (SI) gas engine reduces tank-to-wheel (TTW) CO_2 emissions by 15% with fossil-derived methane. Similarly for short term savings, Scania declares CO_2 reductions of 20% with spark ignition natural gas compared to diesel.[5] Volvo, the only European truck maker selling compression ignition gas trucks, states that a CO_2 reduction of up to 20% at the tailpipe is achievable with its high-pressure direct injection (HPDI) technology.[6] The Natural & bio Gas Vehicle Association (NGVA Europe), the leading gas vehicle lobby group in Europe, claims well-to-wheel (WTW) GHG savings of 6% for SI engines and 15% for Volvo's HPDI technology.[7]

All three truck manufacturers as well as NGVA Europe refer to TTW CO_2 savings of up to 95 - 100% when natural gas is replaced by biomethane.[ii,8,9] NGVA Europe furthermore points towards the potential of

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[i] Onboard fuel storage of methane can be in the form of compressed (CNG) or liquefied natural gas (LNG). The fuel is subsequently gasified and combusted in a modified internal combustion engine. Since long-haul trucks usually require longer vehicle ranges, gas-powered tractor trailers are usually equipped with LNG tanks.

[ii] Depending on the feedstock and production pathway.

power-to-methane, that is synthetic methane produced from renewable electricity, as a viable long-term solution towards decarbonisation.[10]

In terms of air pollutant benefits, IVECO states savings of nitrogen dioxide (NO_2) emissions by 90%, and particulate matter (PM) by 95% compared to diesel.[11,12] NGVA Europe claims that gas vehicles emit up to 95% less PM and up to 70% less NO_x compared to the EURO VI emission standard for HDVs.[13] The German industry association Zukunft Gas reports that LNG trucks would reduce nitrogen oxides (NO_x) by 80 - 90% and 'particles' by almost 100%.[14]

Can LNG trucks live up to these claims and offer a solution to the decarbonisation challenge and improve air quality? To determine whether the suggested emissions savings can be achieved in the real world, T&E commissioned the Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik (FVT), a spin-off company of the Institute of Internal Combustion Engines and Thermodynamics of Graz University of Technology, to undertake testing of a conventional diesel truck and a gas-powered LNG truck, both manufactured by IVECO.

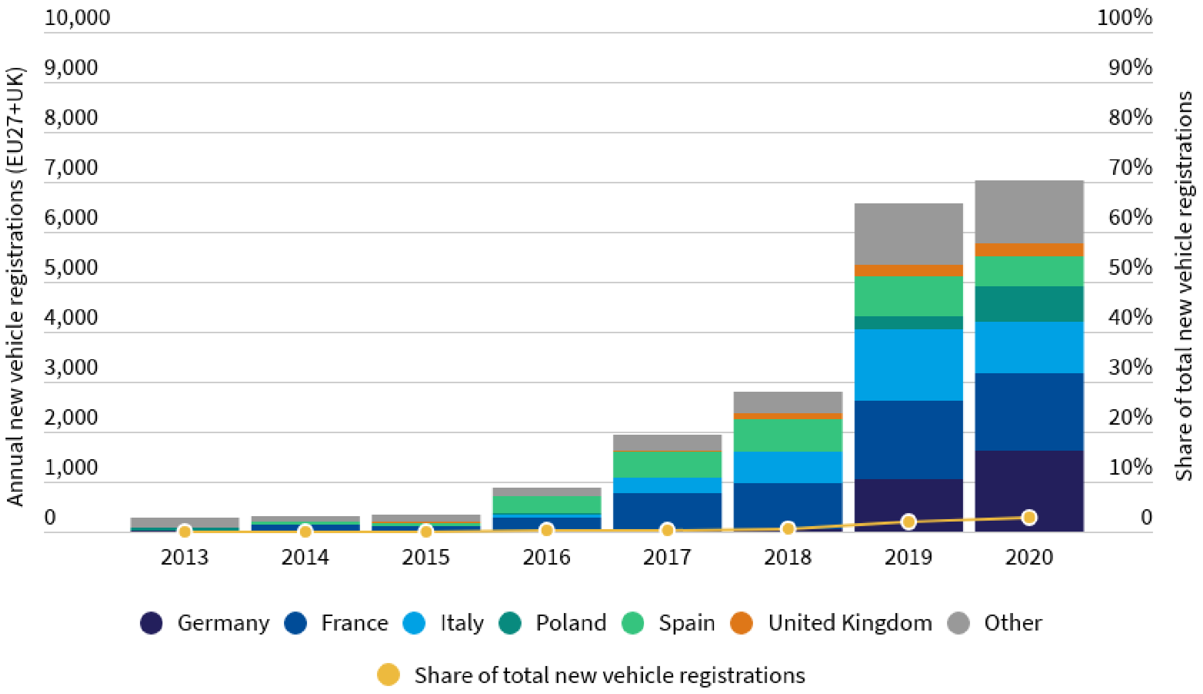
This report presents the TTW GHG and air pollutant emissions performance of the two vehicles on real-world driving cycles as well as the expected well-to-tank (WTT) and well-to-wheel (WTW) GHG emissions based on the latest work of the JEC consortium consisting of the European Commission’s Joint Research Centre, EUCAR (the European council for Automotive Research and development) and Concawe (the scientific body of the European Refiners’ Association for environment, health and safety in refining and distribution).[15] In addition, the report also examines the cost, availability and scalability challenges of sustainably sourced biomethane and renewables-based synthetic methane.

2. LNG truck market in the EU

In recent years, LNG trucks in the HGV segment above 3.5 tonnes gross vehicle weight (GVW) have witnessed an increased level of attention by industry stakeholders and policy-makers. Three major European truck manufacturers - IVECO, Scania and Volvo - have invested in the technology and continue to promote it, while others, including Daimler, MAN and DAF see no future for gas-powered trucks and instead focussed their investments on zero-emission vehicles (ZEVs).[16,17,18]

Mainly due to subsidies, sales of CNG and LNG trucks have increased significantly over the past decade, with annual growth rates roughly doubling in recent years and reaching close to 3% of total vehicle sales (see Figure 1).[19,20] This has been followed by a marked increase in LNG refueling infrastructure. According to NGVA Europe, the number of LNG refuelling stations operating in Europe has more than doubled from 200 in 2019 to 421 today, with the majority of them being located in Italy, Spain, Germany and France.[21,22]

Figure 1. Annual sales of gas trucks in Europe



Notes: 2013 - 2018 sales data based on Eurostat; data for Greece and Slovenia not available. 2019 - 2020 sales data based on ACEA; data for Bulgaria, Croatia, Lithuania and Malta not available. Includes both CNG- and LNG-powered HGVs above 3.5 tonnes GVW.

Sources: Eurostat (2021) and ACEA (2021).

2.1. LNG fuel market

Liquefying natural gas requires its purification and upgrading to remove non-methane components as well as electricity input equivalent to 8% of the energy content of the LNG produced.[23] Shipping LNG to Europe offers an alternative to piped natural gas imports and can build upon a global network of production and export locations, long-distance shipping routes as well as multiple European import and regasification terminals.[24] European LNG imports are either immediately regasified at the import terminal and injected into the natural gas grid or further distributed in their liquefied state, for example via road by tanker trucks to LNG refuelling stations for HGVs.[25]

Besides fossil-derived LNG imports from overseas, there is a small number of so-called micro liquefaction plants for liquefied biomethane.[26] Two larger-scale liquefaction plants are planned to begin operation within the next few years and supply liquefied biomethane to the gas-powered HGV vehicle fleet across North-Western Europe.[27,28] It is therefore reasonable to assume that the current European LNG truck fleet is almost exclusively fuelled by LNG imports from overseas. This has also been the case for this testing project (see Section 4.2).

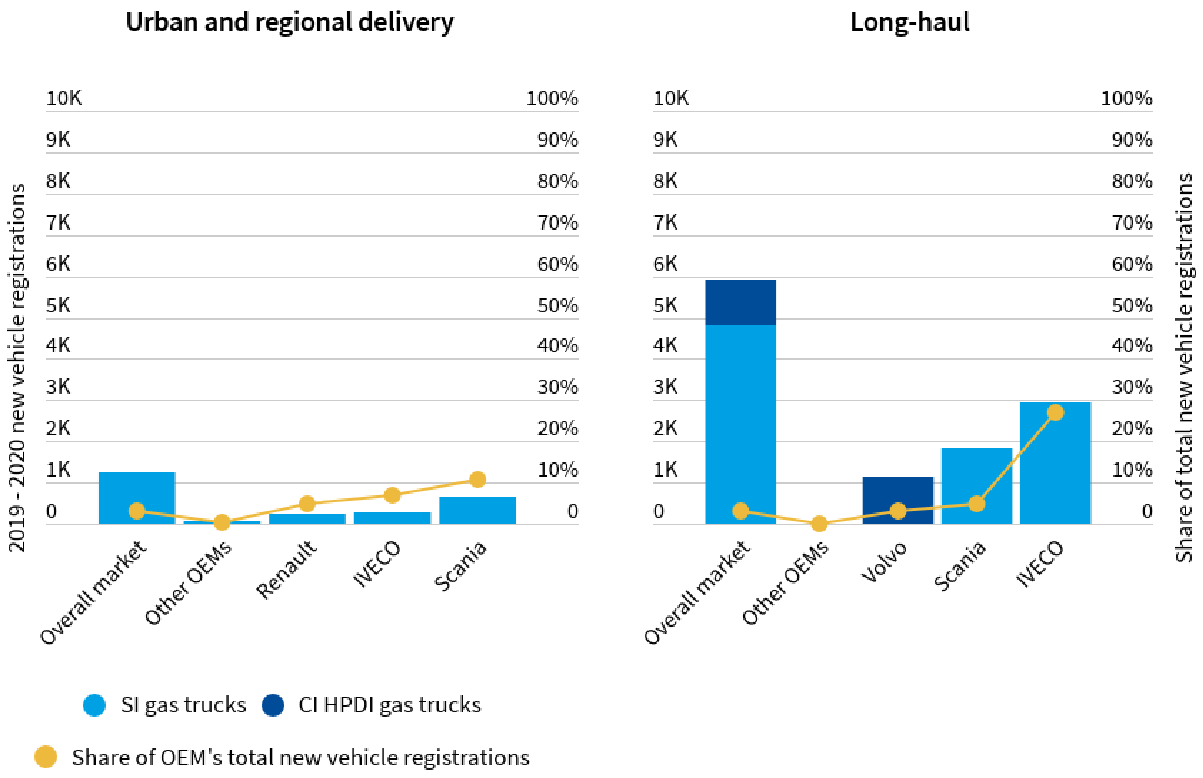
2.2. Gas engine technologies

Gas-powered trucks can either be equipped with a spark ignition (SI) or a dual-fuel compression ignition (CI) engine, which can also be combined with the HPDI technology.[29] SI engines are wholly methane powered while the dual-fuel CI engine is primarily powered by methane and uses small amounts of diesel as a pilot fuel to ignite the fuel-air mix.[30] Compared to conventional diesel engines, there is a reduced fuel efficiency of around 10% with CI engines or 15% to 20% with SI engines, whereas combining CI engines with the latest HPDI technology - as Volvo has done - is claimed to eliminate these efficiency losses.[31,32,33]

2.3. OEM market shares

Since 2019, truck manufacturers and Member States are required to monitor and report the CO_2 emissions and fuel consumption of newly registered HDVs which are subject to certification requirements under EU's Certification Regulation for HDVs.[34,35] The monitoring and reporting data is published by the European Environmental Agency (EEA) on an annual basis.[36] Based on the data from the first reporting period (July 2019 - June 2020), it is possible to gain a deeper insight into the EU's truck market.

Figure 2. Gas truck sales by OEM in the regulated vehicle groups



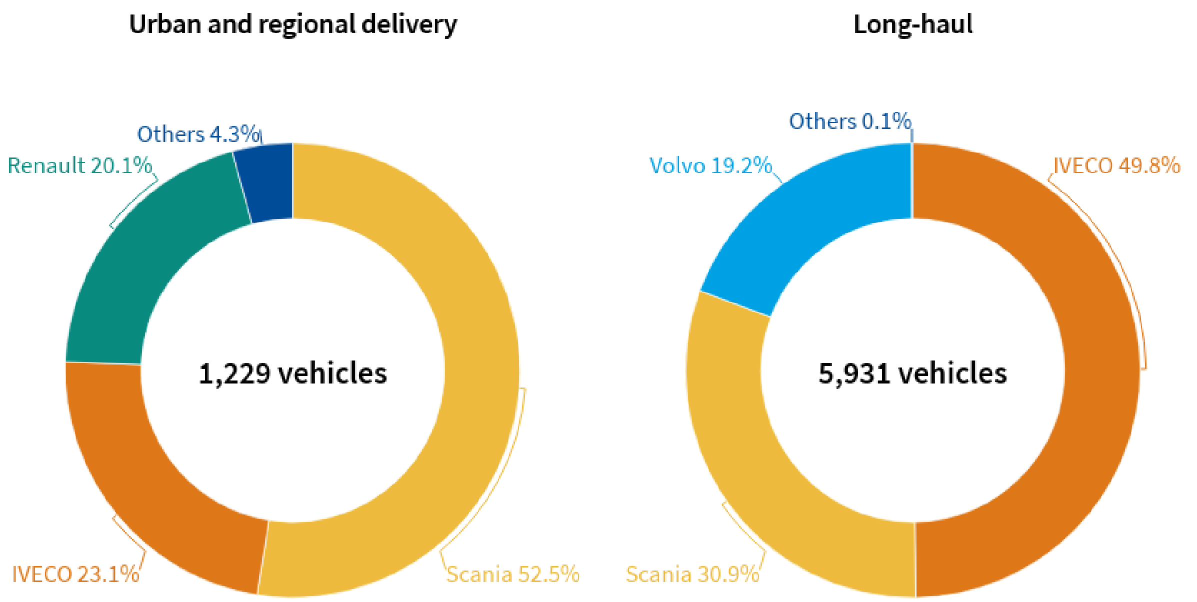
Notes: Covers both CNG and LNG vehicles. Includes new vehicle registrations which were certified and reported during the reference period July 2019 - June 2020 if the registration date was available. Dual-fuel gas trucks, for which certification is currently not available, and regulated vehicles, for which the registration date was not available, are included as well.

Sources: T&E calculations based on EEA (2021).

96% of all new gas trucks, and more than 99% of those in the long-haul segment, were manufactured by IVECO, Scania and Volvo, with IVECO accounting for almost half of all new registrations (see Figure 2). Despite the greater efficiency of CI HPDI gas engines, SI technology continues to dominate the EU market. 84% of new gas-powered trucks that sold during the first reporting period from July 2019 to June 2020 were equipped with a SI engine, while the remaining were dual-fuel engines with HPDI technology (see Figure 3).

Over 80% of all gas trucks were certified as vehicles belonging to the long-haul segment. For IVECO, vehicles with gas engines accounted for almost a third (27%) of their total long-haul truck sales, far more than for Scania and Volvo (5% and 3%). Historical sales data also shows that the share of gas-powered trucks in IVECO's long-haul fleet has been continuously rising since 2016.[37]

Figure 3. Gas truck sales shares by OEM in the regulated vehicle groups



Notes: Covers both CNG and LNG vehicles. Includes new vehicle registrations which were certified and reported during the reference period July 2019 - June 2020 if the registration date was available. Dual-fuel gas trucks, for which certification is currently not available, and regulated vehicles, for which the registration date was not available, are included as well.

Sources: T&E calculations based on EEA (2021).

It is evident that SI engines and IVECO in particular are dominating the market. LNG trucks are increasingly becoming one of IVECO's main compliance strategies to meet its average fleet reduction target under the CO_2 standards for new HDVs. And although Volvo's dual-fuel HPDI technology may offer increased fuel efficiency and CO_2 benefits, it only plays a negligible role in practice as most vehicle purchasers are opting for the SI engine technology, most likely due to its lower purchase costs. Given IVECO's dominance of the EU gas truck market, it was decided to test IVECO's SI LNG truck for this project as it is the best-selling LNG long-haul truck on the market today.

3. Emissions testing

At the beginning of 2021, T&E commissioned FVT to undertake testing of two trucks: a conventional diesel and an SI LNG tractor trailer in order to compare their GHG and air pollutant emissions performance under different driving conditions. Laboratory-based chassis dyno testing was undertaken to ensure the greatest comparability between the tests and to eliminate test-to-test variability and differences in ambient conditions such as temperature and humidity which typically occurs during on-road testing.

3.1. Test vehicles

Two IVECO tractor trailers with a maximum GVW of 40 tonnes, typically used for regional delivery and long-haul haulage, were chosen for the testing project and sourced independently of T&E by FVT. The truck specifications were matched as closely as possible based on model availability on the rental market at the start of the project (see Table 1). Both test vehicles are equipped with a 12-gear AMT transmission system.

While the vehicle mileage is higher for the diesel truck, the vehicle is less than a third of the way through the emission durability period of 700,000 km required by the EURO VI Regulation and significantly lower the typical lifetime mileage of a long-haul tractor in the EU which is estimated to be 1.47 million km on average.[38] It is therefore representative of the typical long-haul tractor operating on European roads and is expected to perform well both in terms of pollutant emissions as well as fuel consumption.

The gas truck was the highest mileage truck available for rental at the start of the testing project. Based on FVT's experience of testing new-generation trucks, this mileage is sufficient to ensure that the emissions performance of the truck has stabilised and as such is representative of the typical on-road performance of such vehicles. This is supported by the work recently presented by FVT as part of the CLOVE consortium which proposes that for the future EURO VII Regulation, a mileage of 3,000 km is sufficient for HDV compliance testing.[39]

Vehicle	Year of registration	GVW (t)	Payload (t)	Engine (L)	Rated power (kW)	Mileage (km)	Axle and body configuration
IVECO Stralis EURO VI - D	2019	28.0	12.5	11.1	353	216,224	4x2 tractor (Diesel)
IVECO S-Way EURO VI - D	2020	28.0	12.4	12.9	338	7,500	4x2 tractor (SI LNG)

Table 1. Truck specifications

Gross vehicle weight was kept constant for both vehicles and test cycles at a total of 28 tonnes GVW, equal to around 50% of the maximum possible payload. As the vehicle curb weight of the LNG truck was 100 kg higher, the payload of the LNG truck was adjusted downwards to 12.4 tonnes compared to 12.5 tonnes for the diesel truck.

IVECO S-Way SI LNG

IVECO Stralis Diesel

3.2. Test cycles

Two different cold start test cycles, representative of a typical regional delivery supermarket and long-haul duty cycle, were developed by FVT. Each vehicle was tested once on each cycle. The first test cycle, the in-service conformity (ISC) test, is based on a typical on-road ISC testing route used to check for pollutant emissions compliance and covers urban, rural and motorway driving.

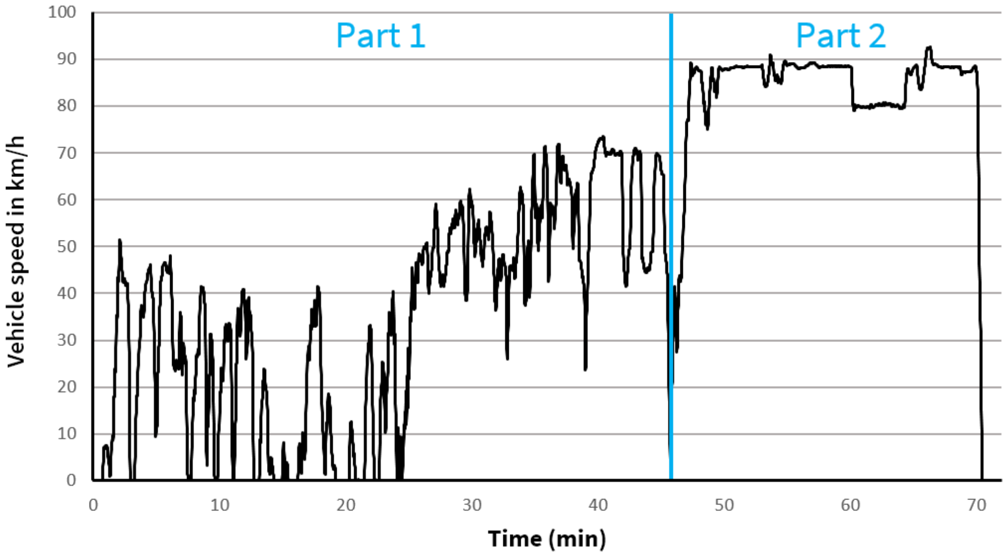
The second test cycle, the regional test, is representative of a regional supermarket delivery cycle and is based on an on-road test profile. The speed profile of the base on-road test is modelled to mimic the engine dyno regional delivery cycle which was developed for the Vehicle Energy Consumption Calculation Tool (VECTO). It includes a mixture of urban, rural and some motorway driving, with idling brakes in between designed to simulate typical stops for (un)loading, for example at a supermarket.

Test cycle	**Distance (km)**	**Time (min)**	**Driving share**			**Average speed (km/h)**		
			Urban	Rural	Motorway	Urban	Rural	Motorway
ISC	61.3	70.5	15%	29%	56%	20.7	55.2	83.7
Regional	52.5	87.5	26%	51%	23%	18.5	47.5	81.1

Table 2. Composition of the ISC and regional test cycle

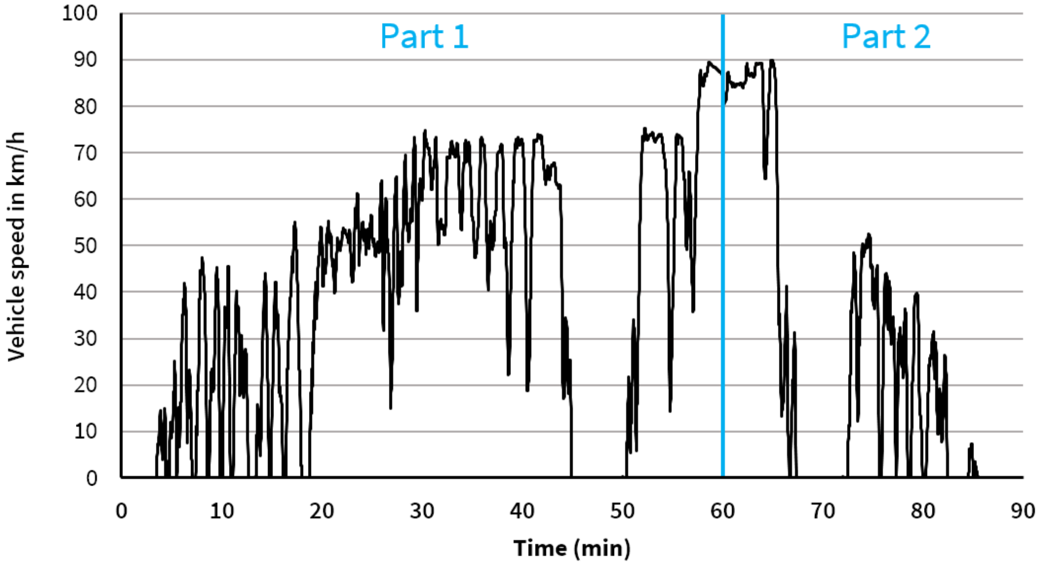
To prevent the vehicle tyres from overheating and, thus, invalidating the test procedure, each test was split into two separate test cycles as shown in Figure 4 and 5 with a break in between each test cycle to cool off the tyres. To exclude the cold start from the second test cycle, each truck was driven on a warm-up cycle at motorway speeds of above 70 km/h for at least 7 minutes just before the start of the second test cycle. The emissions measured during the warm-up cycle are not included in the analysis of the results. This method allows for the incorporation of long constant motorway driving without the cold start effects. The test results presented in this report as the ISC and regional tests contain the combined results of the 1st and 2nd test cycle for each test respectively.

Figure 4. In-service conformity test cycle



Sources: FVT (2021).

Figure 5. Regional test cycle



Sources: FVT (2021).

Chassis dynamometer driving resistance parameters were set according to FVT's internal database that contains real-world parameters for different vehicle and tyre types and the organisation's own expertise from its work on the development of VECTO for the European Commission. The driving resistance parameters were set equal for both vehicles because both vehicles are long-haul tractors of the newest generation. Each vehicle was tested on standard EU pump-grade diesel and LNG fuel, the physical properties of which are listed in Section 4.2.

Regulated pollutant emissions including nitrogen oxides (NO, NO_2 and NO_x), methane (CH_4), hydrocarbons (HC), carbon monoxide (CO) as well as CO_2 were measured continuously at the tailpipe at 1 Hz frequency using an AVL M.O.V.E Portable Emissions Measurement System (PEMS). Particle mass (PM) emissions were measured using the gravimetric filter method. Particle number (PN) emissions were measured using condensation particle counters (CPCs) with cut off size thresholds of >23 nanometers, >10 nanometers and >4 nanometers combined with the DownToTen (DTT) exhaust dilution system. Non-regulated nitrous oxide (N_2O) emissions were measured continuously at 1 hertz frequency using a MKS 2030 HS Fourier Transform Infrared Spectroscopy (FTIR) measurement device.

4. GHG analysis

Use of gas in road transport results in GHG emissions from multiple sources including the tailpipe as well as upstream from the production, processing, transport and distribution of methane. GHG emissions comprise of CO_2 and the more potent greenhouse gases methane and nitrous oxide which have a much greater heat trapping ability in the atmosphere than CO_2. For the analysis of the climate impact of the two trucks tested, the global warming potential (GWP) - a measure of how powerful a climate warming agent is compared to CO_2 - of both 20 and 100 years is used. The GWP values used are listed in Table 3 and are based on the Fifth Assessment Report of the IPCC.[40]

Greenhouse gas	Carbon dioxide equivalent (CO_2e)	
	20-year GWP	100-year GWP
Carbon dioxide (CO_2)	1	1
Methane (CH_4)	84	28
Nitrous oxide (N_2O)	264	265

Table 3. GWP values

This section presents the tailpipe GHG emissions results of the two trucks tested followed by tank-to-wheel (both tailpipe and non-tailpipe) and well-to-tank emissions to determine the total well-to-wheel emissions. The calculations were undertaken based on the test data and relevant literature sources and reflect the GHG emissions performance on a gCO_2e/km basis to ensure compatibility with the literature sources which were used to determine the non-tailpipe tank-to-wheel as well as well-to-tank GHGs, including the latest work of the JEC consortium.

4.1. Tank-to-wheel GHG emissions

Tank-to-wheel (TTW) GHGs include carbon dioxide, methane and nitrous oxide emissions from both tailpipe and non-tailpipe vehicle sources. CO_2 accounts for the majority of the tank-to-wheel GHG emissions. However, methane and nitrous oxide are also emitted in non-negligible amounts. Specific emissions are dependent on the fuel, engine and exhaust emission control used on the truck and vary from vehicle to vehicle.

4.1.1. Tailpipe GHG emissions

In the EU, tailpipe CO_2 emissions from new trucks are regulated through the CO_2 standards which are linked to a vehicle's certified specific CO_2 emissions. This value is calculated based on simulations run using VECTO. On-road CO_2 emissions may vary from those simulated through VECTO for a variety of reasons, including differences in payload, route, driving style or road or weather conditions.

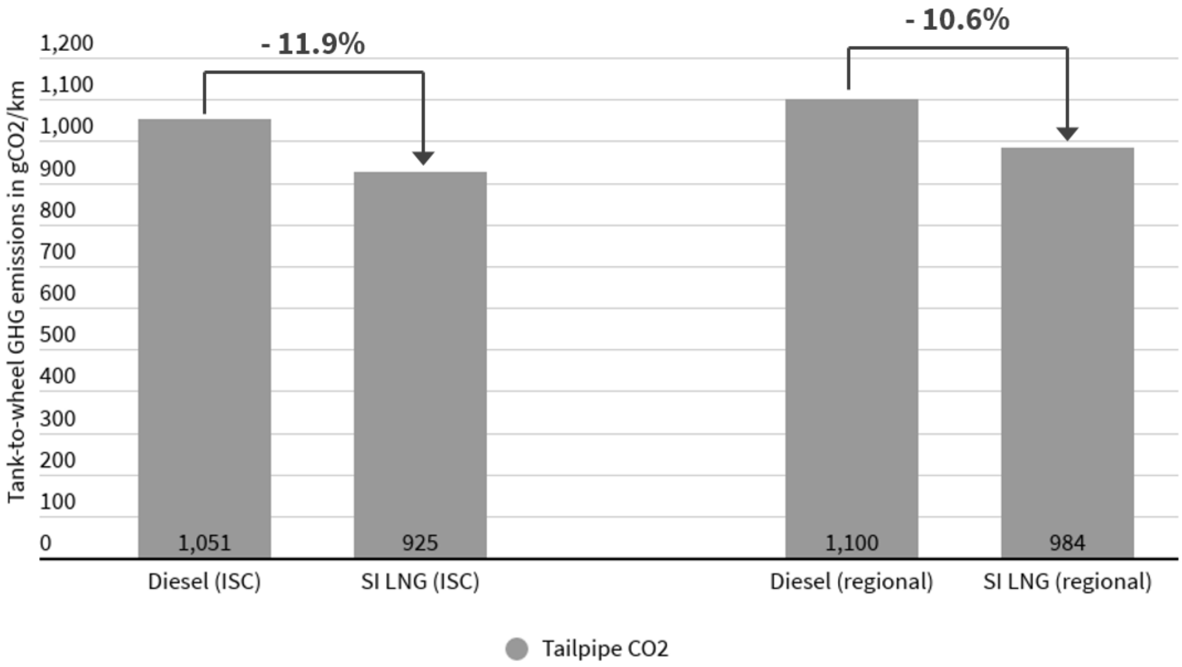
Aside from CO_2, the potent greenhouse gases methane and nitrous oxide are also emitted from truck exhausts. However, neither is regulated through the CO_2 standards. Tailpipe methane emissions are currently regulated through the EU's pollutant emission standards due to its ozone-forming potential but exhaust emissions of nitrous oxide remain unregulated in the EU.

4.1.1.1. Carbon dioxide

CO_2 emissions were measured directly at the tailpipe using PEMS equipment. Overall, the LNG truck emitted less tailpipe CO_2 than the diesel truck on both test cycles. On the ISC test cycle, the LNG truck emitted 925 gCO_2/km compared to 1,051 gCO_2/km for the diesel truck, a reduction of 11.9%. On the regional test the LNG truck emitted 984 gCO_2/km compared to the diesel truck's 1,100 gCO_2/km, representing a slightly smaller reduction of 10.6%.

While the CO_2 reduction measured on these tests tends towards the higher end of the CO_2 savings reported in the literature of between 0.5% and 12%, it is close to the 10.1% reduction reported by TNO in 2018 when the on-road CO_2 emissions of two LNG trucks were measured.[41,42]

Figure 6. Tailpipe CO2 emissions



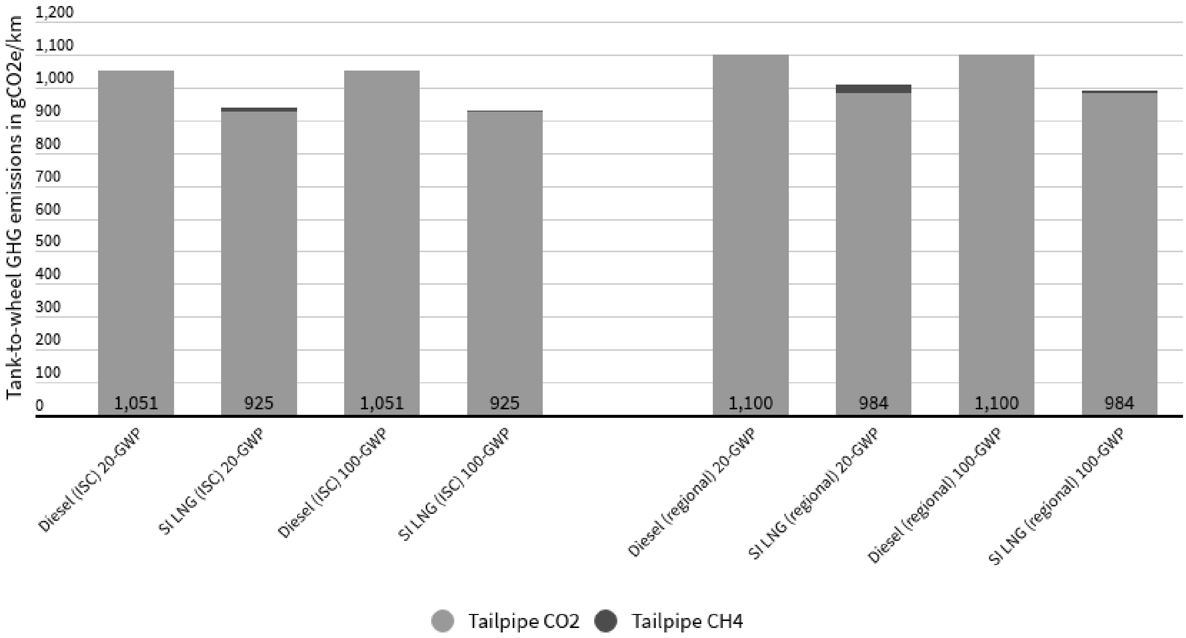
Sources: T&E calculations based on FVT (2021).

4.1.1.2. Methane

Slip of unburned methane from the tailpipe of gas trucks is a well-known issue. Particularly high methane emissions can occur when the engine is first started (the so-called cold start) before the three-way catalyst reaches sufficiently high temperatures which are required to convert methane into CO_2 and water.

The LNG truck emitted 0.15 gCH_4/km during the ISC test cycle and 0.31 gCH_4/km during the regional test cycle. The diesel truck's emissions were less than 0.001 gCH_4/km during both test cycles. When converted to gCH_4/kWh, all test results were below the methane tailpipe emission limit of 0.75 gCH_4/kWh applicable to on-road tests.[iii]

Figure 7. Tailpipe GHG emissions incl. CO2 and CH4



Sources: T&E calculations based on FVT (2021), IPCC (2007), IPCC (2013).

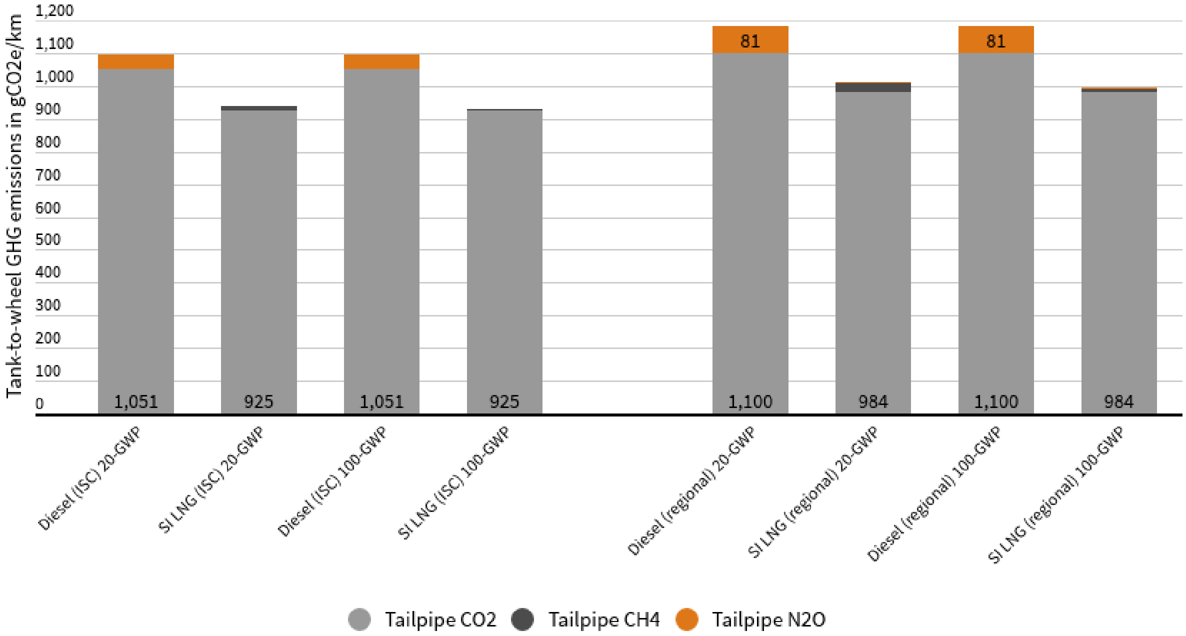
4.1.1.3. Nitrous oxide

Nitrous oxide emissions are generally more of a problem for diesel engines. The use of selective catalytic reduction (SCR) systems to reduce NO_x emissions from diesel vehicles has been shown to increase the emissions of N_2O due to side reactions between the ammonia (AdBlue) used to reduce NO, NO_2 and oxygen present in the exhaust gases. N_2O is also produced in the ammonia slip catalyst fitted to diesel vehicles to reduce their ammonia emissions.

The LNG truck emitted 0.006 gN_2O/km during the ISC test cycle and 0.015 gN_2O/km during the regional test cycle. The diesel truck's emissions were significantly higher at 0.165 gN_2O/km and 0.307 gN_2O/km respectively. The total tailpipe GHG emissions are summed up in Figure 8.

[iii] This is based on the 0.5g/kWh WHTC limit multiplied by the PEMS conformity factor of 1.5. It should be noted that these tests are not type-approval test cycles with a higher share of cold start and urban driving represented than on the type-approval ISC test. As such, official compliance with in-service conformity testing requirements cannot be verified.

Figure 8. Tailpipe GHG emissions incl. CO2, CH4 and N2O



Sources: T&E calculations based on FVT (2021), IPCC (2007), IPCC (2013).

4.1.2 Non-tailpipe GHG emissions

While the tailpipe is the main source of GHG emissions from gas trucks with SI engines, it is not the only one. Methane is also emitted in non-negligible amounts from non-tailpipe sources, however these emissions are not included in the CO_2 standards for new HDVs and their impact on the climate is therefore currently not regulated.[iv] These sources include:

Boil-off

LNG is stored as a very cold, compressed liquid within the onboard storage tank. Although the tank is insulated to prevent heat from the surrounding environment warming up the LNG, over time this does nonetheless occur. The heat transfer causes the stored LNG to gradually evaporate, also known as boil-off, which increases the pressure within the tank. To prevent the tank from reaching too high a pressure, safety valves are fitted to the tank to vent the evaporated methane to the ambient air.

[iv] CI HPDI gas engines have additional sources of non-tailpipe GHG emissions such as crankcase emissions. As these do not apply to SI gas engines, they are not covered in this report.

Refuelling

During the refuelling process, LNG can also escape to the atmosphere either from leaks from the filling nozzles or due to manual venting of boil-off emissions (gas state LNG) from inside the tank which are replaced by the liquid state LNG during the refuelling process. The amount of manual venting can be reduced by ensuring that the pump refuelling pressure is sufficient, venting the boil off into a container at the station before the start of refuelling or using a vent line (either within the nozzle or separately attached) to return any boil off back to the station. However, even with the use of these technologies some manual venting can occur. According to NGVA Europe, the attachment of vent lines from the truck to the filling station is optional which when not used could result in unnecessary manual venting.[43]

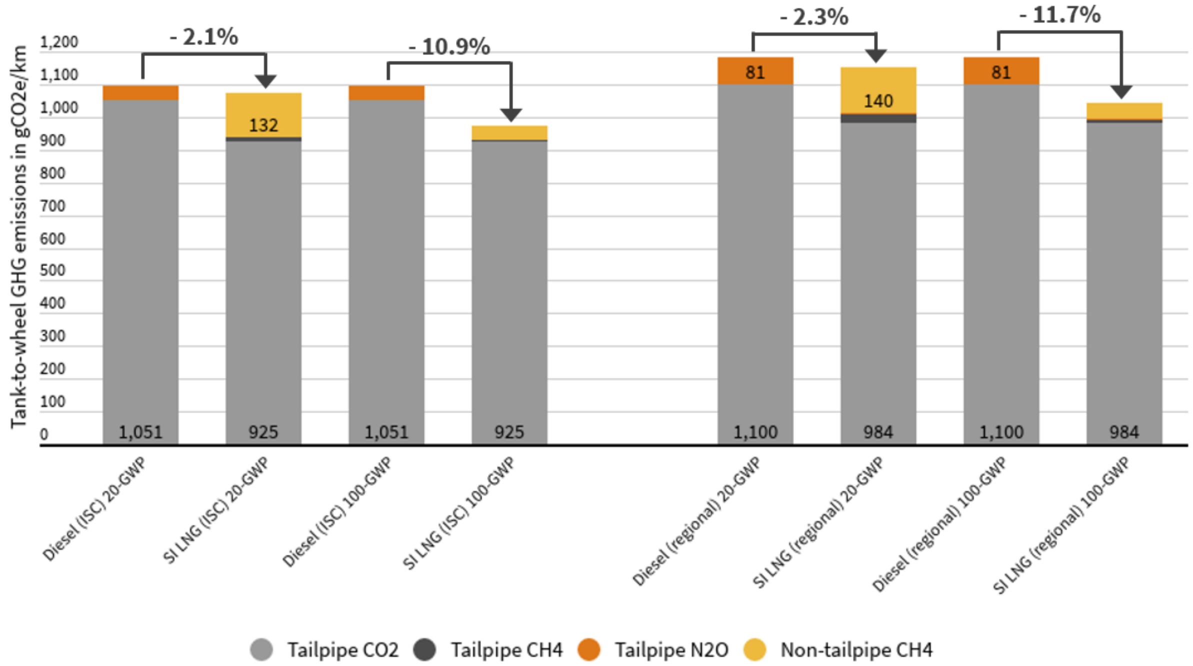
Maintenance

Maintenance of the fuel system during the lifetime of the truck also requires residual LNG to be vented. Any work on tanks themselves or components which are directly connected to the tanks requires all LNG to be removed from the system before performing any work which means that the LNG tank is no longer at the required temperature for LNG storage. When the tank is refilled, there is a quick increase in pressure from the evaporation of LNG in the hot tank which, for safety reasons, results in additional venting to the atmosphere.[44]

The process of measuring non-tailpipe emissions is complex and requires additional equipment and facilities, which fell outside of the resources available to this project. As such, non-tailpipe emissions were not measured during this testing programme. Mottschall et al. estimates that for SI LNG trucks, methane emissions emitted from non-tailpipe sources are equal to around 5.1% of total tailpipe GHG emissions based on a 100-year GWP of 30.[45]

Calculating this based on a 100-year GWP of 28 as used in this report, this would be equivalent to 4.8% of tailpipe CO_2 emissions. Calculating it based on a 20-year GWP of 84, this would be equal to 14.3%. The non-tailpipe methane emissions of the tested LNG truck were calculated based on these estimates and the measured CO_2 tailpipe emissions of the LNG truck. The total tank-to-wheel GHG emissions including non-tailpipe sources are summed up in Figure 9.

Figure 9. Tank-to-wheel GHG emissions incl. non-tailpipe sources



Sources: T&E calculations based on FVT (2021), IPCC (2007), IPCC (2013), Mottschall et al. (2020).

4.2. Well-to-tank GHG emissions

As it is the case for conventional diesel, GHGs are also emitted upstream during the extraction, processing, transport and distribution of methane. These are generally referred to as well-to-tank (WTT) emissions and usually account for a lower share of total Well-to-wheel (WTW) GHG emissions for combustion engine trucks.

In this section the energy density, fuel consumption and subsequently the WTT emissions of both trucks are calculated. To calculate the WTT emissions of the two trucks tested, the two most suitable production pathways of the latest WTW Study conducted by the JEC consortium were chosen as they are the most representative of the diesel and LNG available on the EU market.[46] The JEC's WTW Study evaluates the WTW energy use and GHG emissions for a wide range of powertrains and fuels production pathways in the European context.

It should be noted, however, that the JEC study is not taking into account any LNG imports from the U.S. and Russia which are typically composed of larger shares of shale gas from hydraulic fracturing (U.S.) and prone to higher fugitive methane emissions.[47] WTT emissions from LNG trucks may therefore be underestimated in their work and, thus, in the subsequent calculations.

Fuel production pathways

For the diesel truck, this is the WTT pathway 'COD1' which represents conventional diesel and its associated GHG emissions from typical crude oil production, transport by sea, refining in the EU, distribution and retail. For the LNG truck, the reference used is the 'GRLG1' pathway. This assumes that natural gas is liquefied at the source and transported as LNG by sea and road.

Since the JEC calculates the climate impact of methane and nitrous oxide WTT emissions on the basis of the older GWP values from the Fourth Assessment Report of the IPCC, the GHG emissions of the two WTT pathways have been adjusted to align with the GWP values from the IPCC's Fifth Assessment Report as used in the preceding sections.[48]

Fuel energy density

For the calculation of the fuel consumption of the two vehicles and subsequently the WTT emissions of LNG and diesel, the energy density of the respective fuel must be known. A sample of the diesel fuel used during this testing programme was analysed by an independent laboratory to obtain the exact fuel characteristics including the energy density.

A sample of the LNG test fuel could not be safely obtained or stored due to the sample extraction and storage requiring sufficient pressure to keep the LNG liquefied. To get around this issue, certificates of analysis of the two most recent fuel deliveries prior to the refuelling event of the LNG truck were obtained from the LNG refuelling station. The LNG of both deliveries was loaded at the LNG terminal in Zeebrugge.

Date of delivery	Nitrogen (N_2)	Methane (CH_4)	Ethane (C_2H_6)	Propane (C_3H_8)	Butane (C_4H_{10})	Pentane (C_5H_{12})
17 April 2021	0.2397	93.9934	5.6849	0.0666	0.0138	0.0015
18 April 2021	0.2169	93.7965	5.8986	0.0676	0.0190	0.0014

Table 4. Molar composition of the two LNG test fuel deliveries

The energy density was then calculated from the molar chemical composition shown in Table 4 obtained from the certificate of conformity. The resulting average of the two deliveries is used as the lower heating value of the LNG test fuel. The lower heating values of both the diesel and LNG test fuels are listed in Table 5 and are closely aligned with the calorific values of the WTT production pathways from the JEC.

Lower heating value (LHV)	Diesel	LNG
JEC WTT pathway	43.1 MJ/kg	49.1 MJ/kg
Test fuel	42.5 MJ/kg	49.6 MJ/kg

Table 5. LHV of the JEC WTT pathways and the test fuels

Fuel consumption

The fuel consumption of the test vehicles were subsequently calculated from the CO_2 emissions measured by the PEMS equipment and the lower heating values of the diesel and LNG test fuels. The observed fuel consumption is relatively high compared to the simulated and certified fuel consumption under VECTO. According to FVT, the main reasons for this are differences between the test cycles and the VECTO long-haul and regional delivery cycles such as a different speed profile and road gradient.

Both cycles are based on on-road tests but cold start and urban driving represent a higher share of these tests compared to compliant ISC tests, though such differences occur normally during on-road driving. In fact, certified fuel consumption values under VECTO need to be verified annually by manufacturers through an on-road test based on the so-called verification testing procedure (VTP). The vehicle passes the on-road test if the measured fuel consumption is lower than the certified VECTO simulation result while taking into account a tolerance of up to 7.5%.[49]

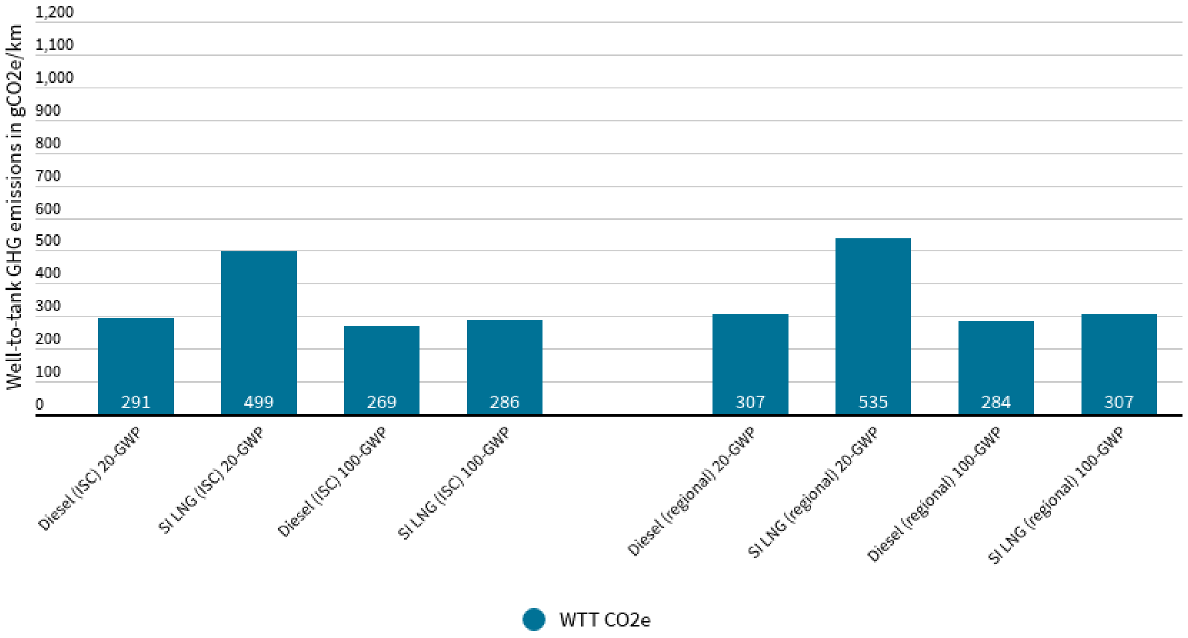
Fuel consumption	**ISC test**		**Regional test**	
	Diesel	SI LNG	Diesel	SI LNG
L_diesel/100km	40.1	-	42.4	-
kg_LNG/100km	-	33.4	-	35.9
MJ/km	14.2	16.6	15.0	17.8

Table 6. Fuel consumption

Results

Based on the lower heating value of the two WTT production pathways and the measured fuel consumption, the WTT GHG emissions in gCO_2e/km for the 20-year and 100-year GWP were calculated. Well-to-tank emissions of the LNG truck are slightly higher on a gCO_2e/km basis than those of the diesel truck, and significantly higher over a 20-year horizon due to the increased methane leakage from the extraction of natural gas and the inland distribution of LNG via tanker truck as well as due to the electricity input for the liquefaction process from on-site gas power plants.

Figure 10. Well-to-tank GHG emissions

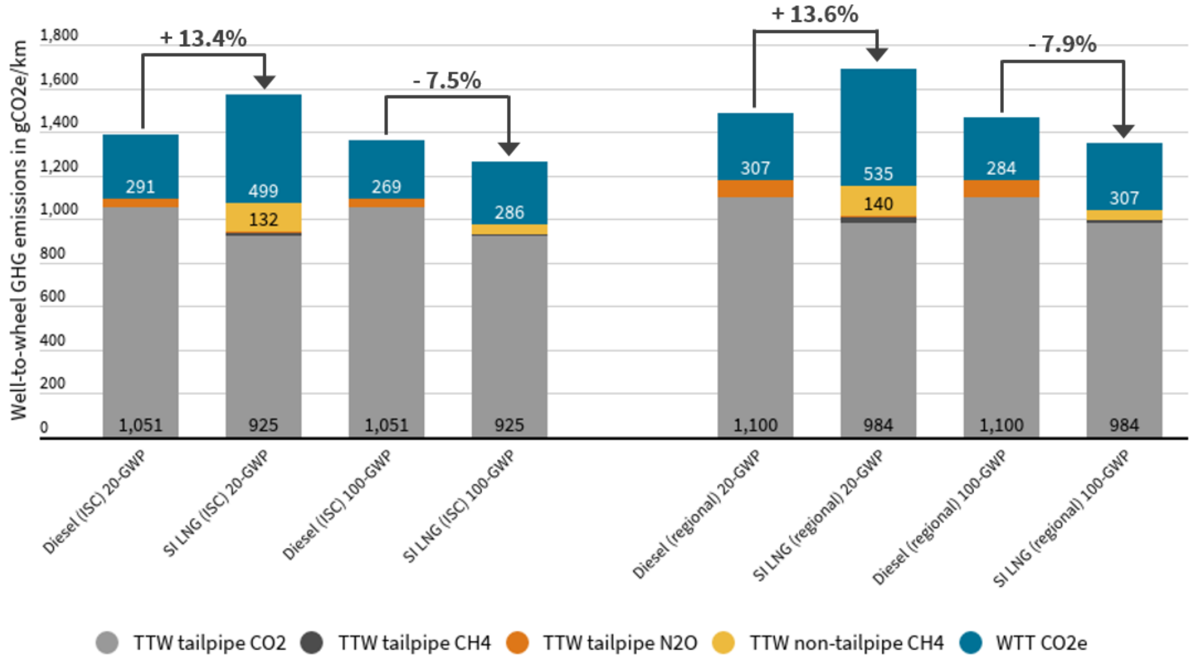


Sources: T&E calculations based on FVT (2021), Prussi et al. (2020), IPCC (2007), IPCC (2013).

4.3. Well-to-wheel GHG emissions

When adding the WTT and TTW (non-)tailpipe GHGs together, the tested LNG truck delivered much lower GHG savings than claimed by IVECO. Over a 100-year GWP, the LNG truck achieved GHG savings of 7.5% and 7.9% compared to the tested diesel truck. When looking at a 20-year GWP time frame, the LNG truck caused significantly higher emissions than the diesel truck, resulting in a 13.4% and 13.6% increase in GHGs respectively.

Figure 11. Well-to-wheel GHG emissions



Sources: T&E calculations based on FVT (2021), Prussi et al. (2020), IPCC (2007), IPCC (2013), Mottschall et al. (2020).

5. Renewable methane

Substituting fossil-derived natural gas with renewable-based methane is often suggested as an effective way to reduce GHGs from gas-powered vehicles. As the chemical composition of fossil-, bio- or electricity-based methane is essentially identical when purified and upgraded for the use as a transport fuel, the same gas engines can be used regardless of the methane source.[50]

Advanced biomethane from waste and residue feedstocks and synthetic methane produced from renewable electricity, also known as e-methane, are commonly considered as the most viable production pathways for renewable methane (see Table 7). Both options face challenges, albeit to varying degrees, in regards to their cost-effectiveness, scalability, time- and space-related deployment limitations as well as sectoral competition. This section discusses in detail those challenges that renewable methane faces as a transport fuel for trucks.

	High-GHG	GHG-neutral
Fossil-derived methane	**Natural gas** produced from both conventional and unconventional sources **Power-to-methane** produced from grid electricity bearing upstream generation emissions without carbon capture and storage (CCS)	**Power-to-methane** produced from electricity bearing upstream generation emissions in a process that captures all fugitive upstream GHGs and process CO_2 through CCS
Renewable methane	**Biomethane** produced from purpose grown-crops with high direct or indirect land-use change (ILUC) emissions	**Power-to-methane** produced from additional renewable electricity with zero GHGs and CO_2 from direct air-capture (DAC) **Biomethane** produced from sustainable and advanced feedstocks whose avoided methane emissions offset or exceed production and combustion GHGs

Table 7. Methane production pathways. Adapted from Searle et al. (2019)[51]

5.1. Biomethane

Biomethane, renewable methane purified and upgraded from biogas, could theoretically be an effective instrument to reduce GHG emissions from gas-powered trucks. Whereas first-generation crop-based feedstocks should not be considered for the production of methane due to their high emissions from direct and indirect land use change as well as other negative environmental impacts such as land conflicts, advanced waste- and residue-based biomethane (produced from anaerobic digestion or biomass gasification) could deliver strong GHG reductions if stringent sustainability criteria are ensured.

Feedstock availability

However, the availability of suitable waste- and residue-based feedstocks for the production of biomethane is limited and insufficient to displace a significant share of the energy demand from HGVs in Europe. Searle et al. estimated the maximum sustainable biomethane potential at different cost levels in different European countries. The study accounted for total lifecycle GHG emissions and considered biomethane production from anaerobic digestion of livestock manure and wastewater sludge as well as the gasification and methanation of sustainably harvested agricultural and forestry residues as those feedstocks can have no or even slightly negative GHG emissions and are therefore considered suitable for the production of sustainable biomethane.[52]

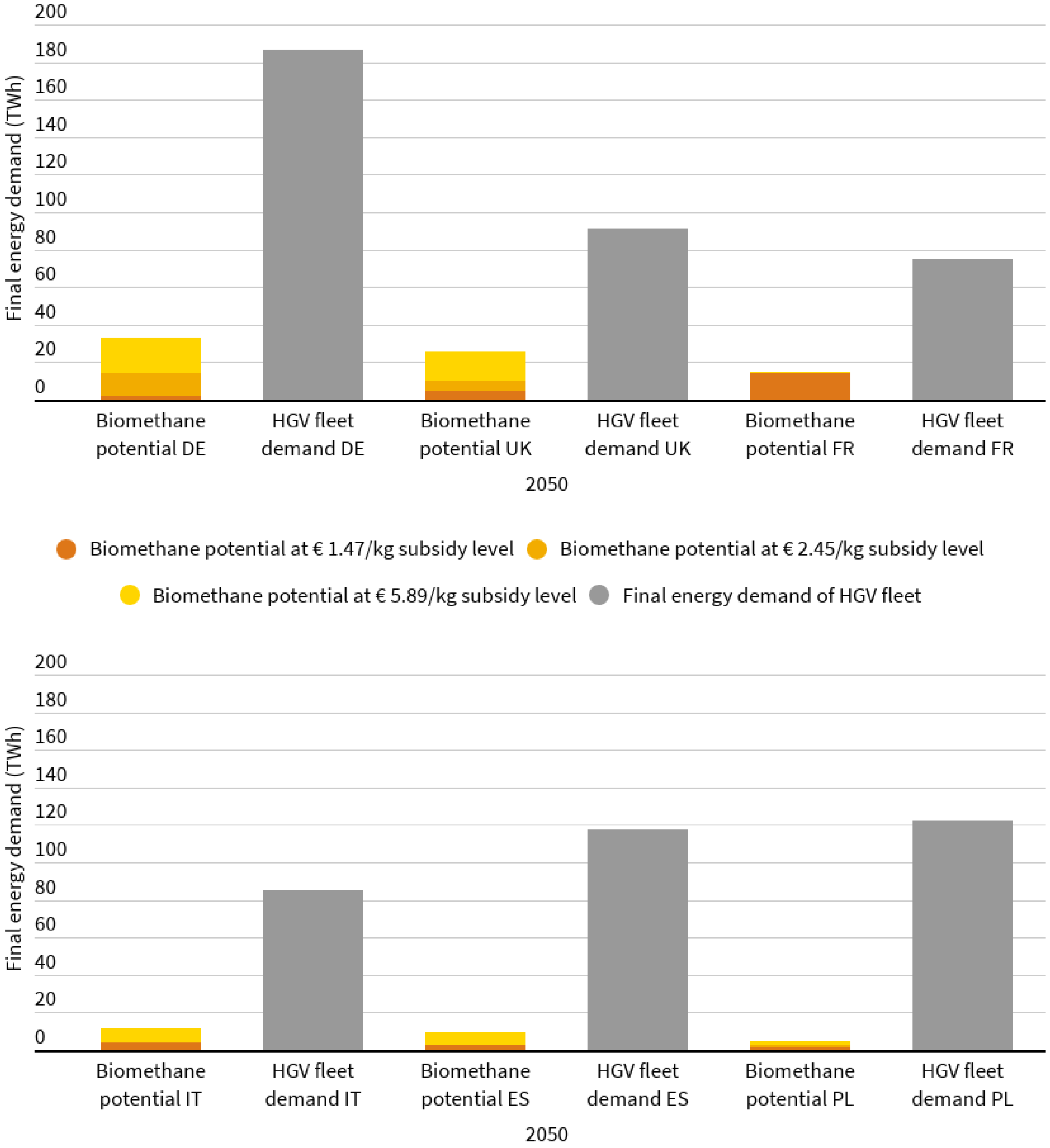
The study concluded that only a low level of sustainable feedstock would be available at competitive production costs and that the cost for unlocking additional feedstocks would increase relatively quickly following the scale-up of production. In 2050, the six biggest European countries could each supply a theoretical annual maximum of sustainably sourced biomethane that amounts to:[53]

Germany	United Kingdom	France	Italy	Spain	Poland
33.3 TWh	25.6 TWh	14.9 TWh	11.5 TWh	9.7 TWh	4.7 TWh

Table 8. Sustainable biomethane potential in 2050

If the HGV fleets of these six countries were fully replaced by gas-powered trucks with CI HPDI engines until 2050, a disproportionately higher volume of biomethane would be needed to fuel those vehicles. In theory, the total production potential listed above could only meet 4% to 28% of the expected final energy consumption of the respective country's future HGV fleet in 2050 (see Figure 12).[54,55,56,57]

Figure 12. Limited biomethane potential despite high subsidies



Notes: Comparing the 2050 final energy demand of a gas-powered (CI HPDI) HGV fleet against the sustainable biomethane potential at a given marginal price. The price level comprises the average price of compressed natural gas (which ranges from € 0.77/kg to € 1.25/kg in the included countries) and the subsidy level listed above. Excluding additional costs due to liquefaction, transport, distribution and storage of LNG. Assuming that all available biomethane is supplied to HGVs, leaving nothing for the power, industry or buildings sector.

Sources: T&E calculations based on Cambridge Econometrics (forthcoming), Searle et al. (2018), CNGEurope (2021).

Production costs

Profit margins in the haulage industry are low and fuel costs make up a large part of the total cost of ownership (TCO). Leveraging the total biomethane potential could therefore only be realised with significant policy support. To deliver the volumes quantified by Searle et al., a subsidy level of € 5.89/kg would be necessary in order to reach price parity with fossil-derived compressed natural gas (CNG) for transport. With average retail prices for CNG ranging from € 0.77/kg to € 1.25/kg in the six examined countries, the required subsidy would be around six times the equivalent of the fossil price, even before additional cost premiums due to liquefaction, transport, distribution and storage of LNG are factored in.[58]

In reality this scenario is highly unlikely. If the entire sustainable biomethane potential was allocated to the road freight sector, nothing would be left for the power, industry or buildings sector. Even if only some of the feedstocks were diverted to producing biomethane for road transport, current biomethane consumers, such as the power sector, would need to compete for the limited sustainable feedstocks available.

Alongside this, additional costly infrastructure would be needed since, at present, the majority of sustainable biomass feedstocks are processed and combusted to generate electricity for the grid at decentralised locations. Diverting advanced biomass feedstocks from current uses towards the HGV fleet would require new infrastructure for processing, transporting and distributing the biomethane from those locations which would further increase cost and reduce the economic viability.

It must therefore be assumed that no larger share of sustainable biomethane would ever be allocated to the road freight sector in these countries bearing in mind that multiple sectors, many of which already have current users of biomethane, would be competing for it.

Retail prices

Additionally, the real biomethane production costs discussed above need to be distinguished from today's retail prices of biomethane at the dispenser which are effectively subsidised by a range of national financial incentives, such as fuel mandates, sub-targets or feed-in tariffs, which offset the higher production costs to a larger extent.

In Germany, liquefied biomethane can be counted towards the greenhouse gas reduction quota and is therefore a compliance option for fuel suppliers for which they pay the producer.[59] The United Kingdom, France and Italy take a different approach, applying a feed-in tariff for biomethane which is injected into the gas grid.[60] In 2018, Italy introduced a dedicated sub-target for biomethane starting from 0.45% and rising to 1.39% by 2022. Alongside this, Italy subsidises the construction of biomethane liquefaction plants and new connections from production plants to the gas distribution grid.[61] Similarly, advanced biomethane can be certified under the Renewable Transport Fuel Obligation (RTFO) and is eligible for certificates in the UK which can be sold to fuel suppliers.[62] Other fiscal incentives, such as fuel duty reductions, also help reduce the cost gap between fossil-derived and biomethane and serve as effective subsidies (see Section 8).

Conclusion

Given the high price and low availability of biomethane and despite the fact that some limited volumes of biomethane are already used in the road transport sector today, it would be unrealistic to take into account any hypothetical GHG savings from advanced biomethane when quantifying the emissions performance of gas-powered trucks.

5.2. Synthetic methane

Synthetic methane, that is power-to-methane produced from renewable hydrogen and CO_2 from direct air-capture (DAC), could theoretically provide a near GHG-neutral pathway for gas-powered trucks. The process requires hydrogen produced from renewable electricity and CO_2 from DAC. These feedstocks are then converted to methane through a process called methanation (or the Sabatier process).

The key challenge for synthetic methane is the low energy efficiency of production due to energy conversion losses across multiple production steps and the comparatively low efficiency of the internal combustion engine resulting in high fuel costs. Alongside this, a lack of meaningful air pollutant emissions reductions and an increased exposure to energy imports from outside Europe due to increased renewable electricity demand makes this decarbonisation option even less attractive.

Production costs

To quantify possible future fuel prices for synthetic methane, the Agora PtG/PtL calculator was used to calculate the production and import cost of synthetic methane to Germany.[63] Two production pathways were considered in the analysis. In the first, the electricity is sourced from offshore wind in the North Sea with connection to domestic e-fuel production plants located near the German coast. The second is from solar photovoltaic in North Africa as the Middle East and North Africa represents a particularly favourable location to produce synthetic methane cheaply due to low renewable electricity costs.[v]

The calculated price of the imported synthetic methane includes the cost of liquefaction, transport via fuel tanker from North Africa (Port Said) to Germany (Port of Wilhelmshaven) and domestic distribution to the refuelling station via tanker truck. Liquefaction, transport and distribution costs are based on Agora Verkehrswende et al. and Bünger et al.

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[v] The fuel cost calculations are based on the reference scenario of the Agora PtG/PtL calculator. The weighted average cost of capital (WACC) was set at 6% and DAC was chosen as the CO_2-extraction method. Offshore wind in the North Sea, the low-temperature PEM electrolysis as well as methanation plant was set at a load factor of 4,000 full-load hours per year. Solar PV in North Africa as well as low-temperature PEM electrolysis was set at 2,344 full-load hours, whereas the methanation plant was set at 4,000 full-load hours and relies on temporary stationary hydrogen storage.

For synthetic methane produced from offshore wind in the North Sea, German-specific taxes and levies on the electricity input for the electrolysis and methanation plants are included.[vi] The currently reduced fuel duty rate for natural gas used as transport fuel of €-cent 13.90/MWh is also included, which will increase to its normal rate of €-cent 30.80/MWh by 2027.[64]

The calculated final prices at the dispenser range from € 4.16/kg in 2030 to € 2.04/kg in 2050 and are comparable to literature values including Pfennig et al. and Ueckerdt et al.[65,66] The current price of fossil-derived LNG in Germany is € 1.13/kg (see Figure 13).[67] Future increases in the CO_2 price for natural gas as a transport fuel would help close the price gap and make synthetic methane more competitive.

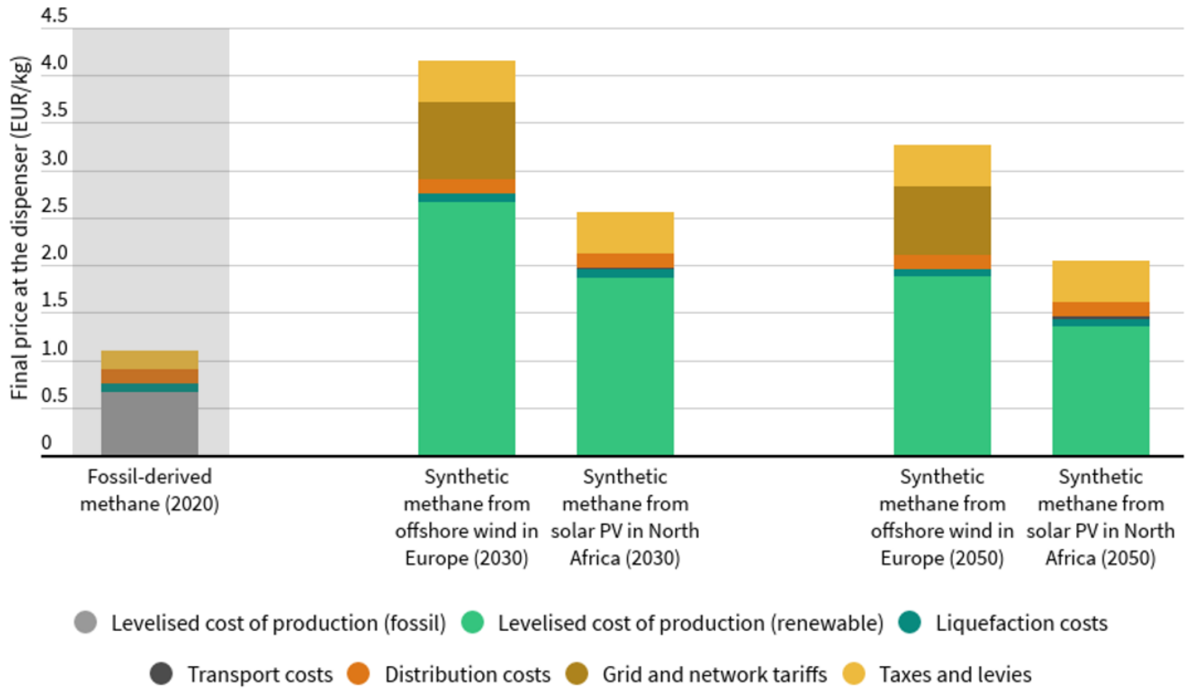
Conclusion

Even when assuming rapid cost reductions in renewables, electrolysers and fuel production technologies, synthetic methane will likely remain significantly more expensive than fossil-derived methane for decades to come. Likewise, time-related deployment limitations and space constraints in favourable regions as well as potential competition between sectors and countries would make it very challenging to provide any substantial volumes of synthetically produced methane to Europe anytime soon.[68]

As it is the case for advanced biomethane, it would make just as little sense to take into account any hypothetical future GHG savings from synthetic methane when quantifying the emissions performance of gas-powered trucks for the coming decades.

[vi] This applies to all taxes and levies except for the renewables levy ('EEG-Umlage') and the network tariffs ('Netzentgelte') from which renewable hydrogen and its derivatives are currently exempt.

Figure 13. Synthetic methane will be expensive, also in the long-term



Notes: Exemplary costs based on Germany. Transport costs refer to shipping from North Africa to Gerrmany via LNG tanker vessel. Distribution costs refer to delivery via LNG tanker truck. In Germany, production of renewable hydrogen and its derivatives is exempt from the renewables levy ('EEG-Umlage) and network tariffs ('Netzentgelte'); all other taxes and levies on electricity input apply.

Sources: T&E calculations based on Transport & Environment (2021), Agora Verkehrswende et al. (2018), Bünger et al. (2016), Bundesnetzagentur (2020), Destatis (2021), Zoll (2020), Zukunft Erdgas (2020), EnWG (2020), EEG (2021).

6. Air pollutant emissions

Air pollution from road transport is a huge problem across Europe, particularly in cities and urban areas where large amounts of traffic release toxic pollutants from exhausts into the ambient air. The gas vehicle industry, particularly NGVA Europe, has claimed strong air quality benefits when using gas-powered vehicles: '[Natural gas emits] virtually none of the pollutants (particle matter and nitrogen oxides) that increasingly contaminate the air in areas with dense traffic.'[69] IVECO also makes several claims as to the air quality benefits of switching away from diesel to their gas-powered trucks which are covered below.

To test the industry's claims, pollutant emissions from both trucks were measured during this testing programme. This section presents both the particle matter (PM) and particle (PM) number as well as nitrogen oxides (NO_x) emissions. To allow for comparison with the EU's pollutant emission limits, all emission results are presented in milligrams or number per kWh. The results have not been post-processed using the moving average window method which is used in the EURO VI Regulation to process test data for emission compliance and removes many of the worst-case emissions measured such as those emitted at cold start i.e. when the engine is first started. As what actually matters for air quality is what the truck emits on the road and not simply on paper, the raw test emission results are presented in this section.

6.1. Particles

Particle pollution is increasingly seen across Europe as the biggest problem for air quality, with the latest report by the European Environmental Agency showing that progress in the reduction of PM 2.5 pollution (particulate matter smaller than 2.5 micrometer) has effectively stalled at a point where 7 out of 10 residents of European cities breathe air above the World Health Organisation’s recommended particle pollution threshold. This is of serious concern to public health as particle pollution causes 379,000 premature deaths in the EU annually and is a contributing cause for a wide range of diseases including Alzheimer’s, cancer as well as cardiovascular and respiratory illnesses.[70,71,72]

Road transport is currently the third biggest source of particle pollution in the EU.[73] The gas vehicle industry has repeatedly claimed that particle pollution is not a problem for gas-powered trucks and that large reductions in particle emissions can be achieved when switching from diesel to gas engines. IVECO has previously claimed that their Stralis LNG truck emits 99% less PM than an equivalent EURO VI diesel truck.[74]

However, recent research shows that trucks with gas engines can emit large amounts of particle pollution, especially when it comes to emissions of very small so-called ‘ultrafine particles' which are increasingly considered to be potentially the most harmful to human health.[75,76] FVT measured currently regulated PM and PM number emissions larger than 23 nanometers of the two trucks. Alongside this, the currently unregulated PM number smaller than 23 nanometers were also measured.

6.1.1. Particle mass

The total mass of particles emitted from a truck’s tailpipe is regulated through the PM emission limit. The EURO VI limit for HDVs is set at 10 mg/kWh. When it comes to the PM reductions by switching from diesel to gas engines, IVECO claims that the S-Way LNG truck can reduce PM emissions by up to 95% compared to diesel.[77] However, the test results show that these claims are false. The LNG truck tested actually emitted more PM than the diesel truck on three of the four test cycles undertaken with the worst emissions measured occurring during urban driving.

Measurement of PM emissions

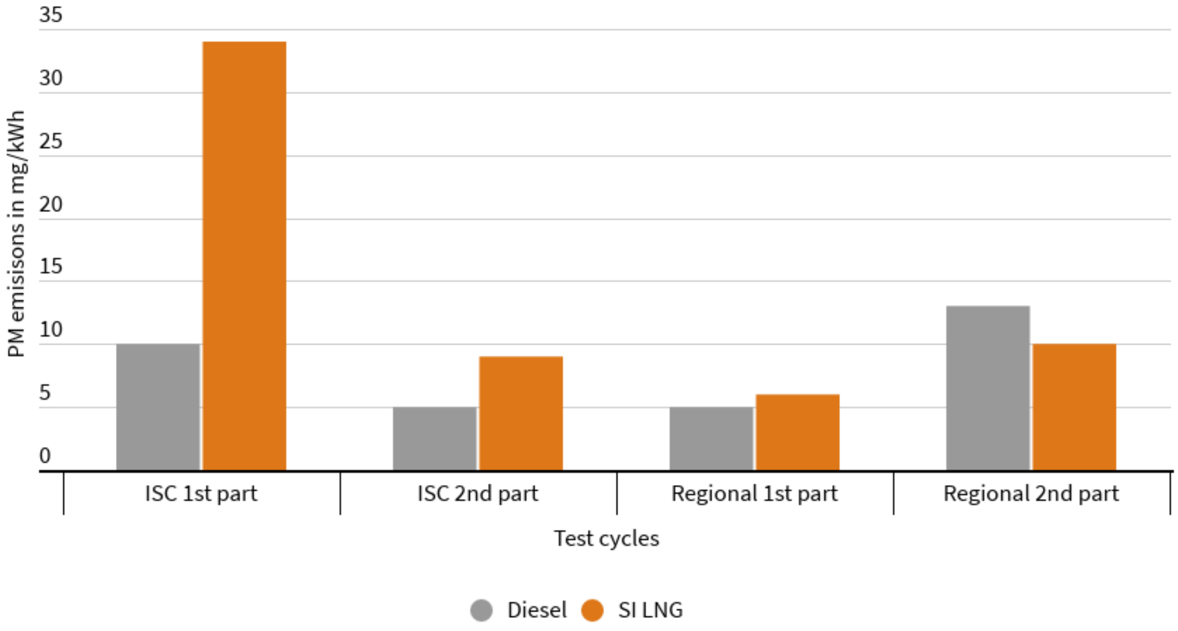
The standard technique for measuring PM emissions during emissions tests is to collect the PM emitted out of the tailpipe on filter paper. This filter paper is subsequently weighted at the beginning and end of the test to determine the total amount of PM emitted. As emissions are not measured second by second, contrary to how it is done for other pollutants, the results of the two test cycles that make up each complete test cannot be easily split into urban, rural and motorway driving. Therefore, in this section test results from each of the two test cycles that make up the ISC and regional tests are presented separately.

During the tests, the LNG truck emitted 1.2 - 3.4 times more PM than the diesel truck on all test cycles apart from the second regional cycle where emissions were 22% lower compared to the diesel truck. The LNG truck performed particularly badly during urban and rural driving. PM emissions during the first part of the ISC test cycle were 34 mg/kWh. This is more than three times higher than the EURO VI PM emission limit and 3.4 times higher than what was emitted by the diesel truck.[vii]

These findings show that the claims stating that LNG trucks reduce PM emissions compared to diesel trucks are false. LNG trucks can emit more PM than diesel trucks under a wide range of driving conditions and can even exceed the legal PM emission limit on the road. Most concerning are the very high PM emissions above legal limits which were measured during urban and rural driving in the first part of the ISC test. Urban emissions occur where people have the highest exposures to air pollution and where PM concentrations in excess of the World Health Organisation's limits occur most often and should therefore be a priority in terms of emissions control.

[vii] This does not necessarily mean that the truck was legally non-compliant as the results were not processed according to the moving average window (MAW) method used for checking on-road emissions compliance with legal limits which averages emissions over the entire test cycle. However, what ultimately matters for air quality and human health is what is emitted out of the tailpipe and not on paper compliance and the MAW method used in the regulation excludes many normal driving conditions including cold start. For EURO VI - D trucks, this would include any emissions which occur when the engine coolant temperature is less than 70 °C.

Figure 14. Particle mass (PM) emissions



Notes: PM emissions are measured by collecting the PM emitted from the tailpipe on filter paper. This filter paper is weighted at the beginning and end of the test to determine the total amount of PM emitted. As emissions are not measured second by second, the results of the two test cycles that make up each complete test cannot be split into urban, rural and motorway driving.

Sources: FVT (2021).

6.1.2. Particle number

Aside from PM emissions, the number of particles emitted from exhausts also matters. This is because it is not just the total mass of particles in the air that determines particle pollution's negative health effects. It is also the size and number of particles that is important. Very small particles, especially ultrafine particles which are less than 100 nanometers in size, are increasingly considered as the most dangerous for health. Medical studies have shown that these particles are able to deposit in the lungs and airways with very high efficiency and, unlike larger particles, can evade the body's immune defences. This means that they are not readily removed and can accumulate within the body.[78] Once deposited in the lungs, they can also travel to other areas of the body such as the brain and the placenta.[79,80] Medical studies show that even short exposure to these particles can cause changes in heart function[81] and these particles have been linked to an increased risk of heart disease and brain cancer.[82,83]

Ultrafine particle pollution is a problem in the EU and road transport is a major source of these particles. In cities, road transport emits more than any other source and is responsible for over 70% of ultrafine particles emitted.[84] However, because these particles are so small, often smaller than a typical virus, they do not contribute much to the total particle mass (PM) emitted. So while a truck's PM emissions can be low, the number of particles emitted from that truck can be huge. For example, for ambient air the WHO air quality guideline for PM2.5 is 10 µg/m^3. One large 2500 nm particle per cm^3 of air will reach this threshold but for ultrafine particles of 20 nanometers in size, 2.4 million particles are needed per cm^3.[85]

To limit the number of particles emitted from trucks aside from a PM limit, trucks' particle emissions are also regulated through a PM number emission limit during type-approval engine testing. The limit of 6 x 10^{11}/kWh includes any solid particles that are larger than 23 nanometers. To ensure compliance with the limit on the road, EURO VI Step E introduces a PM number emission limit to on road (PEMS) testing. This takes place both during type-approval and during the first 700,000 km of a truck and helps ensure on-road compliance with limits. For diesel trucks, the on-road limit for PM number emissions applies from 2021 for new types and from 2022 for all vehicles.

However, due to lobbying by gas truck manufacturers[86], a derogation was granted to gas trucks to which the limit will only apply two years later by 2023 and 2024 respectively.[87] This in effect allows gas trucks to emit more particles than diesel trucks for two additional years. Most importantly, this delays by two years the fitting of particle filter technology, which reduces exhaust particle emissions, to gas trucks which are already standard for diesel trucks.

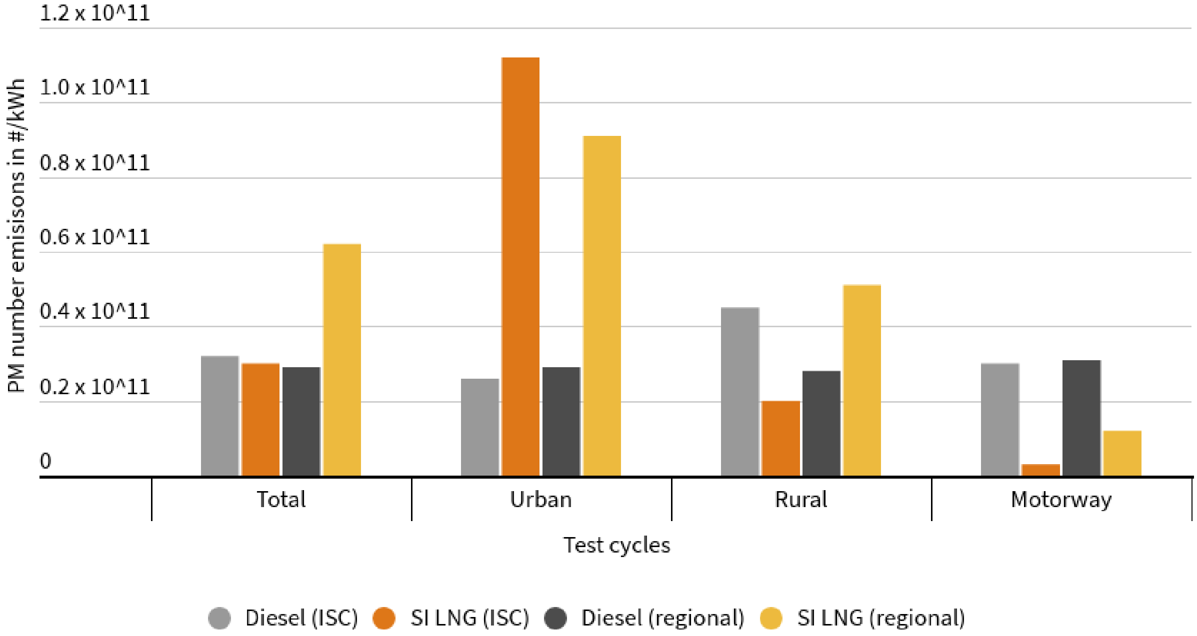
To fully assess and compare particle emissions of different combustion engine technologies, it is important to consider both PM and PM number emissions. This is something that IVECO does not consider. During this testing programme, the PM number emissions of regulated >23 nanometers were measured. It should be noted, however, that as both trucks are of the EURO VI - D emission standard they are not legally required to meet the PM number emission limit on the road, as mentioned previously this only applied to EURO VI - E certified vehicles. To assess the full particle emissions of both trucks, also <23 nanometer particles were measured which are not currently regulated for any internal combustion engines in the EU.

6.1.2.1. PM number >23 nanometers

Overall, both trucks emitted less than the legal PM number limit on both tests including in each urban, rural and motorway section of the test.[viii] However, from the results obtained, it cannot be said that the LNG truck tested emits less particles than the diesel truck as it varies depending on the driving conditions. Over the total ISC test, the LNG truck emitted 8% less >23 nanometer particles. However, over the total regional test, the LNG truck had more than double the particle (+115%) emissions of the diesel truck.

[viii] For emissions measured using the Portable Emissions Measurement System, as is the case for the results presented here, an additional 1.63 conformity factor applies to account for measurement uncertainty.

Figure 15. Regulated >23 nm particle number (PN) emissions



Sources: FVT (2021).

The largest difference between the two trucks was measured during urban operation on both tests, which includes the cold start engine warm-up period. Here, the LNG truck performed much worse than the diesel, emitting between 2-3 times more particles. This is in line with previous studies which have found that LNG trucks have particularly high PM number emissions during the cold start period, an effect observed only on some diesel trucks.[88] Similarly, the LNG truck performed worse during the rural section of the regional test where it emitted 83% more particles.

However, the LNG truck did emit between -62 to -91% less particles during motorway driving as well as -56% less during the rural section of the ISC test. As combined motorway and rural driving accounts for 86% of the total kilometers driven during the ISC test, overall the LNG truck emitted slightly less particles than the diesel truck on this test despite the significantly worse urban emissions performance. On the regional test, urban and rural driving comprised 77% of total kilometers when PM number emissions were higher than the diesel truck resulting in higher overall regional test emission from the LNG truck.

Generally, these results show that the >23 nanometer PN number emissions of the two trucks are highly dependent on the route and driving style. However, the LNG truck can emit more particles than the diesel truck and as such should not be considered as a cleaner alternative particularly for use in urban and rural areas where the particle emissions of the LNG truck can actually be higher than the diesel.

6.1.2.2. PM number >4 nanometers

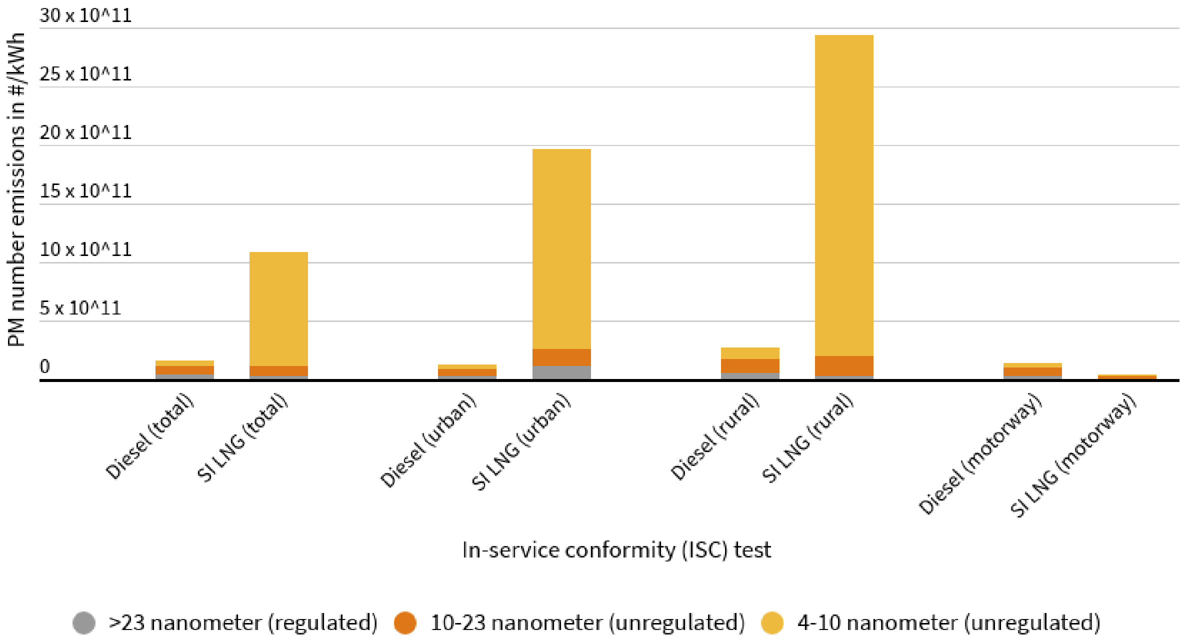
Particle emissions measured during most emissions' tests, such as the ones discussed above, do not actually include all of the particles released from vehicle exhausts. This is because the current method for measuring PM number emissions only includes solid particles larger than 23 nanometers. Particles smaller than this are not included in the measurement. However, tests show that some engine technologies, particularly gas vehicles, can emit more <23 nanometer particles than >23 nanometers.[89]

This means that for many vehicles the majority of particles emitted out of the exhaust are neither measured nor regulated. This is problematic as it means that the full particle pollution impact of vehicles is not considered. Additionally, the very smallest particles may be the worst for human health as they deposit in the lungs with greater efficiency than larger particles.[90]

FVT used new particle measurement equipment (DownToTen) to measure the emissions of these small and currently unregulated particles. Two analysers were used to enable the measurement of >10 nanometer and >4 nanometer particles.

The results of the measurements show that for both trucks, there is a large increase in particles when those smaller than the regulatory 23 nanometer threshold are measured. When it comes to emissions of particles of 4 - 23 nanometer in size, the LNG truck is generally the worst performing, emitting more than the diesel truck on both the ISC and regional tests (see Figure 16).

Figure 16. Total >4 nm particle number (PN) emissions



Sources: FVT (2021).

The LNG truck also had the largest increase in the total particle count compared to the measurement of just >23 nanometer particles. When all particles bigger than 4 nanometers were measured, the total number of particles from the LNG truck increased by 37 times over the ISC test cycle. This was driven by large increases in the number of particles measured during urban (by 18 times) and rural (by 147 times) driving. In comparison, the increase for the diesel truck was more modest, not exceeding 6 times the measured >23 nanometer particle emissions on any section of either test.

The very large emissions of <23 nanometer particles for the LNG truck resulted in the vehicle exceeding the PM number emission limit during urban and rural driving of the ISC test cycle as well as the whole test cycle overall with average emissions of $1.1x10^{12}$/kWh. For comparison, if the on-road PN limit applied under all driving conditions including the entire cold start period and based on raw emissions, >4nm emissions would exceed the current on road PM number limit of 9.8×10^{11}/km by 10%. These results show that LNG trucks do emit large numbers of particles when all particles larger than 4nm emitted out of the tailpipe are measured.

Overall, when emissions of all particles >4nm are considered, the LNG truck emits more particles than the diesel truck on both test cycles as well as during urban and rural operation, emitting between 0.3 to 15 times more particles depending on the driving conditions. The LNG truck only performed better than the diesel truck under motorway driving conditions, however the reduction of -64% (regional test cycle) to -72% (ISC test cycle) is more modest compared to the reduction observed for >23 nanometer particles.

Statements made by IVECO that its LNG trucks are better than diesel trucks in terms of particle pollution are false. The findings of this testing highlight that, in reality, the tested LNG truck is no better than the diesel truck in terms of particle pollution and, under many conditions, actually worse. The higher particle pollution from the LNG truck during urban driving also indicates that switching from LNG trucks to diesel trucks is not an effective strategy for reducing particle pollution in cities and urban areas. It also shows that the decision to delay the introduction of the on-road PM number emission limit by two years for gas trucks was misguided as it allows gas trucks to emit large amounts of particles under real-world driving conditions.

6.2 Nitrogen oxides

Aside from particle emissions, internal combustion engine (ICE) trucks also emit a range of toxic gases, the most problematic of which are nitrogen oxides (NO_x) as emissions from ICE vehicles are its biggest source in the EU.[91] NO_x emissions contain both nitrogen oxide (NO) and nitrogen dioxide (NO_2) gases. NO_2 is the toxic component of NO_x which causes a range of serious negative health effects including inflammation of the airways, reduced lung function and increased asthma attacks.[92].

However, as NO is readily converted to NO_2 once released into the air, tailpipe emissions of both NO and NO_2 are regulated at the tailpipe through a combined NO_x emission limit. NO_2 pollution is particularly a problem in urban areas where traffic levels are high and many cities in the EU still exceed the EU's Ambient Air Quality Directive legal limits for NO_2 meaning that the air in many cities is unsafe to breathe due to toxic levels of NO_2 pollution.[93]

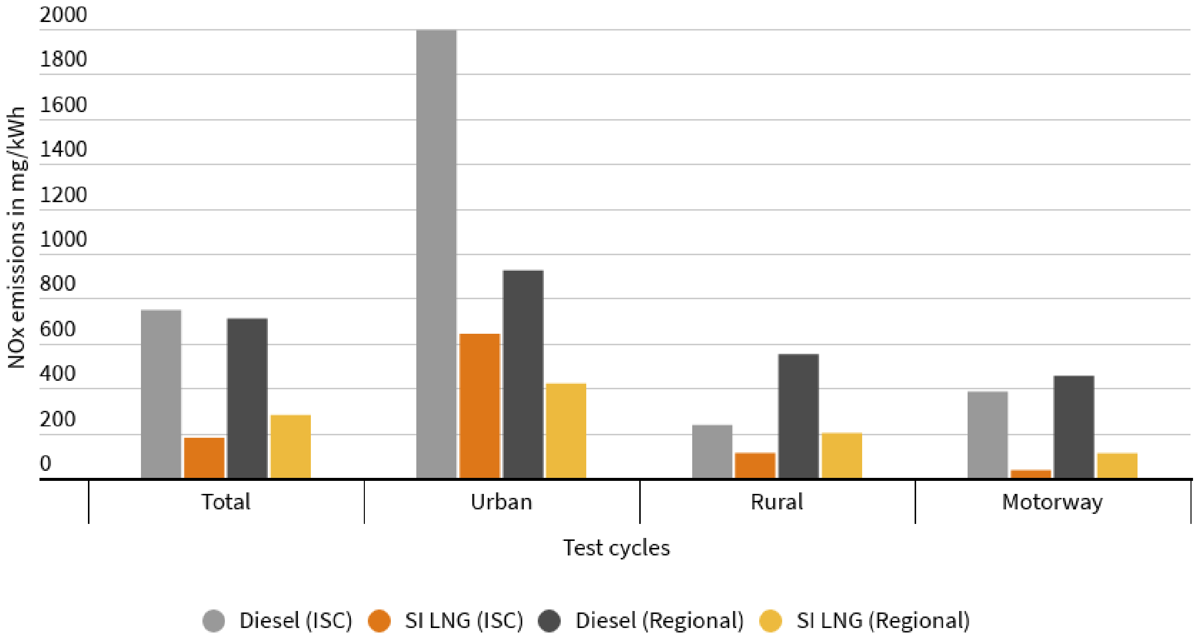
In Europe's big cities, trucks contribute between 12 - 26% of the total NO_x emissions.[94] When it comes to NO_x pollution from gas trucks, IVECO claims that the S-Way LNG truck can reduce emissions of NO_2 by 90% compared to diesel, in effect attesting that LNG is better for air quality. To test these claims, FVT measured the emissions of both NO_x and NO_2.

Firstly, IVECO's claim that NO_2 pollution is reduced compared to diesel trucks is correct. The LNG truck emitted virtually no NO_2 during any of the tests. However, focusing only on NO_2 emissions is misleading because as described above, for air quality, it is not just the emissions of NO_2 that matter. Instead, to credibly assess the air quality impact of switching from diesel to LNG trucks, the amount of total NO_x emissions including NO need be considered.

The tests show that, while the LNG truck emitted less NO_x than the diesel truck, the reduction was much smaller than expected following IVECO's claims. During the ISC test, the LNG truck emitted 76% less NO_x than the diesel and 60% less during the regional test. The smallest reduction was measured during urban (-54 to -68%) and rural driving (-53 to -64%).

The magnitude of the reduction is largely down to the poor NO_x emissions performance of the diesel truck which had very high cold start emissions particularly during the urban section of the ISC test. While no specific emission limit applies to cold start and urban driving, raw emissions during this period of the ISC test were almost three times higher than the road NO_x emission limit of 690 mg/kWh. While the LNG truck emitted less than the diesel truck overall in both tests, it still had high urban emissions on the ISC test of 643 mg/kWh. This indicates that, while the LNG truck tested emitted less than the diesel truck, it still cannot be considered low emission due to high NO_x emissions during urban driving.

Figure 17. Nitrogen oxide (NOx) emissions



Sources: FVT (2021).

7. Conclusions

The tested LNG truck delivered much lower GHG savings than claimed by IVECO. Over a 100-year GWP, the LNG truck achieved a GHG reduction of 7.5% and 7.9% compared to the tested diesel truck. When looking at a 20-year GWP time frame, the LNG truck had higher emissions than the diesel truck, resulting in 13.4% and 13.6% higher GHGs respectively.

These findings run contrary to the industry's claims that gas-powered trucks constitute a viable 'bridge technology' which could deliver meaningful GHG reductions both in the short- and long-term. As the results of this testing project highlight, betting on LNG trucks is counterproductive.

The significantly higher global warming potential of methane over 20 years, compared to a 100-year timeframe, means that increasing the number of LNG trucks on European roads today would actually lead to an increase in global warming over the next few decades compared to what conventional diesel trucks would cause.

The technology therefore represents nothing else than a 'dead end bridge'. The IPCC's most recent Sixth Assessment Report shows that, to have a likely chance to limit global warming to 1.0 - 1.9 °C by the end of the century, GHG emissions need to start falling immediately from 2021 onwards.[95]

Neither sustainable biomethane nor synthetic methane produced from renewable electricity will be sufficiently scalable or affordable to be a viable solution for decarbonising trucking. Even with extremely high subsidies, up to six times the retail price of natural gas, the available biomethane feedstock in the six biggest European countries would only meet 4% to 28% of the expected road freight energy consumption in 2050. It is therefore not credible to take into account any hypothetical GHG savings from renewable methane when quantifying the emissions performance of gas-powered trucks today or in the future.

Continuing the investment in LNG trucks and infrastructure carries a high risk of stranded assets and, in the worst case, will create a fossil fuel lock-in due to the lack of renewable alternatives. As long as some vehicle manufacturers, hauliers and infrastructure operators continue to invest in this technology, they will have a vested interest to protect those investments. Since there will not be enough renewable methane available at competitive costs, even by 2050, the industry would instead need to rely on natural gas in order to meet increasing fuel demand from gas-powered trucks.

Gas trucks are not a credible solution for reducing air pollutant emissions and improving air quality either. Contrary to IVECO’s claims that the LNG truck can deliver large reductions in PM emissions, the testing results are showing that particle emissions from LNG trucks, both particle mass and particle number, can be higher than those from diesel trucks. The tested LNG truck emitted particularly large amounts of very small particles which are increasingly considered as the most harmful to human health.

While overall NO_x emissions were reduced compared to diesel, emissions during urban operation were close to the legal limits. This provides further evidence that gas-powered trucks are not a low-emission option and will not improve air quality in cities and urban areas, where pollution has the biggest adverse impact on human health. To really drive reductions in air pollution and help the EU achieve its zero pollution targets for 2030, such as the reduction of premature deaths due to air pollution by at least 55%, a rapid shift away from diesel- and gas-powered trucks towards zero-emission technology is needed.[96]

8. Policy recommendations

Betting on LNG trucks today, which emit even more GHGs than their diesel counterparts over a 20-year timeframe, could not be more contrary to these challenges. Spending time and money on a technology which can deliver little climate benefit and actually increases emissions over the coming decades is not compatible with the European Green Deal or the Paris Agreement. Instead, the EU and its Member States should end their harmful subsidies for gas trucks and focus exclusively on zero-emission technology.

8.1. EU level

Alternative Fuels Infrastructure Regulation (AFIR)

The EU should aim for an ambitious AFIR that focuses exclusively on electricity and renewable hydrogen, effectively removing gas refuelling (both CNG and LNG) from the scope and turning it into a Zero Emission Infrastructure Regulation (ZEIR).[97] This will ensure that infrastructure investment in the EU is made ready for zero-emission vehicles.

The definition of what qualifies as an ‘alternative fuel’ is important as it defines which fuels the EU considers to be aligned with the European Green Deal. This definition is also at the heart of many European and national funding programmes, structural and investment funds. Therefore, as long as natural gas is part of the scope of the alternative fuel infrastructure law, it benefits from preferential treatment and funding. For example, support from the CEF Transport Blending Facility, the main tool to finance alternative fuels infrastructure and vehicles, is based on this definition of what counts as an alternative fuel.

Energy Taxation Directive (ETD)

Many Member States still give tax breaks to natural gas used in transport despite the lack of environmental benefits.[98] It is welcomed that, as part of the revision of the ETD, the European Commission has proposed to remove the possibility of tax exemptions or reductions to natural gas used as a transport fuel.[99] The proposed minimum excise duty rate for both natural gas and non-sustainable biogas should be set at the same level as petrol and diesel right from the start of the transitional period.

EURO VII emission standards

ICE trucks will likely continue to be sold until at least the 2030s. In order to reduce their negative impact on air quality, health and the environment it is crucial that all ICE trucks sold until the full transition to ZEVs are as low-emission as technically feasible.

Since the EURO VI emission limits for HDVs was agreed upon in 2009, new and better emission control technology such as cylinder deactivation and dual dosing selective catalytic reduction (SCR) systems have been developed. Lower emission limits than the current EURO VI standard are already feasible, including for NO_x, as demonstrated by much lower truck emission limits set into law in California.

At the end of 2021, the European Commission is set to put forward a proposal for a EURO VII Regulation in order to ensure that air pollutants from ICE trucks are reduced to the lowest levels technically possible. As a priority, the upcoming proposal should include:

- A reduction of the emission limits for all regulated pollutants to the lowest levels that are technically feasible. This should include a reduction of the PM number emissions limit to levels which require the fitting of particle filters to gas-powered trucks. A reduction in the methane (CH_4) emissions limit for all trucks is also needed.

- The Introduction of limits for all pollutants that are harmful to health or the environment and can be effectively regulated at the tailpipe. This should include limits for currently unregulated pollutants such as smaller than 23nm particles and the potent greenhouse gas nitrous oxide (N_2O).

- Emission tests which fully cover all driving conditions including cold start (when the engine is first started) and low-speed, low-load urban driving to ensure that emission limits are respected under all possible driving conditions.

- An increase in the durability requirements to ensure that trucks have to meet the emission limits throughout their lifetime. As a minimum, this should increase the current emission durability requirement to 1.3 million kilometres, a standard already set for trucks in the U.S.

- Euro VII must include robust provisions to prevent tampering with emission critical systems. Tampering of emission critical systems such as AdBlue dosing for Selective Catalytic Reduction (SCR) is a big problem for ICE trucks in the EU and results in high NO_x emissions on the road.

CO_2 standards

Neither diesel or gas trucks are a solution for decarbonising trucking or improving air quality. This will require a rapid increase in the supply of zero-emission trucks beyond what truck manufacturers will have to deliver under the current European CO_2 standards for new HDVs.

The review of the CO_2 standards, which is foreseen for 2022, needs to ensure at least 50% zero-emission truck sales by 2030. This is in line with recent public announcements by European truck manufacturers, which already aim for ZEV sales shares between 40% and 50% by the same date.[100] The EU should also adopt a sales phase-out for ICE trucks, taking duly into account different vehicle characteristics, duty cycles and operational needs. The sale of ICE trucks should end by 2035 for the vast majority of vehicle groups.

8.2. National level

Germany

Road charge exemption

Germany must end the current road charge exemption for gas trucks immediately to not further violate EU law. Until the planned CO_2 variation of the infrastructure charge enters into force, EURO VI gas trucks must be tolled at the same level as EURO VI diesel trucks to comply with the previous and new Eurovignette Directive.

From 2023 and according to the new Directive, Germany will have to vary the infrastructure charge for those truck categories which are regulated under the CO_2 standards for new HDVs. For this, ICE trucks as well as ZLEVs will be allocated to five CO_2 emission classes based on their performance against their linear emission reduction trajectory as defined in the CO_2 standards.

Under the CO_2 variation and only from 2023 onwards, gas trucks will be eligible for a reduction on the infrastructure charge between 5% and 30% depending on whether their engine technology qualifies them for CO_2 emission class 2 or 3.

Fleet renewal programme

In Germany, gas-powered trucks will continue to be eligible under the new fleet renewal programme which incentivises the purchase of new EURO VI trucks with up to € 15,000 if a vehicle belonging to an older emission class is scrapped.[101] The funding scheme should be amended and the eligibility of gas trucks removed.

Fuel taxation

Germany is currently applying a very low fuel duty rate to natural gas used as a transport fuel (€ 13.90/MWh) regardless whether it is fossil-derived or sustainable biomethane.[102] The current tax rate will be increased in gradual steps until the original rate of € 31.80/MWh applies from 2027.

Germany should adjust the reduced rate so that it only applies to sustainable biomethane which is sourced from advanced waste- and residue-based feedstocks. Fossil-derived natural gas should not benefit from any reduction and be taxed at the normal rate instead.

United Kingdom

Fuel taxation

The UK is applying a very low fuel duty rate to natural gas used in transport (£-pence 24.70/kg), regardless whether it is fossil-derived or biomethane.[103] The Treasury should adjust the reduced rate so this only applies to certified biomethane which is sourced from advanced waste- and residue-based feedstocks and which qualifies for the Renewable Transport Fuel Obligation (RTFO). Natural gas should be taxed on an energy content basis at the same level as diesel. Biomethane can play a niche role in decarbonising freight but is very unlikely to be able to scale sustainably to play any major role.

France

Special depreciation scheme

The special depreciation system in France for zero-emission trucks and those running on natural gas or biomethane was recently prolonged until 2030.[104] Under this scheme, vehicle owners can depreciate a total of 160% (up to 16 tonnes GVW) or 140% (above 16 tonnes GVW) from the purchase value if the truck is powered exclusively by fossil-derived natural gas, biomethane, liquid biofuels, electricity or hydrogen.[105]

This purchase funding scheme and future ones need to be limited to ZEVs and exclude any combustion-powered trucks including those running on natural gas. The same goes for currently existing regional funding schemes for purchasing commercial gas vehicles.[106] French cities and regions should end such schemes as soon as possible.

Fuel taxation

France is also applying a very low fuel duty rate to natural gas used as a transport fuel (€ 5.23/MWh). The full tax rate for natural gas for household consumption amounts to € 8.43/MWh.[107] As a minimum, at least the full rate should also be applied to natural gas as a transport fuel. Biomethane is currently exempt from the consumption tax on natural gas irrespective of its feedstock origin and GHG emissions savings potential. This exemption should cease to apply unless it is certified biomethane produced from advanced wastes and residues.

Italy

Purchase subsidy

Italy offers purchase incentives for new low- and zero-emission as well as gas-powered trucks exceeding 7 tonnes GVW of up to € 20,000.[108] This purchase subsidy should be limited to ZEVs and not apply to gas trucks.

Fuel taxation

Italy applies an extremely low fuel duty rate to natural gas used as a transport fuel amounting to € 0.09/GJ.[109] This rate should be at least increased to the minimum excise duty rate of € 2.60/GJ as laid out in the ETD.

Spain

Fuel taxation

Spain also applies a very low fuel duty rate to natural gas used in transport of € 1.15/GJ.[110] This rate should be at least increased to the minimum excise duty rate of € 2.60/GJ as laid out in the ETD.

Poland

Fuel taxation

Poland fully exempts natural gas used in transport from fuel duty.[111] Given the lack of environmental benefits, the fuel duty should be at least increased to the minimum excise duty rate as laid out in the ETD.

Annex

Tailpipe carbon dioxide emissions

	ISC test		Regional test	
	Diesel	SI LNG	Diesel	SI LNG
Tailpipe gCO_2/km	1,050.8	925.4	1,100.2	983.7
Savings SI LNG vs. Diesel		- 11.9%		- 10.6%

Tailpipe methane emissions

		ISC test		Regional test	
		Diesel	SI LNG	Diesel	SI LNG
Tailpipe gCH_4/km		< 0.001	0.149	< 0.001	0.309
In gCO_2e/km	20-year GWP	0.002	12.5	0.004	26.0
	100-year GWP	0.001	4.2	0.001	8.7
As a share of tailpipe CO_2	20-year GWP	< 0.1%	1.4%	< 0.1%	2.6%
	100-year GWP	< 0.1%	0.5%	< 0.1%	0.9%

Tailpipe nitrous oxide emissions

		ISC test		Regional test	
		Diesel	SI LNG	Diesel	SI LNG
Tailpipe gN_2O/km		0.165	0.006	0.307	0.015
In gCO_2e/km	20-year GWP	43.5	1.6	81.0	4.0

	100-year GWP	43.6	1.6	81.3	4.0
As a share of tailpipe CO_2	20-year GWP	4.1%	0.2%	7.4%	0.4%
	100-year GWP	4.1%	0.2%	7.4%	0.4%

Non-tailpipe methane emissions

		ISC test		**Regional test**	
		Diesel	SI LNG	Diesel	SI LNG
Non-tailpipe gCH_4/km		-	1.6	-	1.7
In gCO_2e/km	20-year GWP	-	132.2	-	140.5
	100-year GWP	-	44.1	-	46.8
As a share of tailpipe CO_2	20-year GWP	-	14.3%	-	14.3%
	100-year GWP	-	4.8%	-	4.8%

Tank-to-wheel GHG emissions

		ISC test		**Regional test**	
		Diesel	SI LNG	Diesel	SI LNG
Tank-to-wheel gCO_2e/km	20-year GWP	1,094.3	1,071.7	1,181.2	1,154.2
	100-year GWP	1,094.5	975.3	1,181.5	1,043.2
Savings SI LNG vs. Diesel	20-year GWP	- 2.1%		- 2.3%	
	100-year GWP	- 10.9%		- 11.7%	

Well-to-tank GHG emissions

		ISC test		Regional test	
		Diesel	SI LNG	Diesel	SI LNG
Well-to-tank gCO_2e/km	20-year GWP	290.6	498.9	306.7	535.4
	100-year GWP	268.9	285.7	283.7	306.6
As a share of tailpipe CO_2	20-year GWP	27.7%	53.9%	27.9%	54.4%
	100-year GWP	25.6%	30.9%	25.8%	31.2%

Well-to-wheel GHG emissions

		ISC test		Regional test	
		Diesel	SI LNG	Diesel	SI LNG
Well-to-wheel gCO_2e/km	20-year GWP	1,384.9	1,570.6	1,488.2	1,689.6
	100-year GWP	1,363.3	1,261.0	1,465.0	1,349.8
Savings SI LNG vs. Diesel	20-year GWP	+ 13.4%		+ 13.6%	
	100-year GWP	- 7.5%		- 7.9%	

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