Department for Transport

Transport Energy Model
Report

Moving Britain Ahead

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Introduction

1 The challenges and opportunities facing road transport today are unprecedented. The environmental impact of road vehicles is under intense scrutiny and the range of powertrain technologies and fuel choices available is greater than ever. The Transport Energy Model has been developed to provide an objective assessment of the relative environmental impact of the powertrain technologies and fuel choices available to consumers both now and in the future, bringing together both air pollutant and greenhouse gas impacts.

2 The outputs of the Transport Energy Model have been used to develop Government's view on the relative environmental performance of different fuels and technologies, and to underpin the policies set out in the Road to Zero Strategy. This report sets out the development and outputs of the model.

3 The Transport Energy Model has been developed over 18 months, working with stakeholders from industry, academia and environmental groups, and provides a snapshot of the emissions from currently available energy sources and vehicle technologies, as well as current best estimates of future performance. The model provides a simple but powerful tool to make side by side comparisons of a range of different energy sources in a number of different vehicle types.

4 The scope of the model has been defined based on a range of factors including policy aims, vehicle fleet composition and the availability of accurate and reliable data.

5 The model includes greenhouse gas emissions from the production and use (well-to-wheel emissions) of a range of energy sources – including fossil fuels, biofuels, natural gas, electricity and hydrogen – and tailpipe (exhaust) emissions of two air pollutants (oxides of nitrogen and particulate matter) for five vehicle types, ranging from a medium car to a 44 tonne heavy goods vehicle.

6 By necessity, the model uses average vehicle emissions data and does not look at emissions from every make and model of vehicle separately. The model does not cover emissions from the manufacture or disposal of the vehicle, nor does it cover non-exhaust emissions. The reasons for this are outlined in this report.

7 Although the scope and nature of the Transport Energy Model make it a more useful tool for Government policy decision-making than for individual consumer decisions, the Transport Energy Model data and outputs also have the potential to inform future consumer information.

8 It is clear that there may be opportunities to increase the scope of the model as additional data become available, and to update the model as vehicle and fuel technologies develop, but there is also a clear need to use current knowledge of air pollutant and greenhouse gas emissions to steer policy decisions being taken now.

1. Model development and scope

Model development

1.1 The Transport Energy Model (TEM) has been developed by the Department for Transport, working with stakeholders from industry, academia, environmental groups and Government, including vehicle manufacturers, fuel suppliers, vehicle and environmental consultancies, environmental lobby groups and other Government Departments. Initial scoping workshops were held in July 2016, with further peer review workshops in June and July 2017, and detailed data review workshops in November 2017.

1.2 Discussions were also held with a range of stakeholders at individual meetings and at presentations to groups such as the Low Carbon Vehicle Partnership (LowCVP) fuel and vehicle working groups and Society of Motor Manufacturer and Trader (SMMT) policy groups.

1.3 The TEM has been subject to an external quality assurance review by Ricardo Energy & Environment Consultancy.

Model scope, uncertainties and limitations

Vehicles

1.4 The TEM assesses a range of vehicles, each of which is representative of a significant proportion of the relevant section of the vehicle fleet. The TEM focuses on vehicle types which contribute substantially to road transport air pollutant and/or greenhouse gas emissions. The vehicles are: a medium car, a panel van, an 18 tonne heavy goods vehicle (HGV), a 44 tonne HGV and a double deck bus. Table 1 lists the vehicle and powertrain options modelled.

1.5 The TEM allows side by side comparisons of energy consumption and greenhouse gas emissions for a representative new vehicle purchased in 2017. Air pollutant emissions values are modelled for various Euro emissions standards (e.g. Euro 6 for the latest generation of vehicles). Best estimates are then made of future developments to create projections for these in 2020, 2030, 2040 and 2050. The TEM does not perform any modelling of the vehicle fleet.

1.6 The TEM does not cover emissions from the manufacture or disposal of the vehicle. However, the model does include a sensitivity analysis of the additional energy and greenhouse gas emissions required to manufacture batteries for vehicles with electric powertrains, recognising that battery manufacture is an additional energy requirement compared to conventional vehicle manufacturing. Details are provided in Part 4.

1.7 The TEM includes a range of powertrain technologies for each vehicle type which employ a variety of energy conversion technologies (e.g. internal combustion engines, electric motors, full and plug-in hybrids and hydrogen fuel cells). A full list of vehicle / powertrain combinations is set out in Table 1.

1.8 For each vehicle, results are given for a specific representative duty cycle. For example, a mixed urban / extra-urban duty cycle (average speed 34 km/h) is used for cars and vans whereas a long haul duty cycle (average speed 79 km/h) is used for a 44 tonne HGV. The duty cycles used for each vehicle type are specified in the model outputs and were chosen to represent the typical use for that vehicle type. Emissions will be different when assessed at other speeds. In general, energy consumption and tailpipe emissions per kilometre are higher at lower speeds.

Fuels

1.9 The TEM assesses a range of fuels including conventional fossil fuels (petrol and diesel), biofuels, natural gas (compressed natural gas (CNG) and liquefied natural gas (LNG)), liquefied petroleum gas (LPG), hydrogen and electricity. The TEM includes those fuels that are currently widely available to consumers and all those that currently benefit from a fuel duty differential. Other fuels will be considered for inclusion in the TEM as and when sufficient reliable data becomes available.

1.10 For those fuels that can be produced using significantly different production pathways, this has been reflected in the TEM. For example, the TEM includes hydrogen production from steam methane reformation (SMR) and from electrolysis. For biofuels it includes different feedstocks (crops and waste) as well as different production methods. Further details are provided in the relevant model outputs in Part 2.

1.11 Development of the TEM has highlighted the complexities involved in considering the use of low carbon, renewable energy sources in road transport. Low carbon fuels can be used to decarbonise not only the transport sector but also other sectors, such as the heat sector. Limited production capacity and, in the case of biofuels, availability of sustainable feedstock materials mean that there are limitations on the extent to which low carbon fuels can meet energy demand across sectors. Table 2 lists the full range of fuels covered by the TEM.

Greenhouse gas emissions

1.12 The TEM takes account of well-to-wheel greenhouse gas emissions associated with energy production and its use within the vehicle. These emissions are split into:

1. Well-to-tank emissions, from energy production and transportation;
2. Tank-to-wheel emissions, from energy conversion within the vehicle; and
3. Emissions from indirect land-use change (ILUC), which are associated with some forms of agricultural production (this applies to some biofuels).

1.13 ‘Marginal’ greenhouse gas emissions are used where possible to reflect the impact that a change in demand for a particular fuel has on greenhouse gas emissions when the wider energy system is taken into account (including the supply of low carbon energy). Government ‘long run marginal’ electricity emissions factors have been used for electricity and a greenhouse gas emissions reduction factor has been applied to liquid and gaseous fuels covered by the Renewable Transport Fuel Obligation

(RTFO) to reflect greenhouse gas savings from biofuels supplied under the RTFO. More detail on these assumptions can be found in the biofuels section in Part 3.

1.14 The TEM also captures some other greenhouse gas emissions including:

- Nitrous oxide (N_2O) emissions from selective catalytic reduction (SCR) systems – N_2O is a potent greenhouse gas;
- 'Methane slip' which are methane emissions associated with some CNG and LNG vehicles – methane is also a greenhouse gas; and
- CO_2 from diesel fired heating on electric buses.

1.15 Details of the data sources used in the model are set out in Annex B. Based on industry feedback, the TEM includes two scenarios for CNG greenhouse gas emissions. These reflect the difference in energy consumption between the use of CNG from the high pressure gas grid and CNG from the low pressure gas grid. Where CNG is taken from the low pressure gas grid, more energy is needed to compress the gas for use in vehicles than when it is taken from the high pressure gas grid, resulting in higher well-to-tank (and therefore higher well-to-wheel) greenhouse gas emissions.

Air pollutant emissions

1.16 The TEM includes estimates of tailpipe oxides of nitrogen (NO_x) and particulate matter (PM) emissions for all vehicles. Estimates are based on COPERT emissions factors where available and, where these are not available, test data or assumptions have been used. Details of these data and assumptions are set out in Annex B. Where there is significant uncertainty in current or future emissions, the TEM sets out potential scenarios.

1.17 A range of scenarios has been used to reflect uncertainty over future NO_x emissions from diesel cars and vans. This uncertainty is due to the historical gap between real world NO_x emissions and their regulated limits. The introduction of new real world limits (Real Driving Emissions (RDE) limits) for the latest car and van European emissions standard (Euro 6d) should help to close this gap. Euro 6d RDE NO_x test limits will be implemented in two steps. RDE step 1 (RDE1) applied to all new car model type approvals from September 2017, and will apply to all new cars being registered from September 2019. RDE Step 2 (RDE2) applies to all new car model type approvals from January 2020, and all new cars being registered from January 2021. The application dates are one year later for vans. The TEM includes car and van Euro 6 NO_x emissions limits (including test conformity factors) for pre-RDE vehicles, RDE1 and RDE2.

1.18 It should be noted, however, that RDE limits are maximum emission levels permitted under RDE testing, not estimates of actual vehicle performance on UK roads. In order to meet all RDE test requirements, which cover around 95% of all driving conditions, RDE compliant vehicles are expected to emit NO_x levels much lower than the test limit in standard driving conditions. Early evidence suggests this is the case.

1.19 The TEM also includes COPERT estimates of NO_x emissions for RDE compliant vehicles. COPERT emission factors for Euro 6 diesel cars sold in current or future years (2017-19 and 2020 onwards) are not based on testing. These are forecasts of potential real world emissions which take into account that RDE compliant vehicles will make up an increasing proportion of Euro 6 diesel car sales over this time period, as well as that real-world usage conditions may not be fully captured by RDE requirements, such as aggressive driving or wear and tear of abatement equipment.

1.20 For particulate emissions, the TEM includes particulate matter (PM) emissions measured by mass (i.e. grams per kilometre). Particulate number (PN) is not modelled within the TEM because comprehensive data is currently unavailable. Therefore variations in ultrafine particulate emissions (which are thought to have a particularly negative health impact) are not currently captured by the modelling.

1.21 However, PN limits have been in place for all new diesel and direct injection petrol cars and vans since the introduction of Euro 5b standards. This led to the universal fitment of particulate filters in diesel cars which have been very effective in reducing PN emissions. Direct injection petrol cars and vans had a derogation (exemption) and have not as yet fitted particulate filters as standard. However it is anticipated that particulate filters will be fitted to these vehicles with the introduction of RDE1.

1.22 The TEM does not model particulate emissions caused by tyre and brake wear due to the lack of data in this area and uncertainties around the effect of weight and technology on these emissions. There is evidence to suggest that the use of technologies such as regenerative braking, commonly used in hybrid and electric vehicles, can reduce brake wear. However, hybrid and electric vehicles may be heavier than conventionally fuelled equivalents, which may result in increased tyre and brake wear.

1.23 The combined effects of the technology used in hybrid and electric vehicles and their weight have not been studied in detail to determine how their non-exhaust emissions compare with conventional vehicles. The Air Quality Experts Group (AQEG) is reviewing how particulates from tyres, brakes and roads impact on air quality to formulate advice to Government, and we are undertaking a call for evidence on non-exhaust particulate matter to feed into the development of the forthcoming Clean Air Strategy and policies to address this emission source.

1.24 Inclusion in the TEM of updated NO_x data, data on particulate number and non-exhaust particulate emissions will be considered as and when sufficient reliable data becomes available.

Vehicle, powertrain and energy coverage

1.25 Table 1 below lists the vehicle types included in the TEM and, for each vehicle type, the powertrain / energy combinations covered. In this report, the powertrain refers to the vehicle components that convert energy into vehicle propulsion, for example the engine, battery or fuel cell. Some powertrain options, such as spark ignition internal combustion engines (petrol engines), can be powered by more than one energy source.

Table 1: Vehicle and powertrain combinations included in the TEM

Vehicle type	Powertrain / Energy combination
Medium car	- Spark ignition internal combustion engine (petrol, CNG, LPG and methanol) - Battery electric (electricity) - Fuel cell (hydrogen) - Compression ignition internal combustion engine (diesel) - Hybrid electric (petrol) - Plug-in hybrid electric (petrol/electricity)
Panel van	- Spark ignition internal combustion engine (petrol, CNG, LPG and methanol) - Battery electric (electricity) - Fuel cell (hydrogen) - Compression ignition internal combustion engine (diesel) - Hybrid electric (petrol and diesel) - Plug-in hybrid electric (petrol/electricity)
18 Tonne HGV	- Spark ignition internal combustion engine (CNG) - Battery electric (electricity) - Fuel cell (hydrogen) - Compression ignition internal combustion engine (diesel)
44 Tonne HGV	- Spark ignition internal combustion engine (CNG, LNG) - Battery electric: conductive and dynamic charging (electricity) - Fuel cell (hydrogen) - Compression ignition internal combustion engine (diesel)
Double deck bus	- Spark ignition internal combustion engine (CNG) - Battery electric (electricity) - Fuel cell (hydrogen) - Compression ignition internal combustion engine (diesel) - Hybrid electric (diesel)

1.26 Table 2 in the next page lists the range of energy sources included in the model and, for each of these energy sources, the production pathways included in the TEM. Both standard fossil fuels and bio / low carbon substitutes are included.

Table 2: Energy sources included in the TEM

Energy type	Production pathways
Petrol and bio-substitutes	- Fossil petrol - Crop bioethanol (1st generation) - Waste bioethanol (1st generation) - Crop bioethanol (advanced)* - Waste bioethanol (advanced)*
Diesel and bio-substitutes	- Fossil diesel - Crop biodiesel (anaerobic digestion) - Waste biodiesel (anaerobic digestion) - Crop biodiesel (advanced)* - Waste biodiesel (advanced)*
Compressed natural gas (CNG), liquefied natural gas (LNG) and bio-substitutes	- Fossil methane - Crop biomethane (1st generation) - Waste biomethane (1st generation) - Crop biomethane (advanced)* - Waste biomethane (advanced)*
Liquefied petroleum gas (LPG) and bio-substitutes	- Crop bioLPG (anaerobic digestion) - Waste bioLPG (anaerobic digestion) - Crop bioLPG (advanced)* - Waste bioLPG (advanced)*
Methanol and bio-substitutes	- Fossil methanol (from remote natural gas) - Crop biomethanol (1st generation) - Waste biomethanol (1st generation) - Crop biomethanol (advanced)* - Waste biomethanol (advanced)*
Hydrogen	- Steam methane reforming (SMR) - Steam methane reforming with carbon capture and storage (SMR + CCS)* - Electrolysis
Electricity	- Domestic - Commercial - Industrial

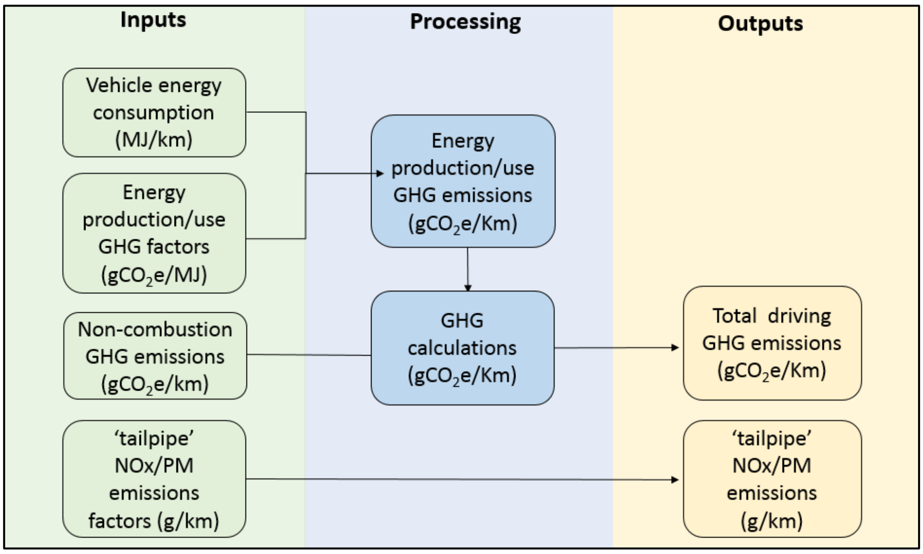
*(*technology not yet commercialised)*

Model methodology

1.27 Figure 1 below shows the flow of data from inputs to outputs in the model, which is as follows:

- Greenhouse gas emissions from energy production and use (gCO_2e/km) are calculated by multiplying vehicle energy consumption (MJ/km) by energy greenhouse gas factors (gCO_2e/MJ);
- Non-combustion greenhouse gas emissions (gCO_2e/MJ) such as nitrous oxide (N_2O) emissions from selective catalytic reduction systems, 'methane slip' in gas powered vehicles and CO_2 from diesel fired heating on electric buses are then added to energy greenhouse gas emissions to give total vehicle greenhouse gas emissions (gCO_2e/km);
- Tailpipe NO_x and PM emissions (g/km) inputs are used directly as model outputs.

Figure 1: Model flow diagram



Key: MJ = mega joules; GHG = greenhouse gas; gCO_2e = grams of CO_2 equivalent; NO_x = nitrous oxide; PM = particulate matter

1.28 Major assumptions include:

- Vehicle energy consumption – which has come from a range of sources including vehicle testing, industry data and research;
- Fossil fuel emissions factors – where possible, Government greenhouse gas reporting factors have been used;
- Grid electricity emissions – Government projections have been used (with an uplift applied to account for fossil emissions associated with gas and coal production); and
- Alternative fuel emissions – a range of sources has been used including Renewable Transport Fuel Obligation statistics and the EU 'well to wheels' project.

A full list of assumptions and data sources used in the TEM are outlined in Annex B and further explanation is provided in the discussion of TEM outputs set out in Part 2.

2. Model outputs

Medium car

2.1 A medium car (similar to a Ford Focus or Vauxhall Astra) was selected for inclusion in the TEM because it is representative of a large proportion of the car fleet. In 2017 sales of cars in the ‘lower medium’ segment – which the ‘medium car’ is based upon - accounted for 29% of total car sales. The emissions from the vehicle will vary depending on the average driving speed. For the purposes of the modelling, the emissions data reflects a mixed urban and extra-urban duty cycle, which has an average speed of 34 km/h.

Greenhouse gas (GHG) emissions

Petrol and diesel

2.2 Out of the options modelled, petrol cars (in 2017) are estimated to have the highest ‘well to wheel’ greenhouse gas emissions – 211 gCO_2e/km. Diesel (compression ignition) engines are inherently more efficient than petrol (spark ignition) engines, so they have lower emissions of 179 gCO_2e/km (a reduction of 15% relative to petrol). However, going forward, the gap between the efficiency of petrol and diesel cars – and therefore greenhouse gas emissions – is expected to narrow as further improvements in the efficiency of petrol vehicles are predicted.

Liquefied petroleum gas (LPG) and compressed natural gas (CNG)

2.3 Energy consumption data for LPG and CNG powered cars is limited. LPG and CNG cars are powered using spark ignition engines (the same technology as petrol) and are therefore assumed to have the same energy conversion efficiency as petrol cars. However, LPG and CNG fuels have a lower greenhouse gas intensity than petrol so the greenhouse gas emissions for these vehicles are also lower. A LPG car is estimated to emit 171 gCO_2e/km (a reduction of 19% relative to petrol) and a CNG car is estimated to emit 158 (high pressure grid) to 164 (medium pressure grid) gCO_2e/km (a reduction of 22% to 25% relative to petrol).

Hybrid (full hybrid and plug-in hybrid)

2.4 Petrol hybrid (full hybrid) cars have an internal combustion engine and an electric propulsion motor. In these vehicles, energy is typically captured by regenerative braking and stored within a small battery. They cannot be plugged in to be recharged. These vehicles have improved energy efficiency relative to conventional petrol cars due to the use of the electric powertrain. Emissions are estimated to be 169 gCO_2e/km (a reduction of 20% relative to standard petrol).

2.5 Plug-in hybrid electric cars have an internal combustion engine and an electric motor which is charged from an external power source (i.e. the vehicle needs to be plugged in). Both the engine and the electric motor are capable of solely propelling the vehicle. Greater use of their efficient electric motor means these vehicles are estimated to use less energy than standard petrol vehicles. Greenhouse gas emissions are estimated to be 119 gCO_2e/km (a reduction of 43% relative to standard petrol).

2.6 The plug-in hybrid output is sensitive to assumptions on how the car is used. The scenario shown in Graph 1 assumes that the car is used efficiently (i.e. 62% of driving is in electric mode and 38% of driving is in petrol mode). Other scenarios such as failure to plug the vehicle in or heavy motorway driving would lead to increased greenhouse gas emissions.

Battery electric

2.7 Electrification delivers a large reduction in energy consumption. Using a 2017 electricity grid emissions factor, a battery electric car is estimated to emit 73 gCO_2e/km (a reduction of 66% relative to standard petrol). Emissions are expected to fall to near zero over the period to 2050 as the electricity grid decarbonises in line with Government projections.

Hydrogen fuel cell electric

2.8 Greenhouse gas emissions from hydrogen fuel cell electric vehicles are highly dependent on how the hydrogen is produced. If the hydrogen is produced using steam methane reformation (SMR) – a typical commercial production pathway for bulk hydrogen which uses methane as a feedstock and releases CO_2 during the production process – the estimated greenhouse gas emissions for a medium car are 119 gCO_2e/km (44% lower than petrol).

2.9 Future addition of carbon capture and storage (CCS) – a technology which captures and stores CO_2 production emissions – to SMR is estimated to have the potential to reduce greenhouse gas emissions significantly. Hydrogen produced via electrolysis (which uses electricity to break water into hydrogen and oxygen) also has the potential to offer significant greenhouse gas savings in the future as the electricity grid decarbonises.

Biofuels

2.10 The use of renewable fuels, including biofuels, can reduce well-to-wheel greenhouse gas emissions. The RTFO requires UK transport fuel suppliers to ensure that a proportion of their overall fuel sales are from a renewable source such as biofuels. The current level of biofuel blending is estimated to reduce overall UK transport fuel greenhouse gas emissions by 1.7%. The results shown in Graph 1 show greenhouse emissions from fossil fuel use with 1.7% subtracted to reflect biofuel blending under the RTFO. Further detail on renewable fuels can be found in Part 3.

Air Pollutant Emissions

Nitrogen oxides (NO_x) emissions

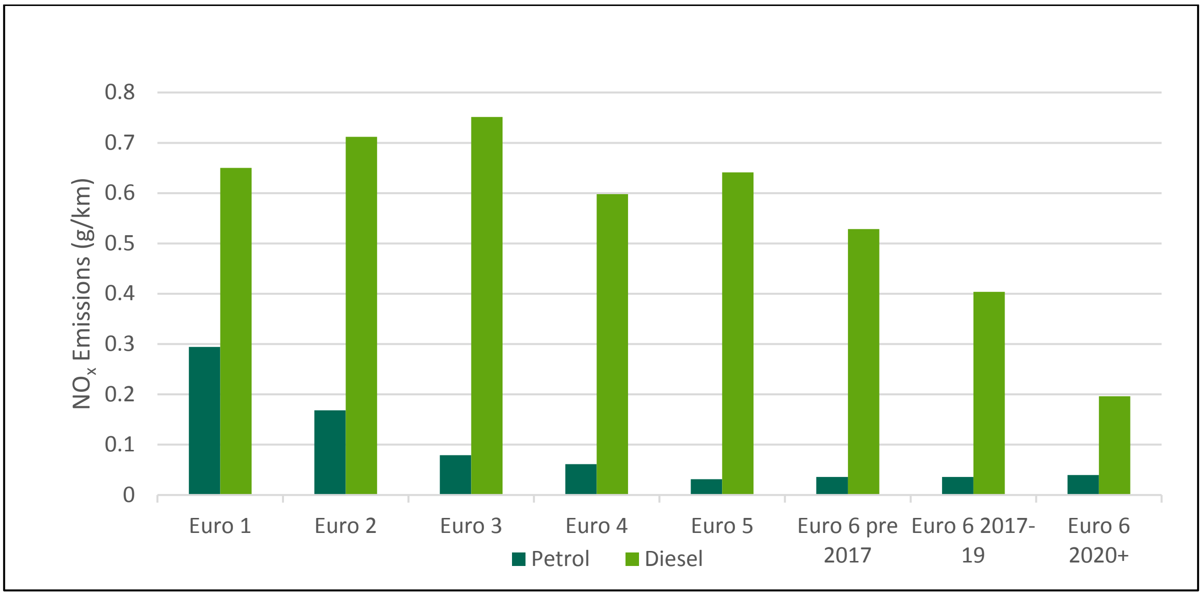
2.11 Diesel cars are assessed as having the highest tailpipe NO_x emissions out of all the powertrain options covered in the model. Real-world testing of pre-2017 Euro 6 diesel cars showed that emissions significantly exceeded regulatory limits – the COPERT value for NO_x emissions from a pre-2017 Euro 6 diesel car is around 0.5 g/km (which is more than 6 times higher than the regulatory limit). To address this, the latest regulations require cars to meet emissions limit values in real-world driving conditions. These regulations will be introduced in two phases (RDE1 and RDE2 – also known as Euro 6d (temp) and Euro 6d (final)).

2.12 While this is expected to deliver substantial benefits, there remains some uncertainty about future emissions from diesel cars as RDE test procedures do not cover all driving styles and conditions. The TEM therefore includes three separate post-2020 scenarios for NO_x emissions from diesel cars: (1) COPERT (0.2 g/km), (2) RDE1 (0.17 g/km) and (3) RDE2 (0.11 g/km). Euro 5 NO_x emissions (0.6 g/km) are also included to provide additional context.

2.13 Petrol, LPG and CNG cars currently have significantly lower tailpipe NO_x emissions than diesel cars, as they use a spark ignition engine rather than a compression ignition engine.

2.14 Figure 2 below shows the reduction in tailpipe NO_x emissions from conventional petrol and diesel cars for different Euro standards.

Figure 2: Estimated real-world NO_x emissions from petrol/diesel cars (source: COPERT)[1]



2.15 Full hybrid (0.022 g/km) and plug-in hybrid (0.006 g/km) cars are assessed as having lower NO_x emissions than a conventional petrol car (0.039 g/km) because they have zero tailpipe emissions when operating in electric mode. Battery electric and hydrogen fuel cell electric cars have zero tailpipe NO_x emissions.

[1] Note: for petrol cars NO_x emissions for 'Euro 6 2020+' use emission factors for Euro 6c compliant engine. Euro 6c is enforced for petrol cars before 2020 (in September 2018)

Particulate Matter (PM) emissions

2.16 PM emissions figures for a Euro 6 medium car, as used in the TEM, are shown in Table 3 below.

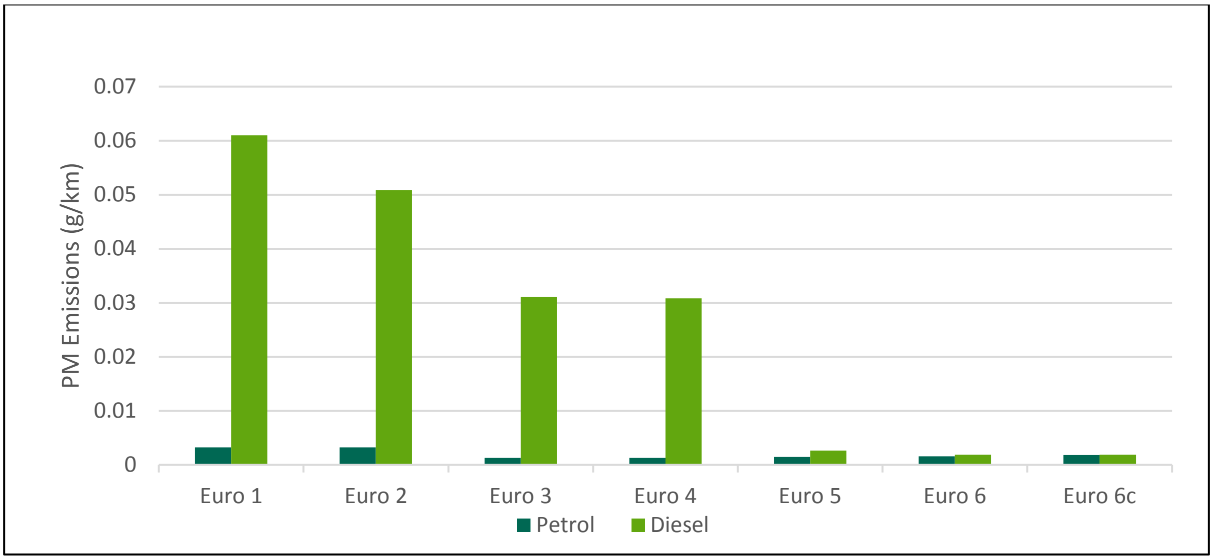
Table 3: Estimated real-world particulate matter (PM) emissions from a Euro 6 medium car

	Diesel	Petrol	CNG	LPG	Battery electric	Hydrogen fuel cell	Hybrid (petrol)	Plug-in hybrid (petrol)
grams/km	0.0019	0.0016	0.0013	0.0013	0.0000	0.0000	0.0023	0.0005

2.17 Estimated particulate matter emissions are relatively closely distributed for internal combustion engine cars, with lower values for hybrids (due to use of the electric powertrain).

2.18 Figure 3 below shows the reduction in tailpipe PM emissions from conventional petrol and diesel cars for different Euro standards.

Figure 3: Particulate matter (PM) emissions from petrol/diesel cars (source: COPERT)



2.19 Battery electric and hydrogen fuel cell electric cars have zero tailpipe particulate emissions.

Medium car greenhouse gas and NO_x emissions graph

2.20 Graph 1 illustrates both greenhouse gas and NO_x emissions on a single chart to highlight the combined impact of these emissions. NO_x emissions are shown due to the differences in emissions between powertrain / fuel combinations, rather than PM emissions where differences in emissions between powertrain / fuel combinations are substantially less.

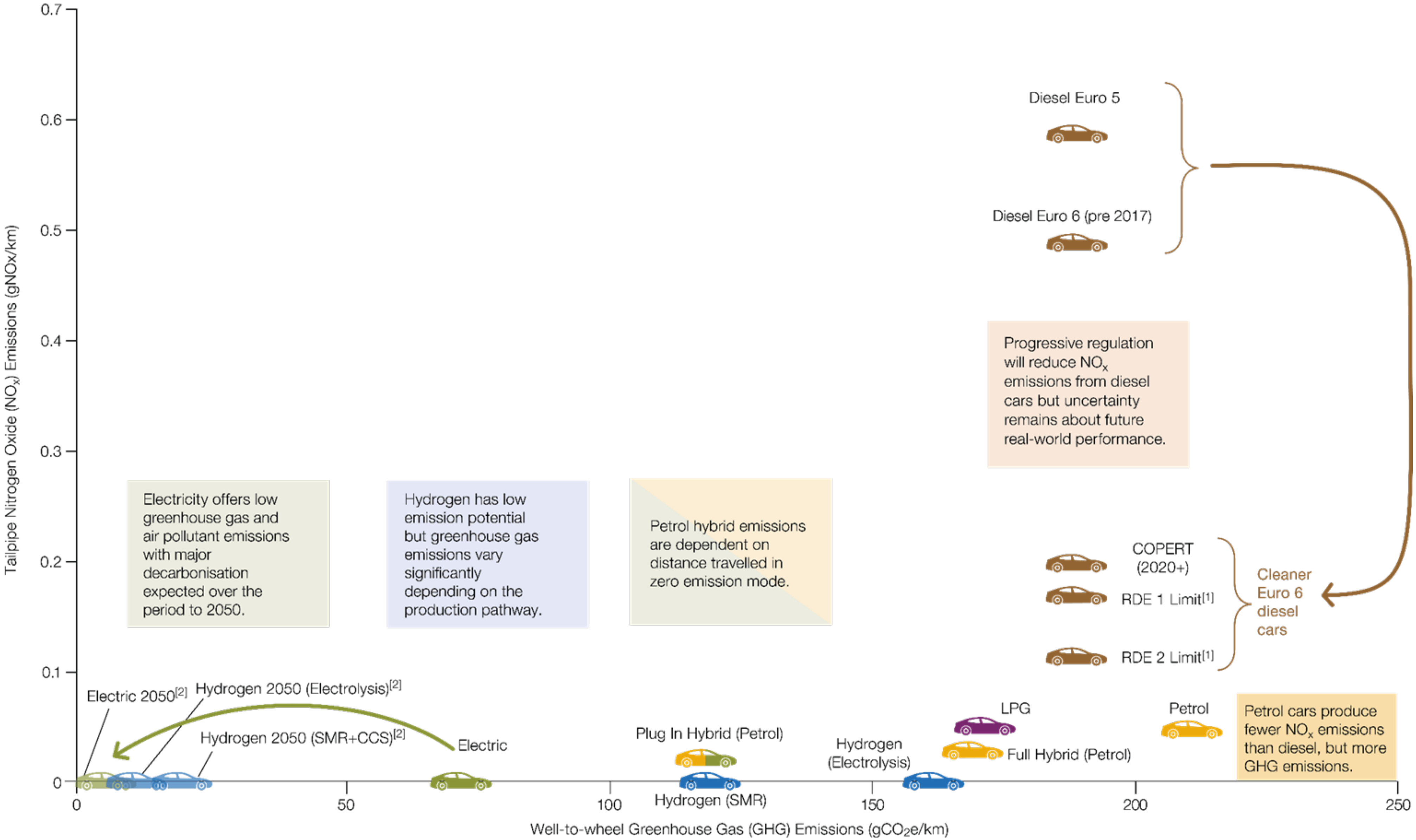
2.21 Graph 1 shows well-to-wheel greenhouse gas emissions (i.e. emissions from fuel production and combustion) and tailpipe emissions of nitrogen oxides (NO_x) for a range of powertrain / fuel combinations for a representative Euro 6 medium car in 2017.

2.22 Given recent interest in NO_x emissions from diesel cars, Graph 1 shows a range of scenarios for NO_x emissions from diesel cars ranging from Euro 5 to the Euro 6 RDE2 requirements which will come into effect in 2020/21.

Powertrain / fuel combinations shown in Graph 1:

- Petrol
- Diesel
- LPG
- Hybrid (petrol)
- Plug-in hybrid (petrol and grid electricity)
- Hydrogen fuel cell (hydrogen produced by steam methane reformation and electrolysis of grid electricity)
- Battery electric (grid electricity)

Graph 1: Estimated greenhouse gas (GHG) and nitrogen oxides (NO_x) emissions for a typical medium car on a mixed urban / extra-urban duty cycle (average speed 34km/h)



[1] RDE Limits included a factor accounting for measurement error.
[2] Future projections (vehicle energy consumption held at 2017 levels).

Panel van

2.23 A panel van (similar to a Ford Transit or VW Transporter) was selected for inclusion in the TEM because it is representative of a large proportion of the van fleet. Latest statistics show that vans in this category (i.e. those weighing between 2.5 and 3.5 tonnes) account for 62% of new van sales. For the purposes of the modelling, the emissions data is based on an average speed of 34 km/h, which reflects a mixed urban and extra-urban[2] duty cycle.

Greenhouse gas (GHG) emissions

Petrol and diesel

2.24 Out of all the options modelled, petrol vans are estimated to have the highest well-to-wheel greenhouse gas emissions – 364 gCO_2e/km. Diesel (compression ignition) engines are inherently more efficient that petrol (spark ignition) engines, so they use less fuel and have lower emissions of 300 gCO_2e/km (a reduction of 18% relative to petrol).

Liquefied petroleum gas (LPG) and compressed natural gas (CNG)

2.25 LPG and CNG vans are powered using spark ignition engines (the same technology as petrol) and are therefore assumed to have the same energy conversion efficiency as petrol vans. However, LPG and CNG fuels have a lower greenhouse gas intensity than petrol so the greenhouse gas emissions for these vehicles are also lower. An LPG van is estimated to emit 296 gCO_2e/km (a reduction of 19% from petrol and 1% from diesel) and a CNG van is estimated to emit 273 (high pressure grid) to 283 (medium pressure grid) gCO_2e/km (a reduction of 22% to 25% from petrol and 6% to 9% from diesel).

Hybrid (full hybrid and plug-in hybrid)

2.26 Petrol hybrid (full hybrid) vans have an internal combustion engine and an electric propulsion motor. In these vehicles, energy is typically captured by regenerative braking and stored within a small battery. They cannot be plugged in to be recharged. These vehicles have improved energy efficiency relative to conventional petrol vans due to the use of the electric powertrain. Emissions are estimated to be 302 gCO_2e/km (a reduction of 17% from standard petrol and increase of 1% from standard diesel).

2.27 Plug-in hybrid electric vans have an internal combustion engine and an electric motor which is charged from an external power source (i.e. the vehicle needs to be plugged in). Both the engine and the electric motor are capable of solely propelling the vehicle. Greater use of the highly efficient electric motor means these vehicles are estimated to use much less energy than standard petrol vans. Greenhouse gas emissions are estimated to be 154 gCO_2e/km (a reduction of 58% from standard petrol and 48% from standard diesel).

[2] Extra-urban represents motorways and country roads

2.28 The plug-in hybrid output is very sensitive to assumptions on how the van is used. The scenario shown in the charts assumes that the van is used efficiently (i.e. 73% of driving is in electric mode and 27% of driving is in petrol mode). Other scenarios such as failure to plug the vehicle in or heavy motorway driving would lead to increased greenhouse gas emissions.

Battery electric

2.29 Electrification delivers a large reduction in energy consumption. Using a 2017 electricity grid emissions factor, an electric van is estimated to emit 120 gCO_2e/km (a reduction of 67% from petrol and 60% from diesel). Emissions are expected to fall to near zero over the period to 2050 as the electricity grid decarbonises (in line with Government projections).

Hydrogen fuel cell electric

2.30 Greenhouse gas emissions from hydrogen fuel cell electric vehicles are highly dependent on how the hydrogen is produced. If the hydrogen is produced using SMR, estimated greenhouse gas emissions for a panel van are 199 gCO_2e/km (a reduction of 45% from petrol and 34% from diesel). Future production of hydrogen using SMR with carbon capture and storage and hydrogen production from electrolysis have the potential to reduce greenhouse gas emissions from hydrogen vehicles significantly.

Biofuels

2.31 The use of renewable fuels, including biofuels, can reduce well-to-wheel greenhouse gas emissions. The RTFO requires UK transport fuel suppliers to ensure that a proportion of their overall fuel sales are from a renewable source such as biofuels. The current level of biofuel blending is estimated to reduce overall UK transport fuel greenhouse gas emissions by 1.7%. The results shown in Graph 2 show greenhouse emissions from fossil fuel use with 1.7% subtracted to reflect biofuel blending under the RTFO. Further detail on renewable fuels can be found in Part 3.

Tailpipe nitrogen oxides (NO_x) emissions

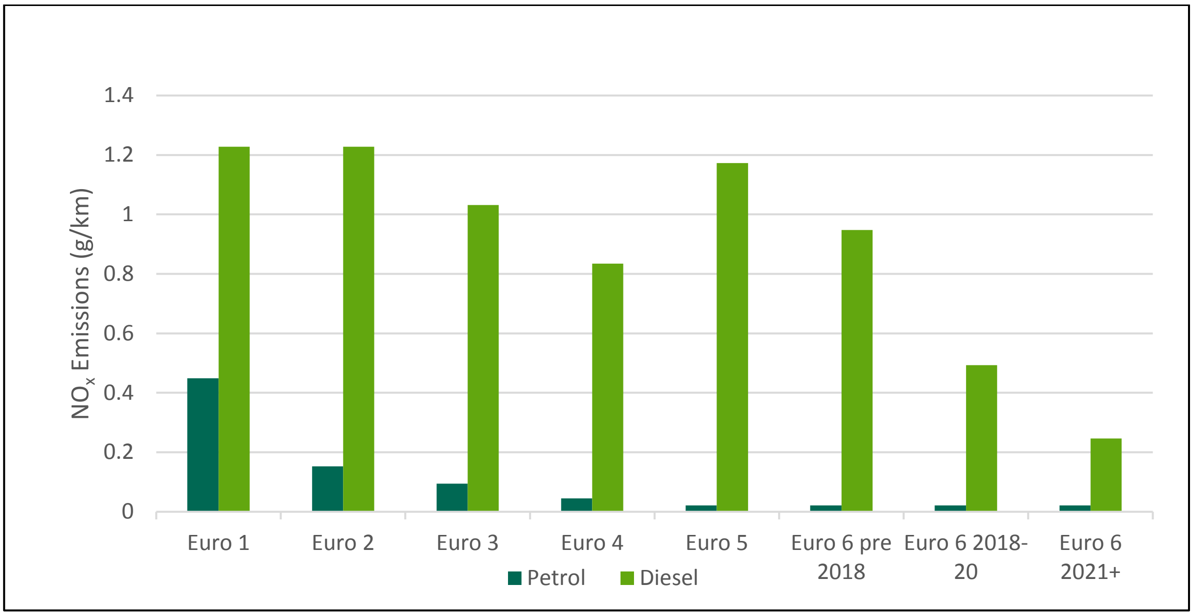
2.32 Diesel vans are assessed as having the highest tailpipe NO_x emissions out of all the powertrain options covered in the model. Real-world testing of pre-2017 Euro 6 diesel vans (0.5 g/km) showed that emissions significantly exceeded Euro 6 limits. To address this, the latest regulations require vans to meet emissions limit values in real-world driving conditions. These regulations will be introduced in two phases (RDE1 and RDE2 – also known as Euro 6d (temp) and Euro 6d (final)).

2.33 While this is expected to deliver substantial benefits, there remains some uncertainty as RDE test procedures do not cover all driving styles and conditions. The TEM therefore includes three separate post-2020 scenarios for NO_x emissions from diesel vans: (1) COPERT (0.2 g/km), (2) RDE1 (0.17 g/km) and (3) RDE2 (0.12 g/km). Euro 4 NO_x emissions are also included to provide additional context.

2.34 Petrol vans currently have significantly lower NO_x emissions than diesel vans, as they use a spark ignition engine rather than a compression ignition engine. LPG and CNG vans also use spark ignition engines and so, on the basis of discussions at stakeholder workshops, NO_x emissions from LPG and CNG vans have been set equal to petrol.

2.35 Figure 4 shows the reduction in tailpipe NO_x emissions from petrol and diesel vans for different Euro standards.

Figure 4: NO_x emissions from petrol/diesel vans (source: COPERT)



2.36 Full hybrid and plug-in hybrid vans are assessed as having lower NO_x emissions than a conventional petrol van because they have zero tailpipe emissions when operating in electric mode. Battery electric and hydrogen fuel cell electric vans have zero tailpipe NO_x emissions.

Particulate Matter (PM) emissions

2.37 PM emissions figures for a Euro 6 panel van, as used in the TEM, are shown in Table 4 below.

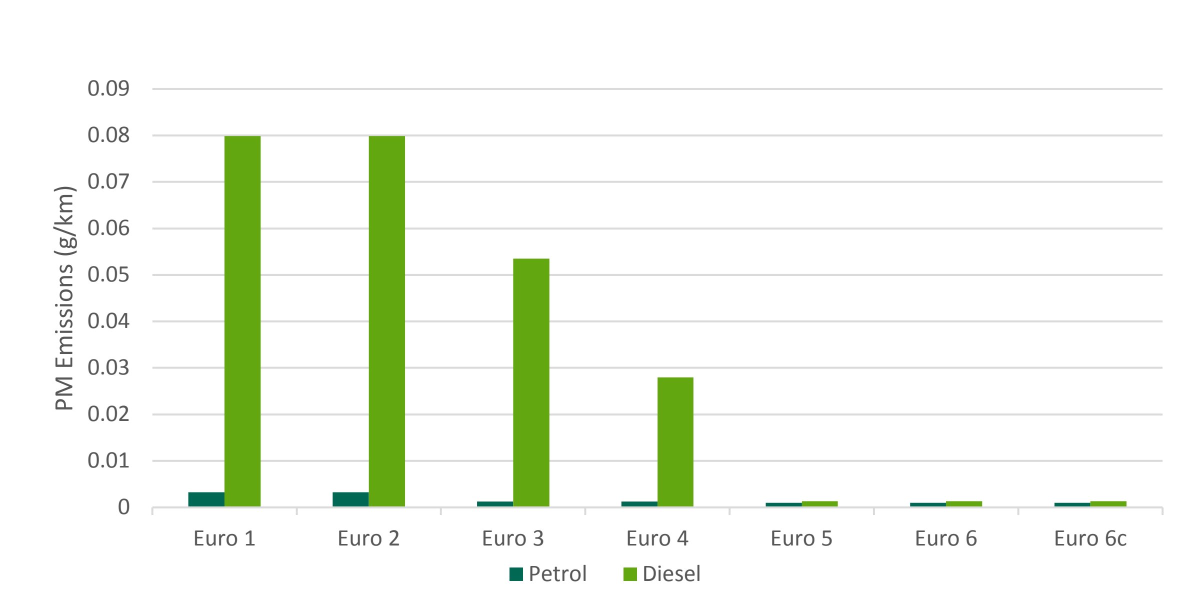
Table 4: Estimated real-world particulate matter (PM) emissions from a Euro 6 panel van

	Diesel	Petrol	CNG	LPG	Battery electric	Hydrogen fuel cell	Hybrid (petrol)	Plug-in hybrid (petrol)
grams/km	0.0013	0.0010	0.0010	0.0010	0.0000	0.0000	0.0013	0.0004

2.38 Estimated PM emissions are relatively closely distributed for internal combustion engine vans, with lower values for hybrids (due to use of the electric powertrain).

2.39 Figure 5 shows the reduction in tailpipe particulate matter emissions from petrol and diesel vans for different Euro standards.

Figure 5: Particulate matter (PM) emissions from petrol/diesel vans (source: COPERT)



2.40 Battery electric and hydrogen fuel cell vehicles have zero tailpipe particulate emissions as no combustion takes place within the vehicle.

Panel van greenhouse gas and NO_x emissions graph

2.41 Graph 2 illustrates both greenhouse gas and NO_x emissions on a single chart to highlight the combined impact of these emissions. NO_x emissions are shown due to the differences in emissions between powertrain / fuel combinations, rather than PM emissions where differences in emissions between powertrain / fuel combinations are substantially less.

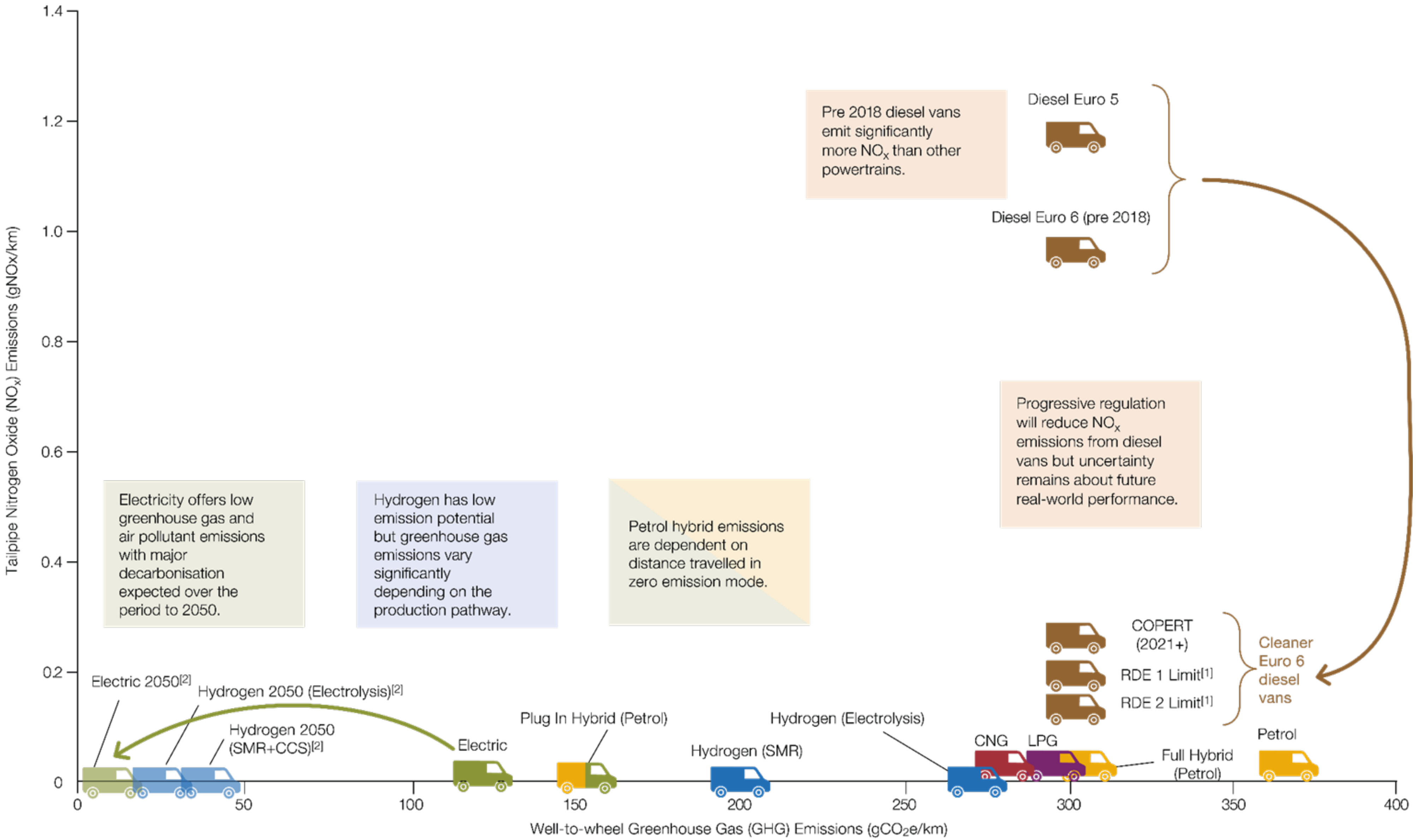
2.42 Graph 2 shows well-to-wheel greenhouse gas emissions (i.e. emissions from fuel production and combustion) and tailpipe emissions of nitrogen oxides (NO_x) for a range of powertrain / fuel combinations for a representative panel van in 2017 and 2050.

2.43 Given recent interest in NO_x emissions from diesel vans, Graph 2 shows a range of scenarios for NO_x emissions from diesel vans ranging from Euro 5 to Euro 6 RDE2 (which is also known as Euro 6d).

Powertrain / fuel combinations shown in Graph 2:

- Petrol
- Diesel
- LPG
- CNG
- Hybrid (petrol)
- Plug-in hybrid (petrol and grid electricity)
- Hydrogen (steam methane reformation and electrolysis of grid electricity)
- Battery electric (grid electricity)

Graph 2: Estimated greenhouse gas (GHG) and nitrogen oxides (NO_x) emissions for a typical panel van on a mixed urban / extra-urban duty cycle (average speed 34 km/h)



[1] RDE Limits included a factor accounting for measurement error.
[2] Future projections (vehicle energy consumption held at 2017 levels).

18 tonne heavy goods vehicle (HGV)

2.44 An 18 tonne HGV (e.g. a large, rigid-bodied delivery truck) was selected for inclusion in the model because it is representative of a significant proportion of the regional and urban delivery fleet (vehicles weighing between 8 and 18 tonnes account for 20% of all registered HGVs). For the purposes of the modelling, the emissions data is based on an average speed of 53 km/h, which reflects a regional delivery duty cycle.

Greenhouse gas (GHG) emissions

Diesel

2.45 A standard diesel 18 tonne HGV is estimated to emit 876 gCO_2e/km.

Compressed natural gas (CNG)

2.46 Latest Government funded test data reports that gas powered 18 tonne HGVs consume 23% more energy than a diesel powered equivalent (when assessed at an average speed of 53 km/h). However, the greenhouse gas impact of this increase in energy consumption is offset by the lower greenhouse gas intensity of the fuel. A CNG vehicle is estimated to emit 770 (high pressure grid) to 799 (low pressure grid) gCO_2e/km. This represents a 9% to 12% reduction in greenhouse gas emissions relative to diesel.

Hydrogen fuel cell electric

2.47 Greenhouse gas emissions from hydrogen fuel cell electric vehicles are highly dependent on how the hydrogen is produced. If the hydrogen is produced using SMR, estimated greenhouse gas emissions for an 18 tonne HGV are 611 gCO_2e/km (29% lower than diesel). To note: hydrogen HGVs are not yet commercially available and data on current performance is limited and to some extent based on assumptions.

2.48 Future production of hydrogen using SMR with carbon capture and storage and hydrogen production from electrolysis have the potential to reduce greenhouse gas emissions from hydrogen vehicles significantly.

Electric

2.49 Electrification (whether via battery or dynamically charged vehicles) delivers a large reduction in energy consumption. Using a 2017 electricity grid emissions factor, an electric 18 tonne HGV is estimated to emit 367 gCO_2e/km (58% lower than diesel). Emissions are expected to fall to near zero over the period to 2050 as the electricity grid decarbonises (in line with Government projections). To note: electric HGVs are not yet commercially available and data on current performance is limited and to some extent based on assumptions.

Biofuels

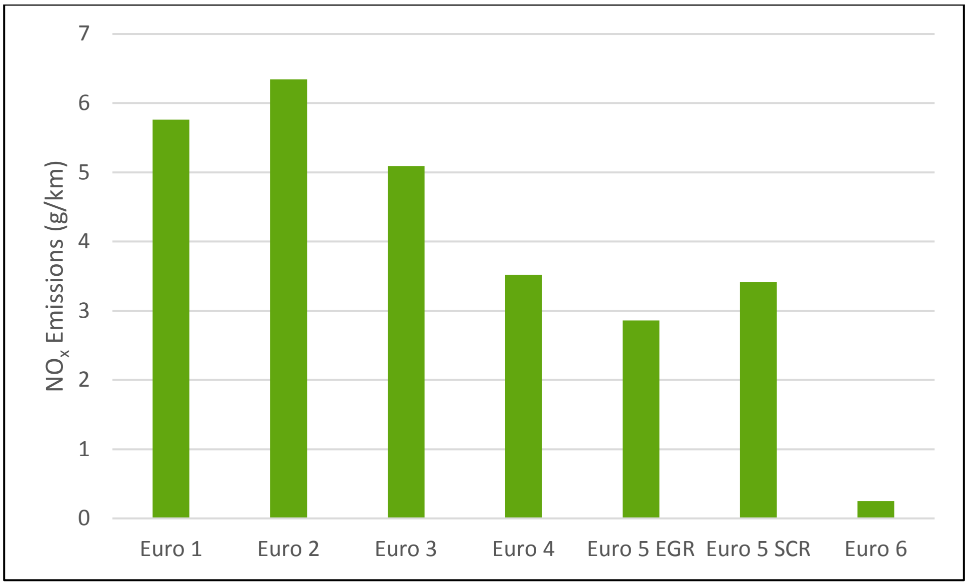
2.50 The use of renewable fuels, including biofuels, can reduce well-to-wheel greenhouse gas emissions. The RTFO requires UK transport fuel suppliers to ensure that a proportion of their overall fuel sales are from a renewable source such as biofuels. The current level of biofuel blending is estimated to reduce overall UK transport fuel greenhouse gas emissions by 1.7%. The results shown in Graph 3 show greenhouse gas emissions from fossil fuel use with 1.7% subtracted to reflect biofuel blending under the RTFO. Further detail on renewable fuels can be found in Part 3.

Tailpipe Nitrogen Oxides (NO_x) emissions

2.51 Estimated NO_x emissions from Euro VI diesel 18 tonne HGVs (0.25 g/km) have improved significantly in response to increasingly stringent emission regulations. This is primarily due to the widespread adoption of effective selective catalytic reduction after-treatment systems in the newest diesel trucks.

2.52 Figure 6 shows the reduction in tailpipe NO_x emissions from diesel 18 tonne HGVs for different Euro standards.

Figure 6: NO_x emissions from diesel 18 tonne HGVs (source: COPERT)



2.53 CNG (0.19 g/km) has lower NO_x emissions than even the latest Euro VI diesel HGV models. This is due to gas being an inherently cleaner fuel than diesel. Electric and hydrogen fuel cell electric vehicles have zero tailpipe NO_x emissions.

Particulate Matter (PM) emissions

2.54 PM emissions for a Euro VI 18 tonne HGV, as used in the TEM, are shown in Table 5 on the next page.

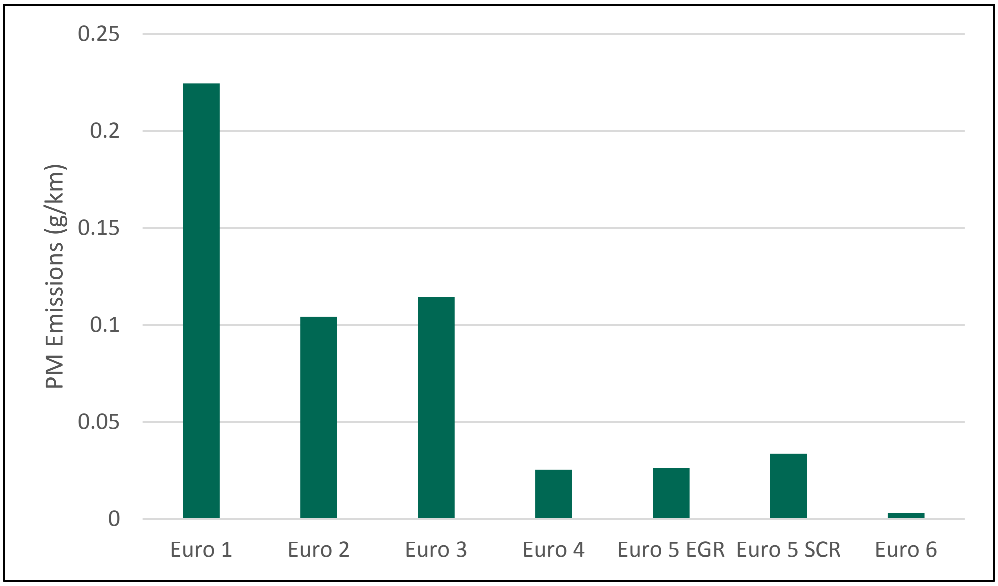
Table 5: Estimated real-world particulate matter (PM) emissions from a Euro 6 18 tonne HGV

	Diesel	CNG	BEV	Hydrogen
grams/km	0.0032	no data available	0.0000	0.0000

2.55 Estimated tailpipe PM emissions from the latest diesel 18 tonne HGVs have improved significantly in response to increasingly stringent emission regulations, with current values only marginally above that of the latest petrol and diesel cars.

2.56 Figure 7 shows the reduction in tailpipe particulate matter emissions from diesel 18 tonne HGVs for different Euro standards.

Figure 7: Particulate matter (PM) emissions from diesel 18 tonne HGVs (source: COPERT)



2.57 We were unable to obtain data on PM emissions for CNG trucks although discussions with stakeholders suggest that these are likely to be low.

2.58 Battery electric and hydrogen fuel cell electric vehicles are assessed as having zero tailpipe particulate emissions.

18 tonne HGV greenhouse gas and NO_x emissions chart

2.59 Graph 3 illustrates both greenhouse gas and NO_x emissions on a single chart to highlight the combined impact of these emissions. NO_x emissions are shown due to the differences in emissions between powertrain / fuel combinations, rather than PM emissions where differences in emissions between powertrain / fuel combinations are substantially less.

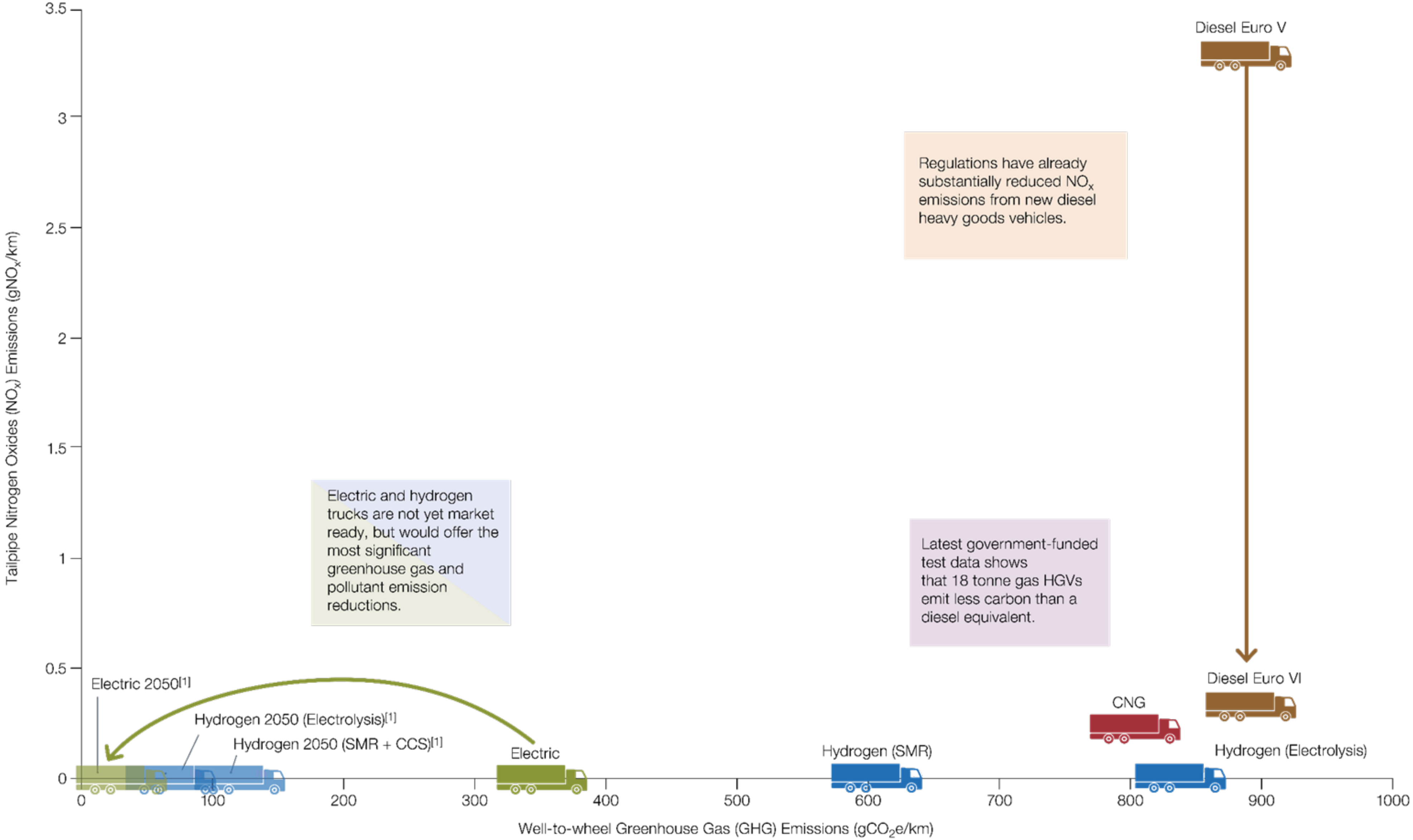
2.60 Graph 3 shows ‘well to wheel’ greenhouse gas emissions (i.e. emissions from fuel production and combustion) and tailpipe emissions of nitrogen oxides (NO_x) for a range of powertrain / fuel combinations for a representative 18 tonne HGV in 2017 and 2050.

2.61 Given recent interest in NO_x emissions from diesel vehicles, Graph 3 shows NO_x emissions from both Euro V and Euro VI 18 tonne HGVs.

Powertrain / fuel combinations shown in Graph 3:

- Diesel
- CNG
- Hydrogen (steam methane reformation and electrolysis of grid electricity)
- Battery electric (grid electricity)

Graph 3: Estimated Greenhouse gas (GHG) and nitrogen oxides (NO_x) emissions for an 18 tonne HGV on a 'regional delivery' duty cycle (average speed 53 km/h)



[1] Future projections (vehicle energy consumption held at 2017 levels).

44 tonne heavy goods vehicle

2.62 44 tonne HGVs are the largest goods vehicles permitted on UK roads and are used to transport a large share of road freight. Vehicles weighing over 41 tonnes account for 22% of all registered HGVs. For the purposes of the modelling, the emissions data is based on an average speed of 79 km/h, which reflects a long haul 'trunking' duty cycle.

Greenhouse gas (GHG) emissions

Diesel

2.63 A standard diesel 44 tonne HGV is estimated to emit 1,152 gCO_2e/km.

Compressed natural gas (CNG) and liquefied natural gas (LNG)

2.64 Greenhouse gas savings from natural gas HGVs are dependent on the relative efficiency of the gas powertrain. Data on the 'energy penalty' associated with natural gas HGVs is mixed. Latest Government funded test data reports that natural gas powered 44 tonne HGVs consume 46% more energy than a diesel powered equivalent when operating on a long haul duty cycle. In contrast, recent industry data suggests a much lower energy penalty of 19%. To reflect this uncertainty two scenarios are presented in Graph 4.

2.65 In the scenario where the energy penalty is 46% ('test data'), greenhouse gas emissions from natural gas HGVs are estimated to be 1,201 gCO_2e/km for CNG (high pressure grid) and 1,382 gCO_2e/km for LNG (4% higher than diesel for CNG and 20% higher for LNG). Whereas in the scenario where the energy penalty is 19% ('industry data'), greenhouse gas emissions are estimated to be 979 gCO_2e/km for CNG and 1,126 gCO_2e/km for LNG (15% lower than diesel for CNG and 2% lower than diesel for LNG). Due to this uncertainty around the benefits of using natural gas in 44 tonne HGVs, further testing of natural gas HGVs is being carried out.

Hydrogen fuel cell electric

2.66 Greenhouse gas emissions from hydrogen fuel cell electric vehicles are highly dependent on how the hydrogen is produced. If the hydrogen is produced using steam methane reformation (SMR) – a typical commercial production pathway for bulk hydrogen – estimated greenhouse gas emissions for a 44 tonne HGV are 1,035 gCO_2e/km (9% lower than diesel). To note: hydrogen HGVs are not yet commercially available and data on current performance is limited and to some extent based on assumptions.

2.67 Future production of hydrogen using SMR with carbon capture and storage and hydrogen production from electrolysis have the potential to reduce greenhouse gas emissions from hydrogen vehicles significantly.

Electric

2.68 Electrification (whether via battery or dynamically charged vehicles) has the potential to deliver a large reduction in energy consumption. This is primarily due to the high efficiency of the electric powertrain (although diesel engines are relatively efficient when used in a long haul duty cycle, so the gains from electrification are less than for other vehicle types duty cycles). Using a 2017 electricity grid emissions factor, an electric 44t HGV is estimated to emit 613 gCO_2e/km (47% lower than diesel). To note: electric HGVs are not yet commercially available and data on current performance is limited and to some extent based on assumptions.

2.69 Emissions are expected to fall to near zero over the period to 2050 as the electricity grid decarbonises (in line with Government projections).

Biofuels

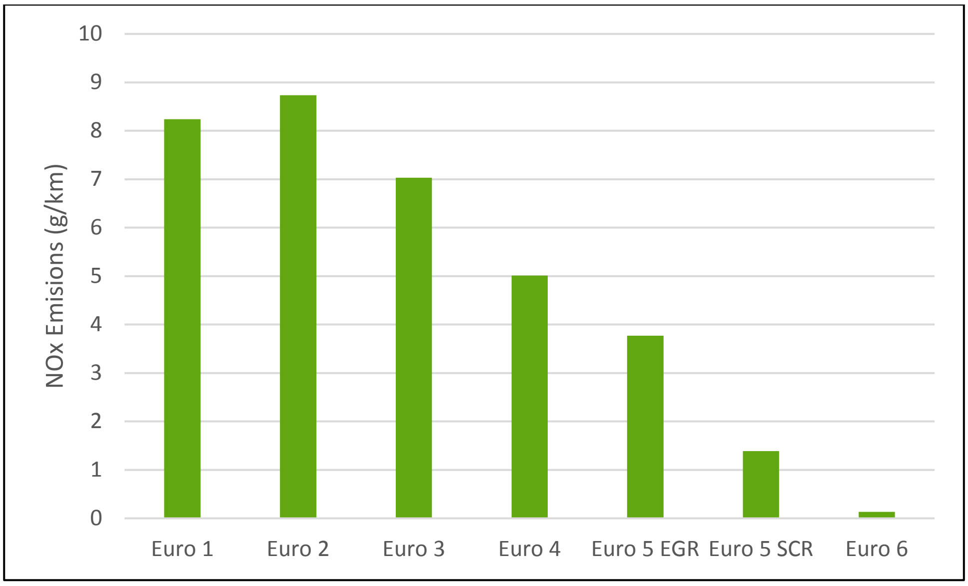
2.70 The use of renewable fuels, including biofuels, can reduce well-to-wheel greenhouse gas emissions. The RTFO requires UK transport fuel suppliers to ensure that a proportion of their overall fuel sales are from a renewable source such as biofuels. The current level of biofuel blending is estimated to reduce overall UK transport fuel greenhouse gas emissions by 1.7%. The results shown in Graph 4 shows greenhouse emissions from fossil fuel use with 1.7% subtracted to reflect biofuel blending under the RTFO. Further detail on renewable fuels can be found in Part 3.

Tailpipe nitrogen oxides (NO_x) emissions

2.71 Estimated NO_x emissions from Euro VI diesel 44 tonne HGVs (0.13 g/km) have improved significantly in response to increasingly stringent emission regulations. This is primarily due to the widespread adoption of selective catalytic reduction after-treatment systems in the newest diesel trucks.

2.72 Figure 8 shows the reduction in tailpipe NO_x emissions from diesel 44 tonne HGVs for different Euro standards.

Figure 8: NO_x emissions from diesel 44 tonne HGVs (source: COPERT)



2.73 CNG and LNG (0.06 g/km) offer lower NO_x emissions than even the latest Euro 6 diesel HGV models. This is due to methane being an inherently cleaner fuel than diesel. Electric and hydrogen fuel cell electric vehicles have zero tailpipe NO_x emissions.

Particulate Matter (PM) emissions

2.74 PM emissions figures for a Euro VI 44 tonne HGV, as used in the TEM, are shown in Table 6.

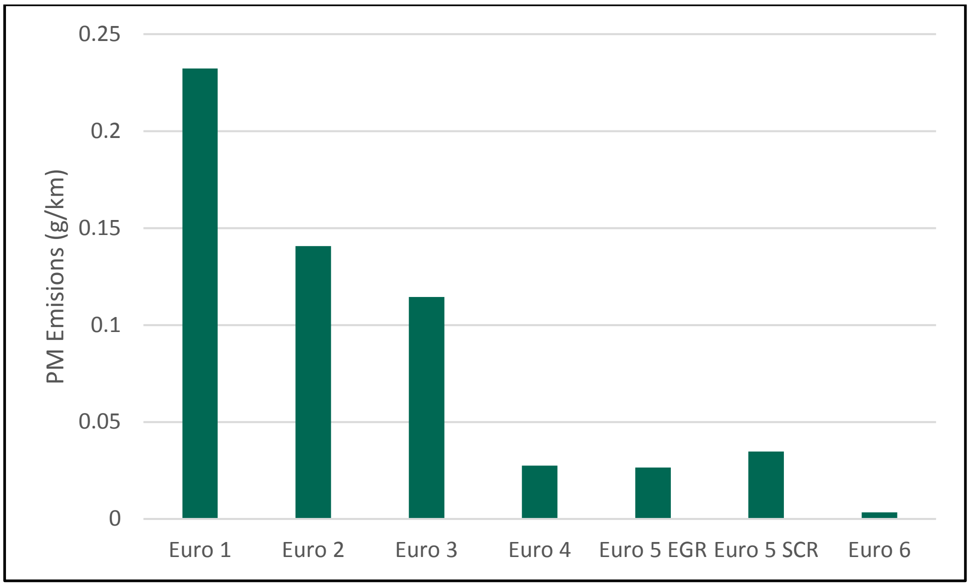
Table 6: Estimated real-world particulate matter (PM) emissions from a Euro 6 44 tonne HGV

	Diesel	Gas	Electric	Hydrogen
grams/km	0.0038	no data available	0.0000	0.0000

2.75 Estimated tailpipe particulate matter emissions from the latest Euro VI diesel 44 tonne HGVs have improved significantly in response to increasingly stringent Euro standards, with current values only marginally above that of the latest petrol and diesel cars.

2.76 Figure 9 shows the reduction in tailpipe particulate matter emissions from diesel 44 tonne HGVs for different Euro standards.

Figure 9: Particulate matter (PM) emissions from diesel 44 tonne HGVs (source: COPERT)



2.77 We were unable to obtain data on PM emissions for CNG trucks although discussions with stakeholders suggest that these are likely to be low.

2.78 Electric and hydrogen fuel cell electric vehicles have zero tailpipe particulate emissions.

44 tonne HGV greenhouse gas and NO_x emissions graph

2.79 Graph 4 illustrates both greenhouse gas and NO_x emissions on a single chart to highlight the combined impact of these emissions. NO_x emissions are shown due to the differences in emissions between powertrain / fuel combinations, rather than PM emissions where differences in emissions between powertrain / fuel combinations are substantially less.

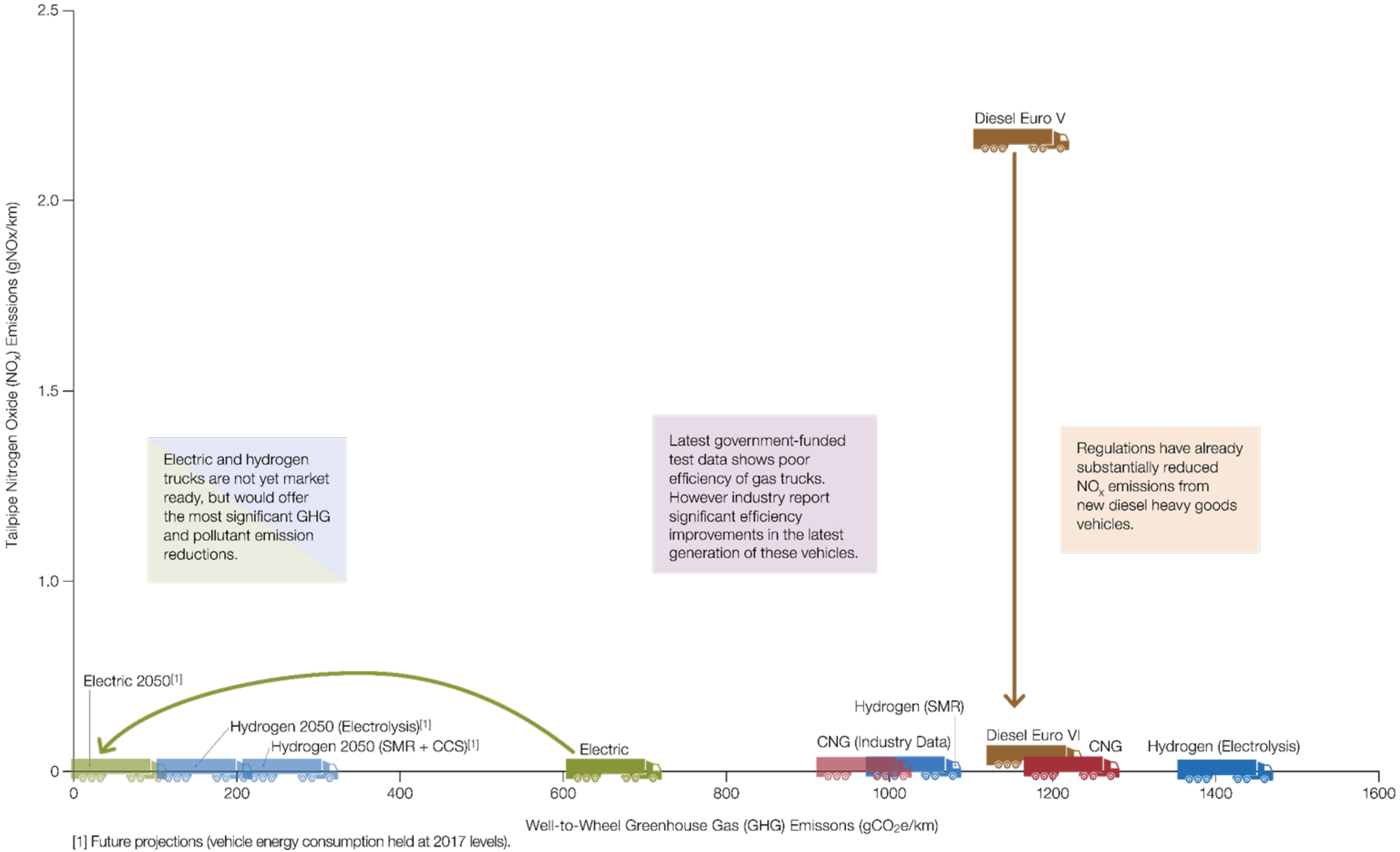
2.80 Graph 4 shows ‘well to wheel’ greenhouse gas emissions (i.e. emissions from fuel production and combustion) and tailpipe emissions of nitrogen oxides (NO_x) for a range of powertrain / fuel combinations for a representative 44 tonne HGV in 2017 and 2050. Two different scenarios for greenhouse gas emissions are shown for CNG trucks as there is uncertainty around energy consumption data for these trucks. The ‘CNG’ scenario is based upon energy consumption data from recent Government funded testing and the ‘CNG (industry data)’ scenario is based upon energy consumption data from recent industry trials. Further independent testing of gas HGVs is being carried out.

2.81 Given recent interest in NO_x emissions from diesel vehicles, Graph 4 shows NO_x emissions from both Euro V and Euro VI 44 tonne HGVs for comparison.

Powertrain / fuel combinations shown in Graph 4:

- Diesel
- CNG
- Hydrogen (steam methane reformation and electrolysis of grid electricity)
- Electric (grid electricity)

Graph 4: Estimated (GHG) and nitrogen oxides (NO_x) emissions for a 44 tonne HGV on a 'long haul' duty cycle (average speed 79 km/h)



Double deck buses

2.82 Double deck buses are the most common type of bus on UK roads (latest statistics show that double deck buses accounted for 55% of new bus registrations in Q4 2017). The emissions from the vehicle will vary depending on the average driving speed. The emissions data presented in the TEM is based on the LowCVP Urban Bus test cycle which has an average speed of 22.4 km/h and reflects a mixed urban and extra-urban duty cycle. Additionally the results for the Millbrook London Transport Bus Cycle (MLTB) which has a lower average speed of 14.9 km/h are presented in Graph 6.

Greenhouse gas (GHG) emissions

Diesel and efficient diesel

2.83 Standard diesel buses are estimated to emit 1,244 gCO_2e/km. Efficient diesel buses (which are also known as micro-hybrids) have estimated greenhouse gas emissions of 1,123 gCO_2e/km (a reduction of 10% relative to standard diesel). Industry stakeholders have indicated that efficient diesel buses show a significant reduction in energy consumption relative to standard diesel buses and are increasingly becoming the default choice for bus operators.

Diesel hybrids

2.84 Hybridisation of buses delivers significant energy efficiency improvements. Serial hybrid buses are estimated to emit 895 gCO_2e/km. This represents a 28% reduction in greenhouse gas emissions relative to standard diesel and 20% reduction relative to efficient diesel. Other hybrid technologies are available (such as ‘parallel hybrids’) but for the purposes of the modelling a serial hybrid has been taken as a representative model.

Compressed natural gas (CNG)

2.85 Latest test data reports that gas buses consume 51% more energy than a standard diesel bus and 67% more energy than an efficient diesel when assessed at a 22.4 km/h average speed. However, the greenhouse gas impact of this increase in energy consumption is offset by the lower greenhouse gas intensity of the fuel. Assuming that the gas is drawn from the low pressure grid (bus garages are assumed to generally not be situated next to the high pressure gas grid), a CNG bus is estimated to emit 1,398 gCO_2e/km. This represents a 12% increase in greenhouse gas emissions relative to a standard diesel bus and 24% increase relative to an efficient diesel bus.

Hydrogen fuel cell electric

2.86 Greenhouse gas emissions from hydrogen fuel cell electric buses are highly dependent on how the hydrogen is produced. If the hydrogen is produced using SMR estimated greenhouse gas emissions are 689 gCO_2e/km (45% lower than a standard diesel and 39% lower than an efficient diesel). Future production of hydrogen using SMR with carbon capture and storage and hydrogen production from electrolysis have the potential to reduce greenhouse gas emissions from hydrogen vehicles significantly.

Battery electric

2.87 Electrification of buses delivers a large reduction in energy consumption. This is due to the efficiency of the electric motor and also the stop-start nature of a bus duty cycle (internal combustion engines perform relatively poorly under these conditions). Using a 2017 electricity grid emissions factor, an electric bus is estimated to emit 448 gCO_2e/km (64% lower than a standard diesel and 60% lower than an efficient diesel). Emissions are expected to fall to near zero over the period to 2050 as the electricity grid decarbonises (in line with Government projections).

2.88 It should be noted that the electric bus in the TEM is assumed to use diesel for heating. Vehicle manufacturers have indicated that they expect that future electric buses may use electric heating.

Biofuels

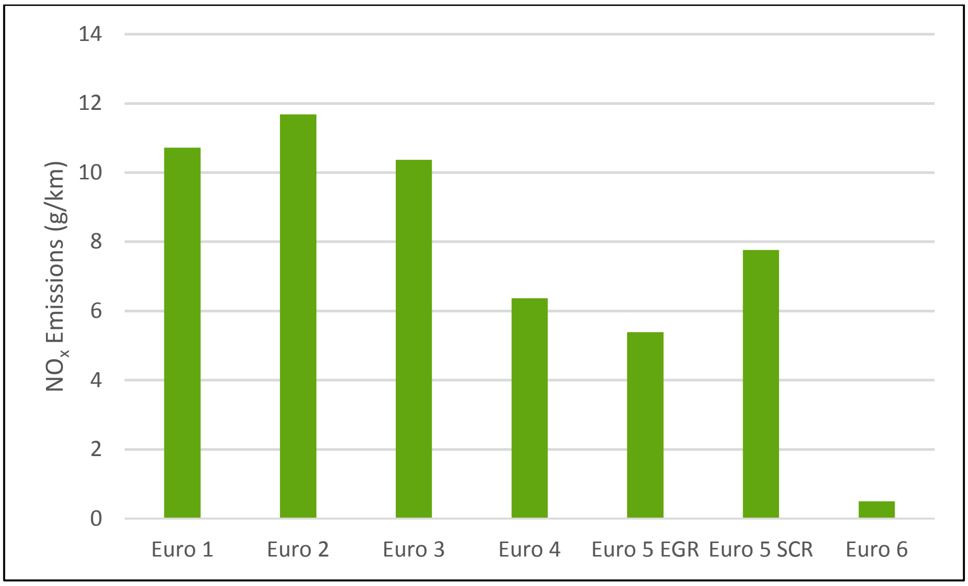
2.89 The use of renewable fuels, including biofuels, can reduce well-to-wheel greenhouse gas emissions. The RTFO requires UK transport fuel suppliers to ensure that a proportion of their overall fuel sales are from a renewable source such as biofuels. The current level of biofuel blending is estimated to reduce overall UK transport fuel greenhouse gas emissions by 1.7%. The results shown in Graph 5 and Graph 6 show greenhouse emissions from fossil fuel use with 1.7% subtracted to reflect biofuel blending under the RTFO. Further detail on renewable fuels can be found in Part 3.

Tailpipe Nitrogen Oxides (NO_x) emissions

2.90 Estimated NO_x emissions from Euro VI diesel double deck buses (0.5 g/km) have improved significantly in response to increasingly stringent emission regulations. This is primarily due to the widespread adoption of effective selective catalytic reduction after-treatment systems in the newest diesel buses. We do not have reliable test data on NO_x emissions from diesel hybrids, so these are assumed to be the same level as a 100% diesel bus.

2.91 Figure 10 below shows the reduction in tailpipe NO_x emissions from diesel buses for different Euro standards.

Figure 10: NO_x emissions from diesel buses (source: COPERT)



2.92 CNG and LNG double deck buses (0.2 g/km) emit less NO_x than even the latest Euro 6 diesel models. This is due to gas being an inherently cleaner fuel. Battery electric and hydrogen fuel cell electric vehicles have zero tailpipe NO_x emissions.

Particulate matter (PM) emissions

2.93 PM emissions figures for a Euro VI double deck bus, as used in the TEM, are shown in Table 7 below.

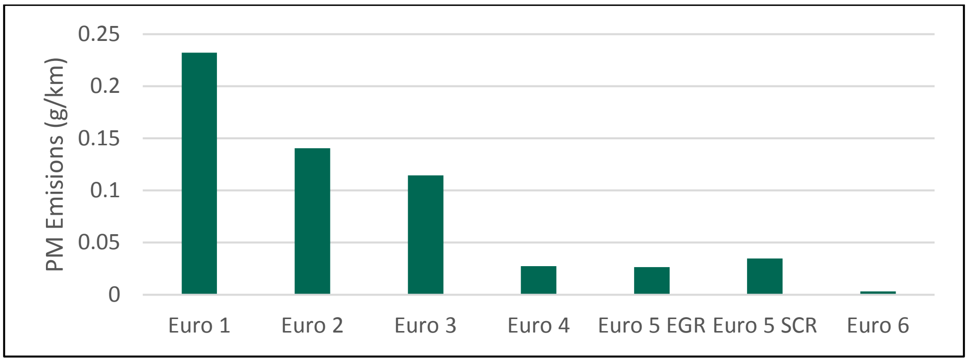
Table 7: Estimated real-world particulate matter (PM) emissions from a Euro 6 double deck bus

	Diesel / efficient diesel	CNG	Hybrid	BEV	Hydrogen
grams/km	0.0061	no data available	0.0023	0.0000	0.0000

2.94 Estimated tailpipe particulate matter emissions from the latest Euro VI diesel buses have improved significantly in response to increasingly stringent Euro regulatory standards, with current values only marginally above those of the recent petrol and diesel cars. Estimated emissions are lower for hybrids (due to use of the electric powertrain).

2.95 Figure 11 shows the reduction in tailpipe particulate matter emissions from diesel buses for different Euro standards.

Figure 11: Particulate matter emissions (PM) from diesel buses (source: COPERT)



2.96 We were unable to obtain data on PM emissions for CNG buses although discussions with stakeholders suggest that these are likely to be low.

2.97 Battery electric and hydrogen fuel cell vehicles have zero tailpipe particulate emissions.

Double deck greenhouse gas and NO_x emissions chart

2.98 Graph 5 and Graph 6 illustrate both greenhouse gas and NO_x emissions on a single chart to highlight the combined impact of these emissions. NO_x emissions are shown due to the differences in emissions between powertrain / fuel combinations, rather than PM emissions where differences in emissions between powertrain / fuel combinations are substantially less.

2.99 These figures show 'well to wheel' greenhouse gas emissions (i.e. emissions from fuel production and combustion) and tailpipe emissions of nitrogen oxides (NO_x) for a range of powertrain / fuel combinations for a representative double deck bus in 2017 and 2050.

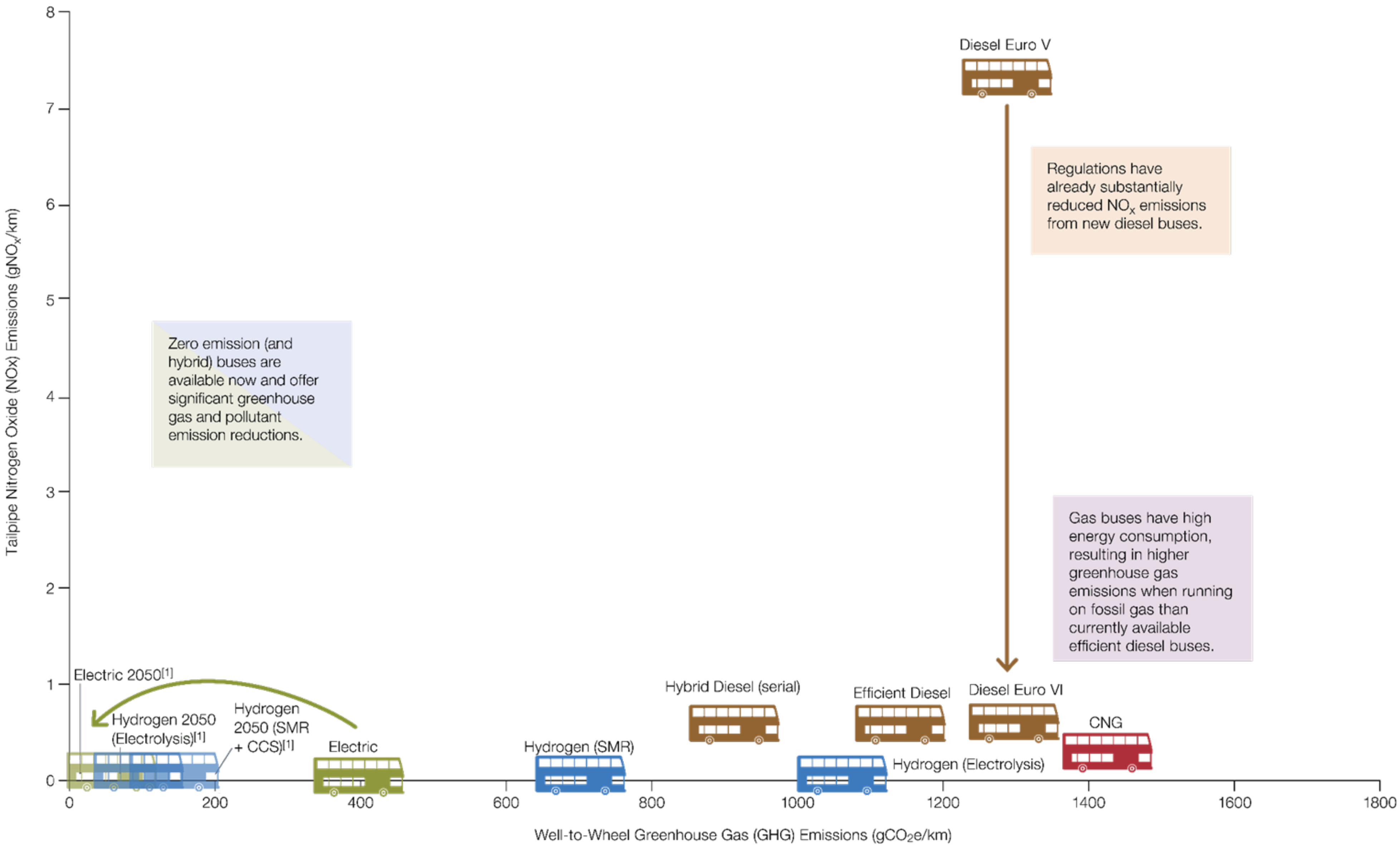
2.100 Given recent interest in NO_x emissions from diesel vehicles, they show NO_x emissions of both Euro V and Euro VI diesel buses.

2.101 Graph 5 shows the emissions over the Low CVP Urban Bus test cycle, which includes both low and high speed elements. Graph 6 shows emissions over the Millbrook London Transport Bus test cycle, which is slower speed and therefore more representative of inner city driving.

Powertrain / fuel combinations shown in Graph 5 and Graph 6:

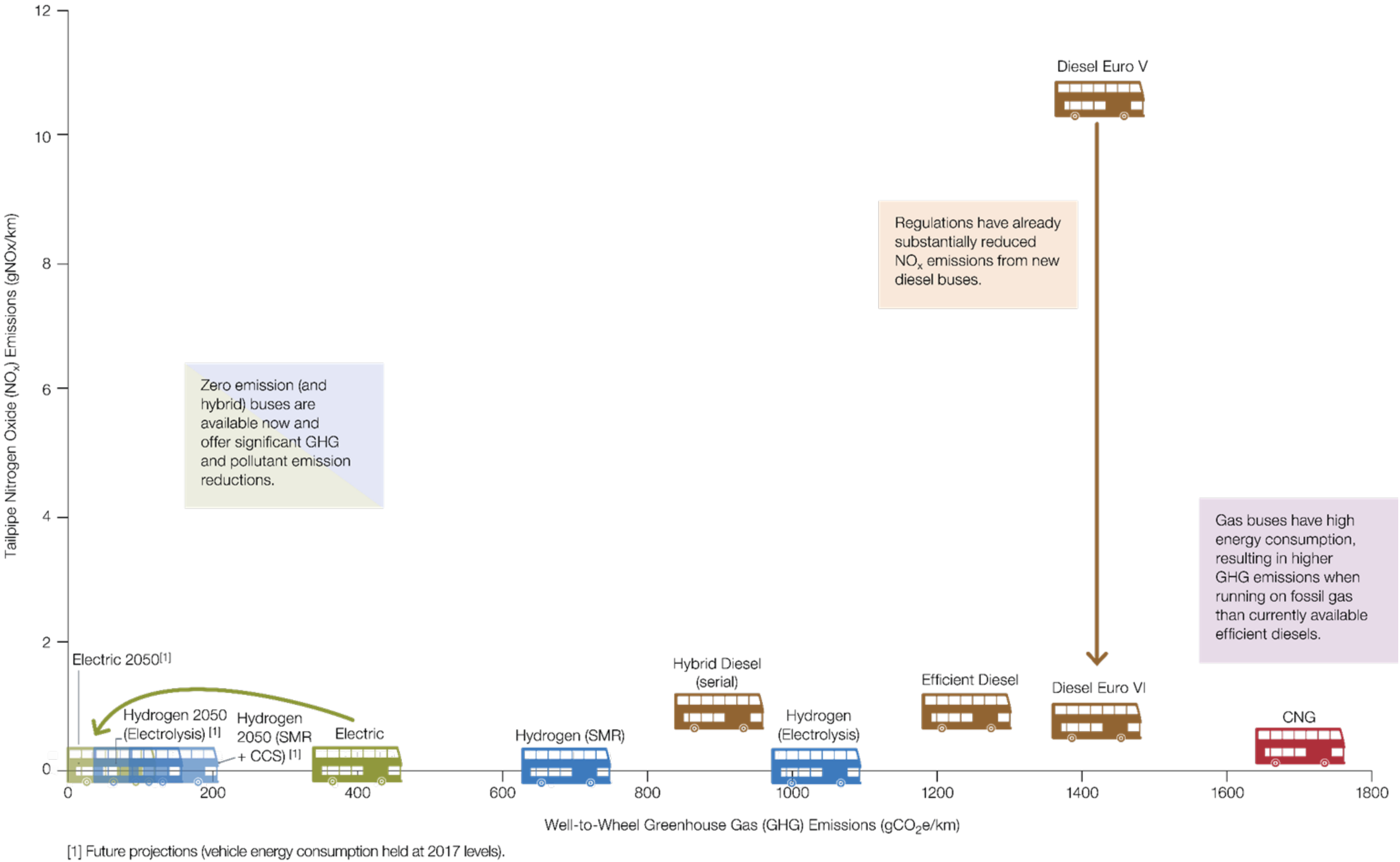
- Diesel
- Efficient diesel (micro hybrid)
- Hybrid diesel (serial hybrid)
- CNG
- Hydrogen (steam methane reformation and electrolysis of grid electricity)
- Battery electric (grid electricity)

Graph 5: Estimated (GHG) and nitrogen oxides (NO_x) emissions for a double deck bus on the LowCVP Urban Bus test cycle (average speed 22.4 km/h)



[1] Future projections (vehicle energy consumption held at 2017 levels).

Graph 6: Estimated (GHG) and nitrogen oxides (NO_x) emissions for a double deck bus on the Millbrook London Transport Bus test cycle (average speed 14.9 km/h)

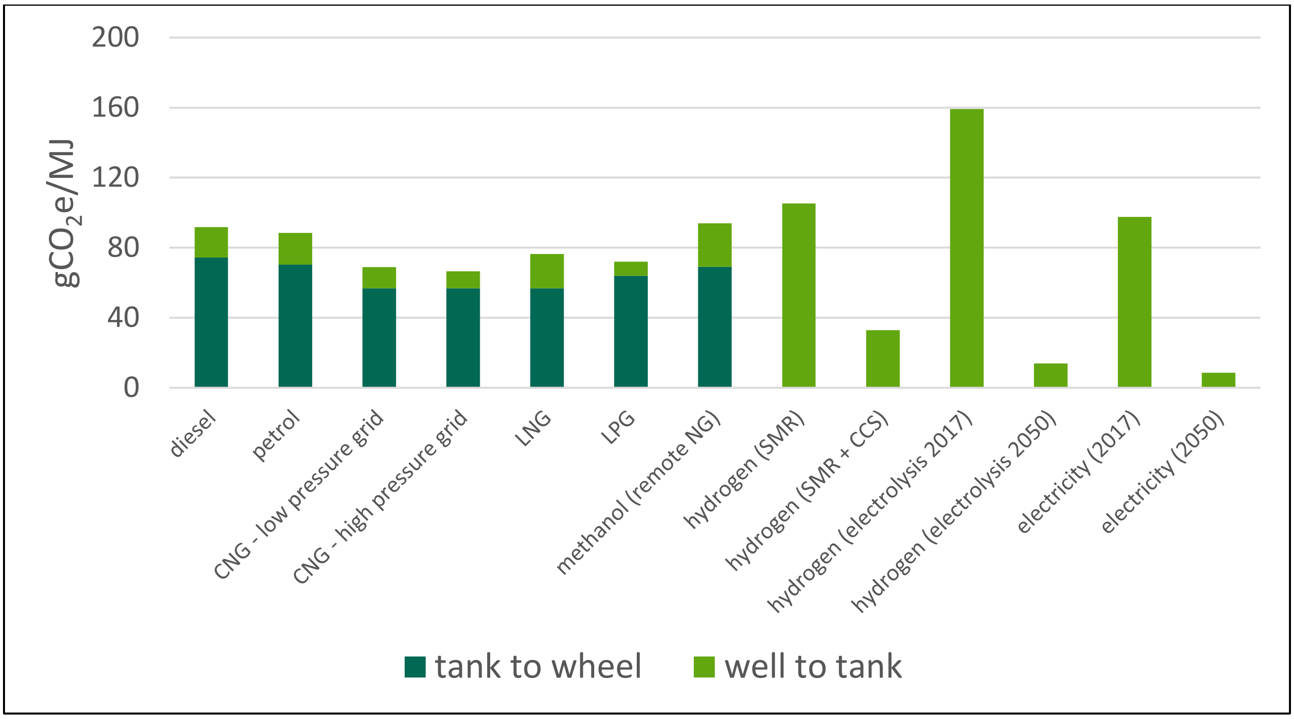


3. Energy
Fossil fuel, electricity and hydrogen

3.1 Figure 12 shows well-to-wheel greenhouse gas emissions for a range of fossil fuels and grid electricity. Greenhouse gas emissions are split into two separate categories:

- Well-to-tank – emissions from energy production (e.g. oil extraction and refining) and transportation; and
- Tank-to-wheel – emissions from energy conversion / combustion within the vehicle.

Figure 12: 'Well-to-wheel' greenhouse gas emissions – fossil fuels and electricity



Key: CNG (compressed natural gas), LPG (liquefied petroleum gas), remote NG (remote natural gas), H_2 (hydrogen), SMR (steam methane reformation), CCS (carbon capture and storage),

Hydrocarbon fossil fuels

3.2 For hydrocarbon fossil fuels, the majority of greenhouse gas emissions associated with the fuel are tank-to-wheel (i.e. they are emissions which are produced from combustion within the vehicle). Well-to-tank emissions (i.e. emissions from production and distribution) are smaller but still significant for many fuels.

3.3 Emissions factors for diesel, petrol, CNG, LNG and LPG have been sourced from the Government's Greenhouse gas reporting: conversion factors 2017. CNG values have been modified to reflect lower emissions of taking gas from the high pressure grid (where less electricity is required to compress the gas for use in vehicles, and therefore has lower greenhouse gas emissions). Data on methanol emissions have been sourced from JRC WELL-TO-TANK Appendix 4 - Version 4a. Methanol is assumed to be produced using remote natural gas (gas which cannot be connected to a grid) as a feedstock.

Electricity and Hydrogen

3.4 In contrast to fossil fuels, vehicles running on electricity and hydrogen produce no tank-to-wheel greenhouse gas emissions because there is no combustion taking place inside the vehicle. These vehicles have zero tailpipe emissions. Therefore all the greenhouse gas emissions associated with these fuels occur in the well-to-tank phase, i.e. in the production and distribution of the energy sources.

3.5 Electricity emissions factors have been sourced from the Government's Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal. In line with the guidance, we have used the 'long run marginal' emissions factor to assess changes to electricity demand resulting from electric vehicle use. For consistency, a 15% uplift factor has been added to these values to reflect fossil fuel production emissions (i.e. emissions associated with the production of coal or gas used for electricity generation).

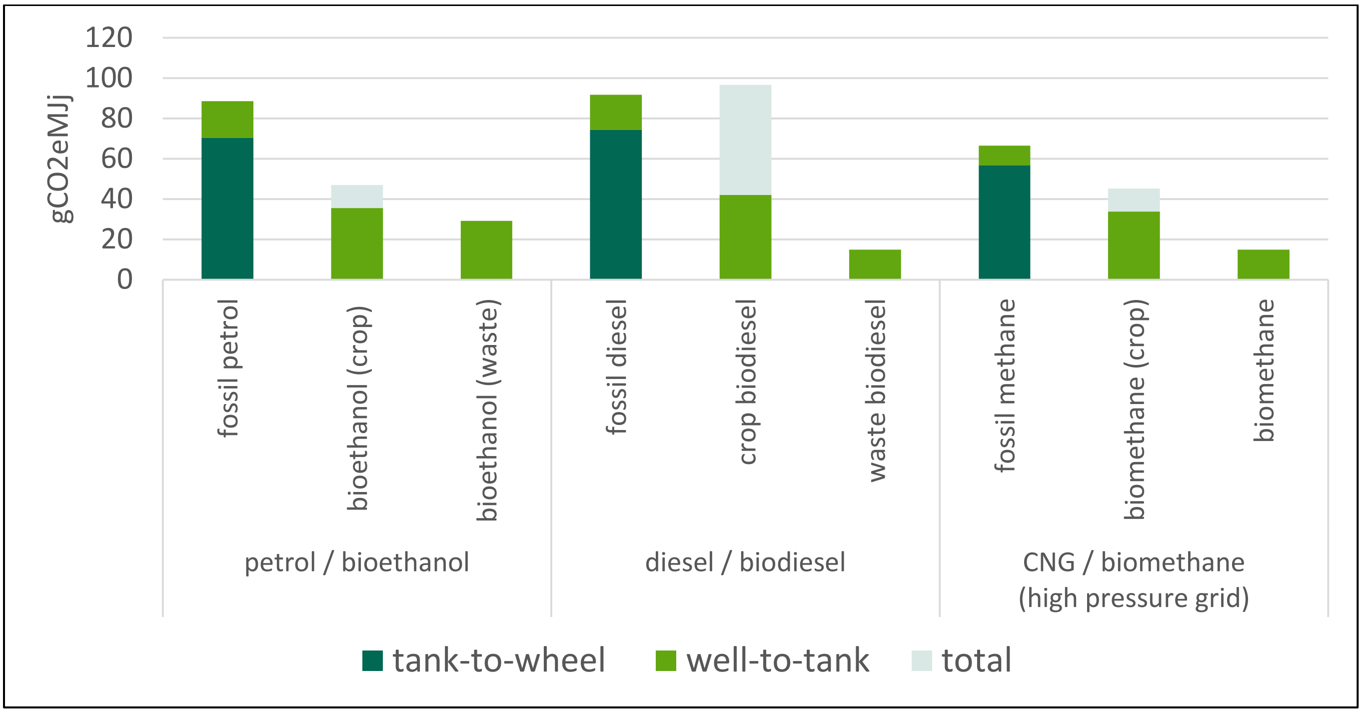
Hydrogen emissions factors are based upon values taken from JRC WELL-TO-TANK Appendix 4 - Version 4a. However, these values have been modified to reflect UK electricity grid emissions where electricity is used in hydrogen production and distribution (e.g. hydrogen produced from electrolysis of water). It should be noted that data on hydrogen emissions are based on hydrogen employed to propel a fuel cell electric vehicle and not on hydrogen used in an internal combustion engine.

Biofuels greenhouse gas emissions

3.6 Figure 13 shows well-to-wheel greenhouse gas emissions for a range of biofuels. For biofuels, greenhouse gas emissions are split into three separate categories:

- **well-to-tank** – emissions from energy production (e.g. oil extraction and refining) and transportation;
- **tank-to-wheel** – emissions from energy conversion / combustion within the vehicle; and
- **ILUC** – emissions from indirect land-use change (i.e. emissions from cropland expansion caused by impact of biofuels on global agricultural commodity demand).

Figure 13: 'Well to wheel' greenhouse gas emissions – biofuels and blends



RTFO and biofuel blending

3.7 The RTFO requires UK transport fuel suppliers to ensure that a proportion of their overall fuel sales are from a renewable source such as biofuels. The target for 2017/18 (the base year for the TEM analysis) was set at 4.75% – this means that fuel suppliers have to demonstrate that 4.75% of fuel supplied is from a renewable source. The RTFO biofuels target is legislated to increase sharply to 9.75% in 2020 and then gradually to 12.4% in 2032.

3.8 Based on the 2017/18 target, the RTFO is estimated to reduce overall UK transport fuel greenhouse gas emissions by 1.7% (calculated using RTFO data). This reduction has been applied to fossil fuel greenhouse gas emissions shown in Graphs 1, 2, 3, 4, 5 and 6.

3.9 In reality, some fuels will have a higher level of biofuel blending than others. However, as the RTFO target is set at a fixed level, an increase in RTFO supported biofuel blending into one fuel stream will be offset by less biofuel blending in other fuel streams. Therefore the greenhouse gas savings from a relatively high level of biofuel blending into one fuel stream cannot be considered as 'additional' greenhouse gas savings as they will be offset by lower greenhouse gas savings in other fuel streams. The approach of applying a uniform greenhouse gas reduction factor across all fuels obligated under the RTFO has therefore been taken to avoid biasing comparisons between fuels where the level of biofuel blending is currently relatively high against fuels which are currently supplied as 100% fossil.

Biodiesel

3.10 Biodiesel is a diesel substitute which can be produced from a variety of bio-feedstocks (e.g. oil crops, waste oils, municipal waste, woody biomass). It can be blended into the standard diesel fuel stream up to a concentration of 7% (B7) and at higher concentrations into dedicated high blend fuel streams which can be used by adapted vehicles (e.g. B30, B100). In recent years, the vast majority of biodiesel supplied in the UK has been produced using waste oil feedstocks (e.g. used cooking oil). In the future, development of advanced conversion technologies could see a greater proportion of biodiesel being produced from non-vegetable oil waste feedstocks.

3.11 In the TEM, crop-derived biodiesel is assessed as causing both well-to-tank and ILUC greenhouse gas emissions. ILUC emissions from crop biodiesel are estimated to be very high due to the link between demand for vegetable oil crops and tropical deforestation associated with palm oil cultivation. In contrast, waste biodiesel is assessed as having no ILUC emissions as waste feedstock does not require land. Overall, crop biodiesel is estimated to increase greenhouse gas emissions by 5% (relative to fossil diesel) and waste biodiesel is estimated to give an 84% greenhouse gas saving.

Bioethanol

3.12 Bioethanol is a petrol substitute which can be produced from a variety of bio-feedstocks (e.g. sugar/starch crops, woody biomass, waste products). At present, most petrol in the UK is supplied as E5 (a petrol ethanol blend containing up to 5% bioethanol). The volume of bioethanol supplied in the UK could be increased by introducing E10 petrol, which contains up to 10% ethanol (E10). Supply can also be increased by introducing ‘high blend’ fuel streams which can be used by adapted vehicles (e.g. E85). In recent years, the vast majority of bioethanol supplied in the UK has been produced using crop feedstocks. In the future, development of advanced conversion technologies could see a greater proportion of bioethanol being produced from non-crop feedstocks.

3.13 In the TEM, crop-derived bioethanol is assessed as causing both ‘well-to-tank’ and ILUC emissions. However, ILUC emissions from crop bioethanol are estimated to be significantly lower than ILUC emissions from crop biodiesel. Waste bioethanol has no ILUC emissions attributed as waste feedstock does not require land. Overall, crop bioethanol is estimated to give a 47% greenhouse gas saving (relative to petrol) and waste bioethanol is estimated to give a 70% greenhouse gas saving.

Biomethane

3.14 Methane produced from bio-feedstock (e.g. crops, waste food, and municipal waste) is chemically identical to fossil methane which is the key component of natural gas. Biomethane can therefore be injected into the gas grid and used as a substitute for CNG or liquefied and used as a substitute for LNG. In the model, crop biomethane is estimated to give a 32% greenhouse gas saving (relative to fossil methane) and waste biomethane is estimated to give a 78% greenhouse gas saving. Biomethane production is supported by both the RTFO and the RHI (Renewable Heat Incentive).

Other biofuels

3.15 In addition to the biofuels above, other fossil fuels (e.g. LPG) have bio substitutes. However, at present these fuels are not supplied in significant volumes. Overall, greenhouse gas savings from these fuels will follow the same pattern for the biofuels described above. The highest greenhouse gas savings are attributed to fuels made from waste products. Crop derived fuels tend to have lower greenhouse gas savings due to agriculture emissions (e.g. fertiliser) and ILUC emissions. Fuels made from (non-waste) vegetable oils tend to be associated with high levels of ILUC emissions.

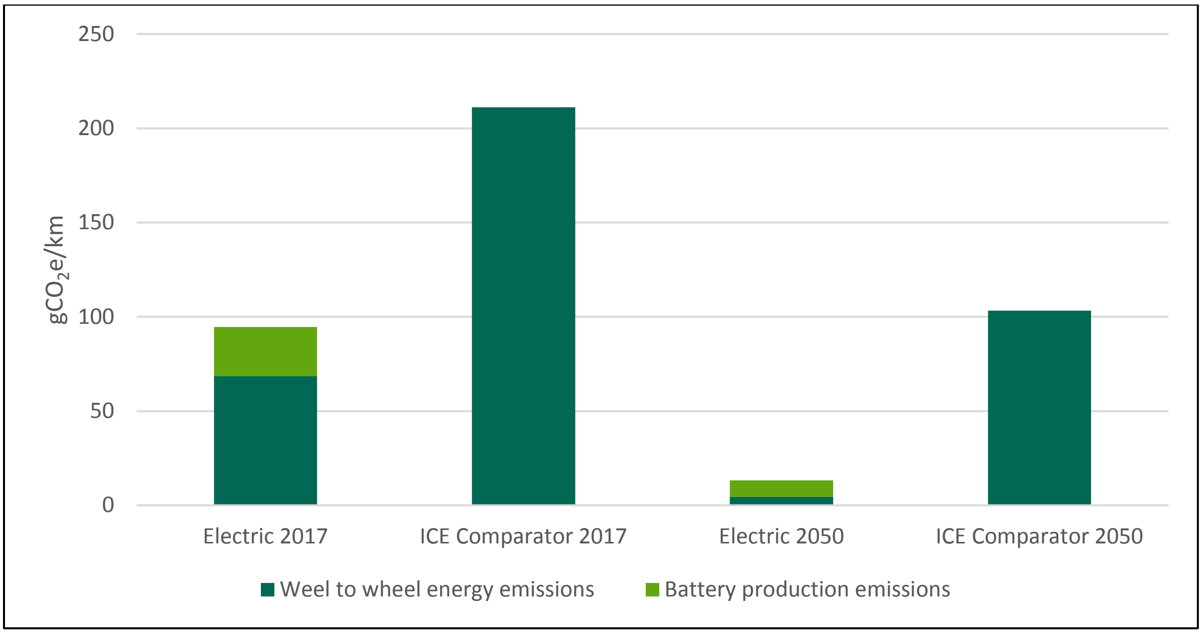
4. Sensitivities

Battery production emissions sensitivity

4.1 In general, emissions from vehicle manufacturing are not captured by the TEM. However, greenhouse gas emissions from battery manufacturing are thought to be significant and, during the model development process, many stakeholders suggested that these emissions should be taken into account. In order to address these concerns we have carried out an additional sensitivity assessment looking at the impact of battery production emissions on electric vehicle greenhouse gas emissions.

4.2 The results of this analysis suggest that battery production emissions are currently significant (around five tonnes of CO_2e for a 35 kWh battery – a typical current size for a medium car). However, when these emissions are spread over the lifetime of a typical vehicle, an electric powertrain still delivers significant greenhouse gas savings relative to a conventional comparator. As we move into the future, battery production greenhouse gas emissions are expected to fall significantly even though battery capacity is projected to increase. This fall in production emissions is attributed to increased battery power density (i.e. less raw material is required to store charge) and large falls in greenhouse gas emissions from electricity, which is a major input in battery production.

Figure 14: Battery electric vehicle (medium car) greenhouse gas emissions (well to wheel energy emissions and battery production emissions)



Key: ICE = Internal Combustion Engine

Methodology

4.3 Battery emissions (kgCO_2e/battery) are calculated by multiplying production emissions intensity (kgCO_2e/kWh) by battery capacity (kWh).

4.4 In the example shown in Figure 14, 2017 battery capacity is 34.9 kWh and the battery production emissions intensity is 143 kgCO_2e/kWh. This gives total 2017 production emissions of 4,976 kgCO_2e per battery. Spreading these emissions over a 15 year battery lifetime and annual vehicle mileage of 12,700 km gives battery production emissions of 26.1 gCO_2e/km.

4.5 By 2050, battery capacity is assumed to have increased to 43.3 kWh and battery production emissions intensity falls to 38 kgCO_2e/kWh. This gives total 2050 production emissions of 1,647 kgCO_2e per battery. Spreading these emissions over a 15 year battery lifetime and annual vehicle mileage of 12,700 km (average car mileage) gives battery production emissions of 8.6 gCO_2e/km.

Key Assumptions (battery emissions)

- **2017 Battery production emissions** (143 kgCO_2e/kg) is average taken from 2 recent metastudies (1) Swedish Government funded study (175 kgCO2e/kWh); and (2) academic paper referenced in recent Transport & Environment (NGO) report (110 kgCO_2e/kWh) 2050 Battery production emissions (38 kgCO_2e/kg) was supplied by Ricardo Energy & Environment.
- **Battery Lifetime assumption** (15 years or 190,500 km) was supplied by Ricardo Energy & Environment.
- **Battery size assumption** for medium car (34.9 kWh in 2017 and 43.3 kWh in 2050) are taken from Element Energy ECCo model.
- Greenhouse gas impact of **battery 'second life'** (e.g. use as home energy storage for solar panels) and **battery disposal** have not been included in the analysis.

Annex A: Glossary

Emissions

CO_2 (carbon dioxide) – a greenhouse gas.

CO_2e (carbon dioxide equivalent) – a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally 100 years).

COPERT – COPERT emissions factors are produced on behalf of the European Environment Agency and are the standard emissions factors for assessing road transport NO_x and PM in Government analysis.

EGR (Exhaust gas recirculation) – a nitrogen oxide (NOx) emissions reduction technique used in petrol / gasoline and diesel engines which works by recirculating a portion of an engine's exhaust gas back to the engine cylinders.

Euro 6c – Euro 6c is the full Euro 6 emissions standard (but excluding RDE). Euro 6c introduced a particle number limit for petrol direct injection engines.

Euro standard – European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in EU and EEA member states. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards.

GHG (greenhouse gas) – a gas in an atmosphere that absorbs and emits radiant energy and is associated with the ‘greenhouse effect’.

ILUC – Indirect land-use change where the cause is at least a step removed from the effects – the knock-on effects on expansion of agricultural land-use resulting from the cultivation of biofuel feedstocks.

ILUC emissions – emissions from indirect land-use change, such as emissions from cropland expansion caused by the impact of biofuels on global agricultural commodity demand.

N_2O (nitrous oxide) – a powerful greenhouse gas.

NO_x (oxides of nitrogen) – an air pollutant including both nitrogen oxide and nitrogen dioxide.

PM (particulate matter) – particles suspended in air. Particulates come in various sizes (e.g. $PM_{2.5}$ which describes particulates which are less than 2.5 micrometres or less in diameter and PM_{10} which describes particulates between 2.5 and 10 micrometres in diameter).

RDE (real driving emissions) – for NO_x and particle number emissions the latest car and van Euro standards require that new vehicles meet both laboratory and real world limits. The limits for the RDE test are fixed in relation to the laboratory test by a ratio known as a conformity factor. This is the maximum permitted ratio that the emissions recorded in the RDE test can exceed the laboratory emissions test limit.

$$RDE\ test\ limit = Conformity\ factor \times laboratory\ limit$$

From RDE2 the conformity factor will be 1, i.e. parity with the laboratory test limit (with an allowance of 0.43 for measurement uncertainty).

SCR (selective catalytic reduction) – a means of converting nitrogen oxides (NOx) with the aid of a catalyst and reducing agent, such as a urea solution, into diatomic nitrogen (N2) and water (H2O).

Tailpipe emissions – emissions emitted directly from the exhaust of a vehicle.

Tank-to-wheel emissions – greenhouse gas emissions from energy conversion / combustion within the vehicle.

Well-to-tank emissions – greenhouse gas emissions from energy production (e.g. oil extraction and refining) and transportation.

Well-to-wheel emissions – the combination of well-to-tank and tank-to-wheel emissions.

Energy

Biodiesel – a liquid biofuel which is used as a diesel substitute.

Bioethanol – a liquid fuel which is used as a petrol substitute.

CCS (carbon capture and storage) – a technology which captures CO_2 and stores it underground. This can be added to steam methane reformation (SMR) to reduce the greenhouse gas impact of hydrogen production from methane. This technology has yet to be demonstrated on a large scale.

CNG (compressed natural gas) – natural gas which is taken from the gas grid and compressed for use in vehicles. Methane (the main component of natural gas) is relatively clean burning and has a lower greenhouse gas intensity per unit of energy than petrol or diesel.

Electrolysis – electrolysis is a hydrogen production process where water is reacted with electricity to produce hydrogen and oxygen.

LNG (liquefied natural gas) – natural gas (fossil methane) which is stored at very low temperatures in a liquid state. Liquefying gas requires significant energy which means that LNG has higher greenhouse gas emissions than CNG.

LPG (liquefied petroleum gas) – a hydrocarbon fuel, consisting primarily of butane and propane, which can be used as an alternative to petrol in spark ignition engines. This fuel is also sometimes referred to as Autogas.

SMR (Steam Methane Reformation) – a hydrogen production process where methane is mixed with steam at high temperature. This process produces CO_2 as a by-product.

Vehicles

Battery electric vehicle – a vehicle which is driven solely by an electric motor, powered by a battery that can be plugged in to be recharged. No combustion takes place within the vehicle.

Compression ignition engine – an internal combustion engine which ignites the fuel-air mixture by compression. Compression ignition engines are typically powered by diesel (although ‘dual fuel’ variants may allow other fuels to be used in combination with diesel).

Dual fuel vehicle – a vehicle which uses two fuels in the same engine (and is a distinct category from hybrids – see below). It is typically compression ignition and uses diesel at low speeds and switches to an alternative fuel (e.g. CNG, LNG, and LPG) at higher speeds.

Duty cycle – a pattern of use for a particular vehicle (e.g. a supermarket delivery van operating in a city would have an ‘urban delivery’ duty cycle).

Fuel cell electric vehicle – a vehicle which uses an on-board fuel cell to react hydrogen with oxygen from the air to produce electricity, with water the only by-product. The vehicle is driven solely by an electric motor, using the electricity produced by the fuel cell.

Full hybrid electric vehicle – a hybrid vehicle in which energy is typically captured by regenerative braking and stored within a small battery. It cannot be plugged in to be recharged.

Hybrid electric vehicle – a vehicle which is powered partly by electricity used in an electric motor and partly by a conventional engine (most commonly a petrol engine). There are a range of hybrid electric vehicles, ranging from mild and full hybrids to plug-in and range extended electric vehicles. The TEM includes a full hybrid and a plug-in hybrid.

Internal combustion engine (ICE) – a conventional engine which burns a hydrocarbon fuel to produce energy.

Plug-in hybrid electric vehicle – a hybrid vehicle in which the electric motor is charged from an external power source (i.e. the vehicle need to be plugged in).

Range extended electric vehicle – A vehicle driven by electric motor. The battery pack can be recharged from an external power source, but also by an auxiliary power unit (most commonly a combustion engine) which can be used to recharge the battery to extend the vehicle’s range.

Spark ignition engine – an internal combustion engine which ignites the fuel-air mixture with a spark. It is mainly powered by petrol but is also used with alternative fuels such as LPG, CNG, LNG and methanol. Spark ignition engines are typically less efficient than diesel (compression ignition) engines.

Other

Sensitivity analysis – additional analysis to check the sensitivity of results to variability in one or more factors. It involves alteration of the variable in question whilst keeping other variables constant.

Annex B: data sources

Energy Greenhouse Gas Emissions

Hydrocarbon fossil fuels

Emissions factors for diesel, petrol, CNG, LNG and LPG have been sourced from the Government's Greenhouse gas reporting: conversion factors 2017 ('conversion factors 2017 – advanced' excel file). CNG values have been modified to reflect lower emissions of taking gas from the high pressure grid (where less electricity and therefore greenhouse gas emissions is required to compress the gas for use in vehicles). Methanol (which is assumed to produced using remote natural gas as a feedstock) emissions have been sourced from JRC WELL-TO-TANK Appendix 4 - Version 4a.

Electricity and hydrogen

Electricity emissions factors have been sourced from the Government's Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal (data table 1). In line with the guidance, we have used the 'long run marginal' emissions factor to assess changes to electricity demand resulting from electric vehicle use. For consistency, a 15% uplift factor has been added to these values to reflect fossil fuel production emissions (i.e. emissions associated with the production of coal or gas used for electricity generation).

Hydrogen emissions factors are based upon values taken from JRC WELL-TO-TANK Appendix 4 - Version 4a. However, these have been modified to reflect UK electricity grid emissions where electricity is used in hydrogen production and distribution (e.g. hydrogen produced from electrolysis of water).

Biofuels

Emissions factors for first generation biofuels have been based upon historical Renewable Transport Fuel Obligation data (from year 4b onwards - RTFO_05_C&S_data table). Emissions factors for advanced biofuels have been taken from the Renewable Energy Directive Annex V, part D.

Biofuel Blending Assumptions

Biofuel blending assumptions have been set in line with blending trajectories set out in the recent Renewable Transport Fuel Obligation consultation and Government response (the central scenario from the cost benefit analysis).

Biomethane blending levels (into the gas grid) have been calculated using data from the Digest of UK Energy Statistics (biomethane supply volumes appear in tables 6.1, 6.2, and 6.3 as a “transfer out”).

Vehicle energy consumption

Medium car and panel van

MJ/km energy consumption values for diesel, petrol, electric, hydrogen and hybrid cars have been based on numbers taken from the ECCo model (Element Energy) with some adjustments based on analysis of testing data and feedback received at stakeholder workshops.

CNG, LPG and methanol energy consumption values have been set in line with petrol as they also use a spark ignition engine.

A ‘real world’ uplift of 35% (internal combustion vehicles) and 40% (electric and hydrogen fuel cell vehicles) was added to energy consumption values for internal combustion engine cars in order to reflect the difference test cycle (NEDC) and real world driving conditions. A 40% uplift was applied to electric and hydrogen vehicles for the same reason.

18 tonne HGV

Diesel and CNG energy consumption values have been taken from Government funded vehicle testing (table 6). In the absence of data, electric and hydrogen fuel cell values have been approximated by applying conversion factors to the diesel energy consumption value.

44 tonne HGV

Diesel and gas (CNG and LNG) energy consumption have been derived using data taken from Government funded vehicle testing (table 6). Additionally, the ‘high efficiency’ scenario for gas vehicles has been developed using data provided by gas industry representatives.

Electric tonne HGV assumptions has been developed using data received from representatives of companies currently working on testing electric HGVs. Hydrogen fuel cell values have been developed by applying a conversion factor (representing fuel cell efficiency) to the values for electric HGVs.

Double deck bus

Data on bus energy consumption has been taken from the low emission bus certification scheme.

Nitrogen oxides (NO_x) and particulate matter (PM) emissions

Medium car

COPERT v5.0 values NO_x and PM emissions factors have been used for diesel, petrol, CNG and LPG vehicles. Hybrid and plug-in hybrid values have been taken from Government commissioned research (unpublished). Methanol values have been set in line with petrol.

Panel van

Where possible COPERT v5.0 values NO_x and PM emissions have been used for diesel and petrol vehicles. Hybrid and plug-in hybrid values have been taken from Government commissioned research (unpublished). CNG, LPG and methanol values have been set in line with petrol.

18 tonne HGV

COPERT v5.0 values NO_x and PM emissions have been used for diesel vehicles. Government funded vehicle testing (table 5) data has been used for NO_x emissions from CNG vehicles.

44 tonne HGV

COPERT v5.0 values NO_x and PM emissions have been used for diesel vehicles. Government funded vehicle testing (table 5) data has been used for NO_x emissions from CNG vehicles.

Double deck bus

COPERT v5.0 values NO_x and PM emissions have been used for diesel vehicles. Diesel hybrid NO_x and PM emissions have been set in line with standard diesel vehicles. Data on gas bus NO_x emissions have been taken from the low emission bus certification scheme.

Nitrous oxide (N_2O) emissions

N_2O emissions factors have been taken from the European Emissions Agency air pollutant emissions inventory guidebook (table 3.64).