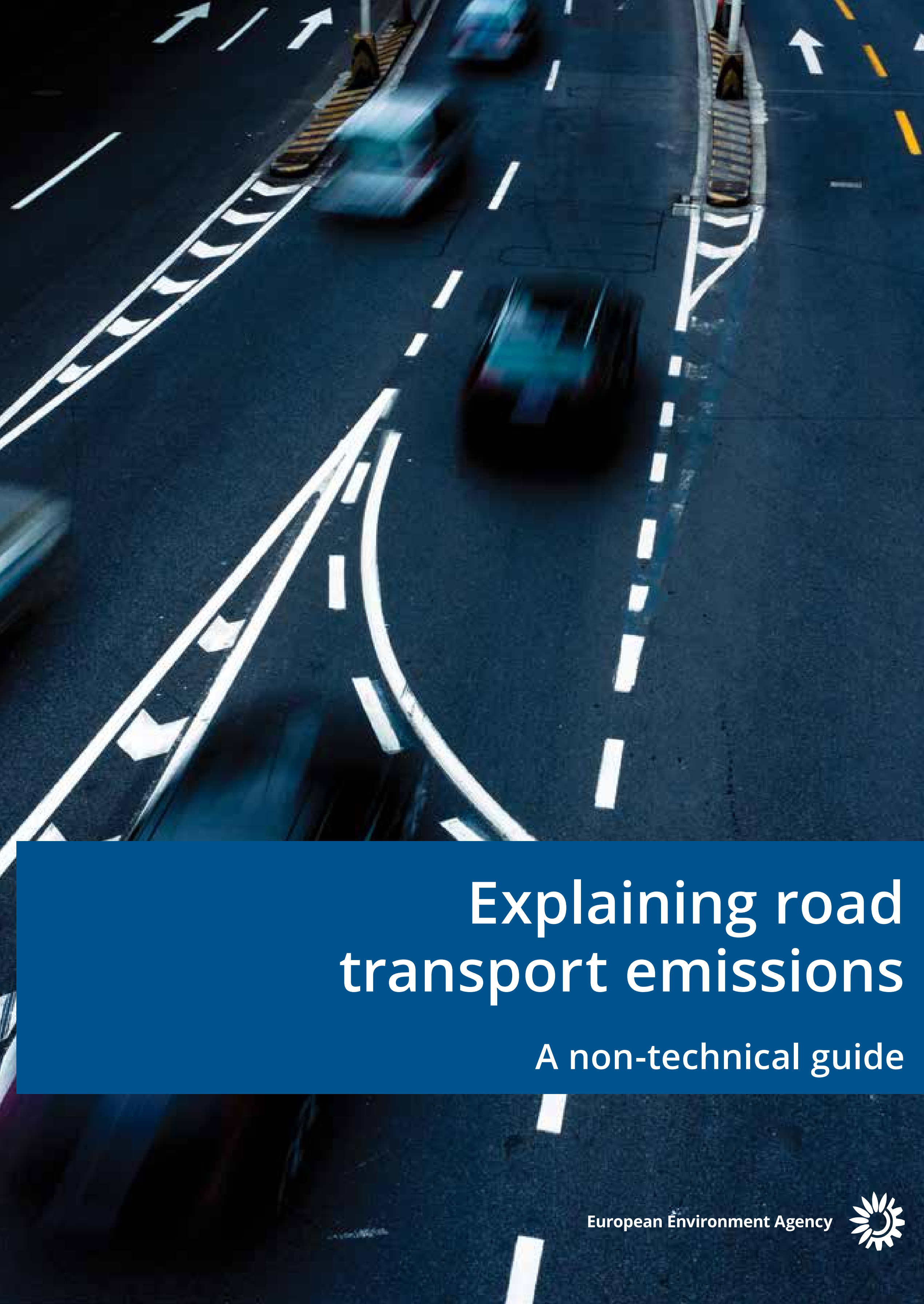

Explaining road transport emissions

A non-technical guide

European Environment Agency

Cover design: Formato Verde
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CONTENTS

Reading this report

This report provides a summary of the current knowledge on vehicle emissions in Europe. It also explains how emissions are monitored and the common technologies used to limit them.

The report is organised as follows:

- The first four sections provide a non-technical description of how vehicle emissions occur and how they are tested, and the reasons for the differences observed between tested and real-world driving emissions.
- The next two sections present a more detailed summary of the testing procedures used for estimating vehicle emissions, as well as the technologies that are currently in place for their reduction.
- The final section provides additional sources of information for consumers, researchers and policymakers.

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Why limit emissions from road transport?

Road transport is an important source of both greenhouse gases and air pollutants. Despite improvements in vehicle efficiencies over past decades, today the sector is responsible for almost one fifth of Europe's greenhouse gas emissions. Emissions from vehicles also lead to high concentrations of air pollutants above EU standards in many of Europe's cities.

Transport, and in particular road transport, delivers many benefits to our society. It allows the movement of people and goods, it supports economic growth and it provides employment. However, despite these benefits and the many technological and efficiency improvements achieved over the past decades, the road transport sector is still a major contributor to Europe's emissions of greenhouse gases (GHGs) and air pollutants. While poor air quality and climate change are very different phenomena, each harms human health, the environment or both. Such harmful impacts caused by road transport pollution cause real economic costs to society.

Good progress has been achieved over the past 25 years in limiting exhaust emissions of many pollutants from road transport. These achievements have resulted from a combination of policies and measures, such as setting technological standards for vehicle emissions and fuel quality, legislation establishing air quality limits, and measures implemented at the local level to manage transport use, such as improved transport planning and public transport incentives.

Nevertheless, the overall increases in passenger and freight demand, as well as the under-performance of certain vehicle standards under real-life driving conditions, has meant that emission reductions over recent decades have not always been as large as originally planned.

This report provides a non-technical summary of the sometimes scattered and often very complex information available concerning road transport emissions. It provides a summary of the current knowledge on vehicle emissions, how they are monitored and the common technologies used to control them. In addition, information on the following is included:

- how vehicle emissions are measured according to European Union (EU) legislation;
- the reasons for the differences observed in certain pollutants between emissions monitored according to legislative tests and real-world driving emissions;
- key policy implications of such differences.

Impacts on health and the environment

Greenhouse gases

While GHG emissions from all other main sectors of the economy have fallen in recent decades, those from transport have increased. Road transport GHG emissions are today around 16 % above the levels in 1990. As emissions from other sources have decreased, the contribution that road transport makes to total EU emissions has increased by around half — from a 13 % share in 1990 to almost 20 % share in 2013.

Air pollution

Air pollution can be defined as the presence of pollutants in the atmosphere at levels that harm human health, the environment and/or cultural heritage (e.g. by damaging buildings, monuments and materials). Identifying the relationship between emissions of air pollutants, their concentrations in the air and their subsequent impacts is complex. The quality of the air that each of us breathes depends on many factors, including the mix of emission sources in a given area, the local landscape and meteorology, all of which can affect the formation and the dispersion of the pollutants.

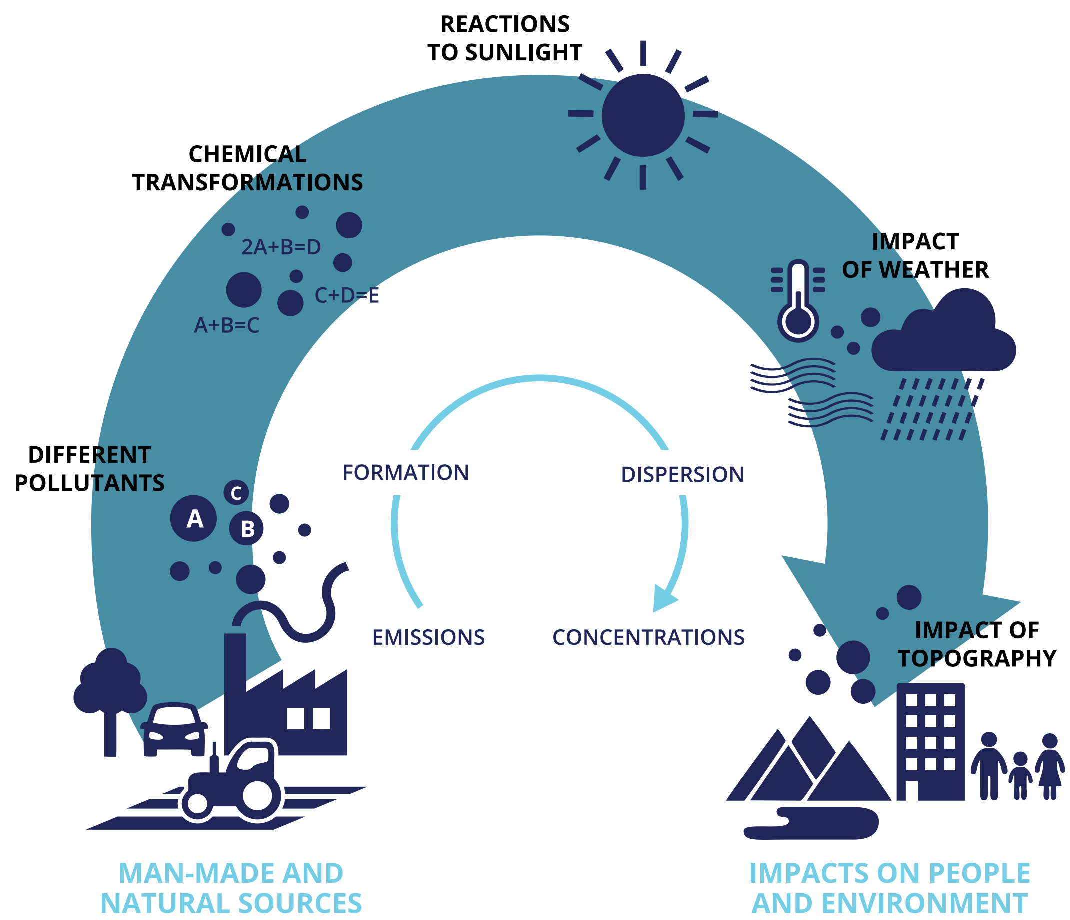
Road transport remains an important source of some of the most harmful air pollutants. In particular, road transport is responsible for significant contributions to emissions of nitrogen oxides (NO_x) and particulate matter (PM). Pollution released by vehicles is particularly important, as emissions generally occur in areas where people live and work, such as cities and towns. Therefore, although emissions from the transport sector may not be as great in absolute terms as those from other sources, population exposure to the pollutants released by road transport can be higher than for sources such as power plants or large industrial facilities, which often tend to be located in remoter, less populated areas.

In contrast to GHG emissions, emissions of the main air pollutants from transport have generally declined over the past two decades. However, the latest air quality assessment published by the European Environment Agency (EEA) reveals that a significant fraction of the European urban population was exposed to air pollution levels exceeding EU air quality standards over recent years (EEA, 2015a). For example, the EU annual limit value for nitrogen dioxide (NO_2), the harmful component of NO_x, is still widely exceeded across Europe, mainly at roadside locations. Similarly, a number of Member States report levels of PM higher than the respective EU air quality standards.

To reduce the negative effects on air quality caused by road transport emissions, EU emission standards for exhaust emissions have become increasingly stringent over the past decades for both light- and heavy-duty vehicles. Vehicle manufacturers have subsequently achieved compliance with the decreasing emission limits, mainly by introducing technological solutions, in particular through the gradual implementation of enhanced emission-control technologies such as exhaust catalysts.

Air pollution: from emissions to exposure

Poor air quality is a serious health and environmental problem. Certain harmful air pollutants are emitted directly from vehicles, such as 'primary' particulate matter (PM) and nitrogen oxides (NO_x). Others, such as ozone and 'secondary' PM, form in the atmosphere after emissions of precursor pollutants, including NO_x and volatile organic compounds. Different sources of pollution, including transport and non-transport sources, emit different types and ratios of pollutants. The extent to which the population and environment are exposed to harmful levels of air pollution is a complex issue, dependent on how pollutants travel in the atmosphere, their mixing and how they react under different meteorological conditions. Road transport emissions are, relatively, more harmful than those from other sources, as most emissions tend to occur in areas where people live and work, such as cities and towns.



Road transport contributes about 23 % of the EU's total emissions of carbon dioxide.

More than 30 % of NO_x emissions in the EU come from road transport.

Around 12 % of the EU's primary $PM_{2.5}$ emissions come from road transport.

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Pollutants emitted by vehicles

Road vehicles emit a variety of greenhouse gases and air pollutants. As well as being emitted from vehicle exhausts, certain pollutants are also released from brake wear and from the evaporation of fuel.

A number of different air pollutants and GHGs are emitted by road vehicles. These can be split into two groups: those that are regulated under EU road transport legislation and those that presently are not.

The 'regulated' pollutants include:

Carbon dioxide (CO_2), which is the main product of fuel combustion in vehicle engines, along with water. CO_2 is the most significant GHG influencing climate change, posing a threat to public health and the environment.

Hydrocarbons (HCs), which are produced from either incomplete or partial combustion and which are toxic to human health. HCs, and particularly the volatile organic compounds (VOCs), contribute to the formation of ground-level ozone and photochemical smog in the atmosphere. Ozone irritates the eyes, damages the lungs and aggravates respiratory problems.

Carbon monoxide (CO), a product of incomplete combustion, which occurs when the carbon in the fuel is only partially oxidised, forming CO and not CO_2. It is colourless and odourless but highly toxic. Direct exposure to CO reduces the flow of oxygen in the bloodstream and is particularly dangerous to people with heart disease. Like HCs, CO also contributes to the formation of ground-level ozone and smog.

Particulate matter (PM), which is a product of incomplete combustion and a complex mixture of both primary and secondary PM. 'Primary' PM is the fraction of PM that is emitted directly into the atmosphere, whereas 'secondary' PM forms in the atmosphere following the release of precursor gases (mainly sulphur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3) and some VOCs). In terms of its potential to harm human health, PM is one of the most important pollutants, as it penetrates into sensitive regions of the respiratory system and can cause or aggravate cardiovascular and lung diseases and cancers.

Nitrogen oxides (NO_X) (see also box on nitrogen emissions from motor vehicles), which constitute a group of different chemicals that are all formed by the reaction of nitrogen — the most abundant gas in air — with oxygen. NO_X comprises colourless nitric oxide (NO) and the reddish-brown, very toxic and reactive nitrogen dioxide (NO_2). NO_X emissions also lead to the subsequent formation of 'secondary' PM and ground-level ozone in the atmosphere, and cause harm to the environment by contributing to the acidification and eutrophication of waters and soils.

Pollutants emitted by vehicles that are not currently regulated by vehicle emission standards in the EU include: **certain acidifying pollutants**, such as NH_3 and SO_2 (although emissions of the latter are indirectly addressed via fuel quality legislation, which limits the amount of sulphur permissible in fuels); certain **carcinogenic and toxic organic pollutants**, such as polycyclic aromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), dioxins and furans; and **heavy metals**, such as lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium and zinc.

Types of vehicle emissions

Vehicles emissions can be categorised into three groups:

Exhaust emissions — the emissions produced primarily from the combustion of different petroleum products such as petrol, diesel, natural gas (NG) and liquefied petroleum gas (LPG). These fuels are mixtures of different hydrocarbons, i.e. compounds that contain hydrogen and carbon atoms. In a 'perfect' engine, oxygen in the air would react in a combustion process with all of the hydrogen in the fuel to form water and with all of the carbon in the fuel to form CO_2, and the nitrogen in the air would remain unaffected. In reality, no combustion process is 'perfect'; thus, vehicle engines emit many different pollutants in addition to water and CO_2. The amount of each pollutant emitted is very dependent on the type of fuel used, e.g. whether a vehicle is diesel or petrol powered, and engine technology.

Abrasion emissions — the emissions produced from the mechanical abrasion and corrosion of vehicle parts. Abrasion is only important for PM emissions and emissions of some heavy metals. Significant levels of PM emissions can be generated from the mechanical abrasion of the vehicle's tyres, brakes and clutch, the road surface wear or the corrosion of the chassis, bodywork and other vehicle components.

Evaporative emissions — the result of vapours escaping from the vehicle's fuel system. Evaporative emissions are important for only VOCs. Petrol fuel vapour contains a variety of different HCs, which can be emitted any time there is fuel in the tank, even when the vehicle is parked with its engine turned off.

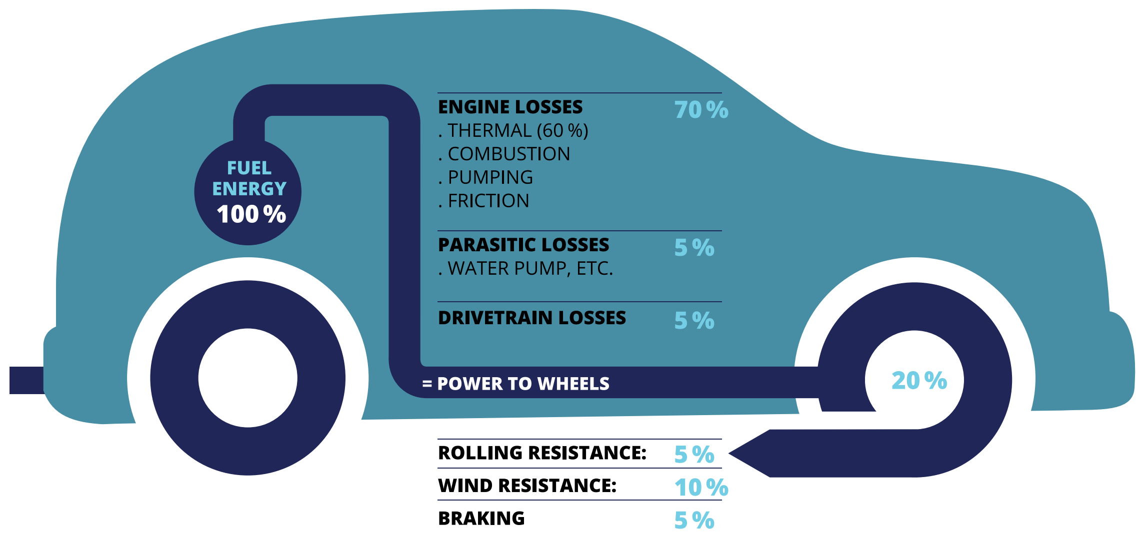
Nitrogen emissions from motor vehicles

Nitrogen oxides (NO_x) are produced when fuel is combusted in the engine in the presence of air. NO_x comprises a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2). NO is not harmful to health at the concentrations typically found in the atmosphere. However, in contrast, NO_2 is associated with a range of environmental and health problems. The proportion of harmful NO_2 in the NO_x emissions of a diesel vehicle is far higher than the proportion found in the emissions of a conventional petrol vehicle. In older diesel engines, approximately 95 % of NO_x emissions were NO and only 5 % were NO_2. For new diesel passenger cars, both engine size and exhaust aftertreatments (e.g. catalytic converters) affect the level of NO_2 emissions: the NO_2 to NO_x ratio can vary from 12 % to 70 % (EEA, 2013).

Some catalytic converters may also, while significantly reducing the emissions of carbon monoxide, NO_x and hydrocarbons, produce other nitrogen-containing pollutants such as NH_3 and the GHG nitrous oxide (N_2O). The road transport emissions of both these pollutants, although relatively small, have increased since 1990 as a result of the increased use of three-way catalytic converters. These release NH_3 as a by-product. However, NH_3 emissions have fallen since 2000, and are projected to fall further in the future as the second generation of catalysts — which emit lower levels of NH_3 than the first generation of catalysts — become more widely used in the vehicle fleet.

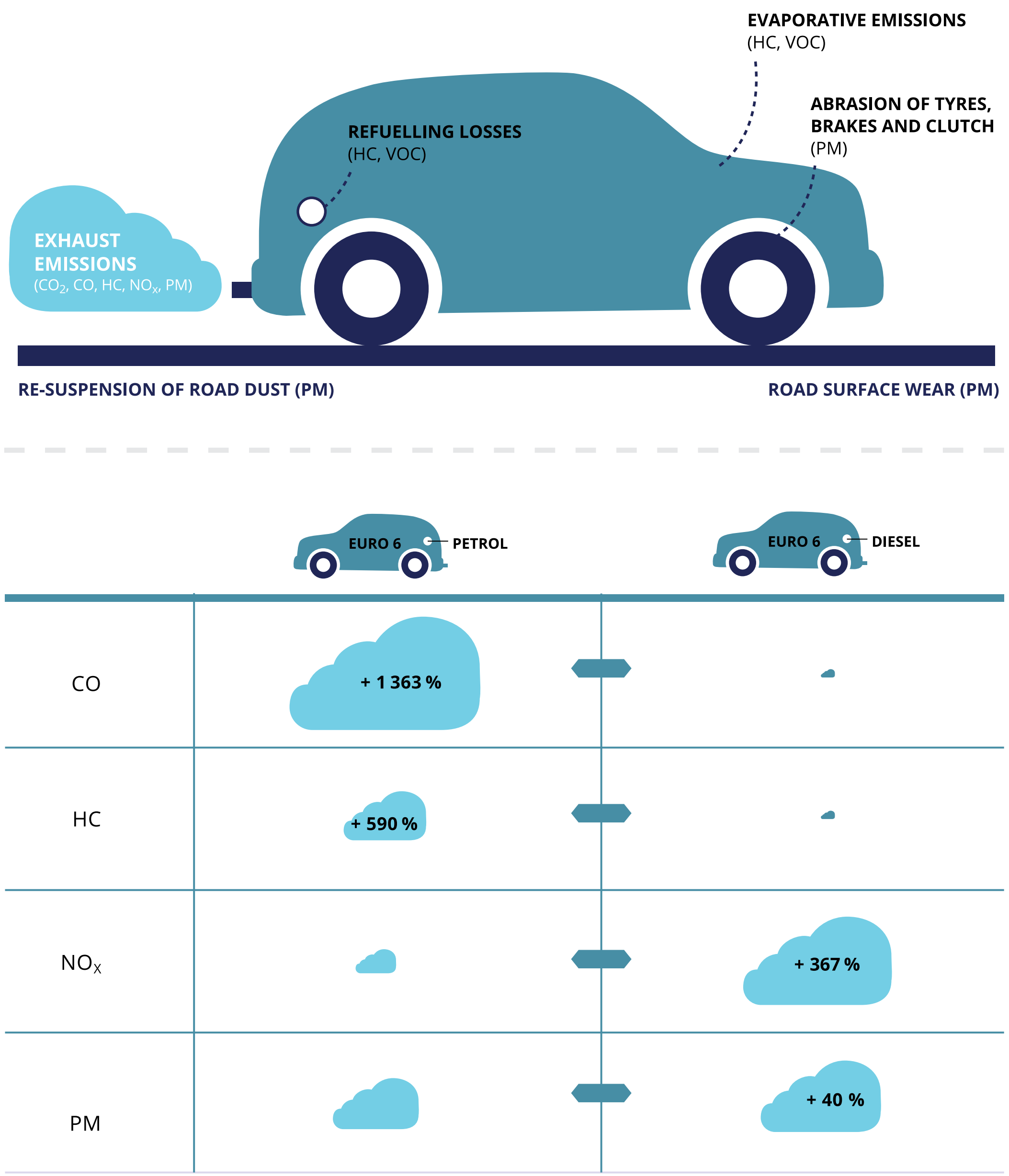
Vehicle emissions and efficiency

In a conventional vehicle, only about 18 to 25 % of the energy available from the fuel is used to move it on the road, depending on the driving conditions. The rest of the energy is lost to engine and drivetrain [1] inefficiencies. A small proportion of the energy produced is used to power vehicle accessories (e.g. radio, air conditioning). Therefore, the potential to further improve fuel efficiency using advanced technologies remains significant. While newer diesel engines remain more fuel efficient than petrol engines, their impact on air pollution is worse because of the higher levels of NO_x and PM that they emit.



(1) The drivetrain of a motor vehicle is the group of components that deliver power to the driving wheels. This includes the transmission, the axles and the wheels.

The different types of emissions from vehicles, and a comparison of the relative amounts of selected pollutants released by the latest Euro 6 petrol and diesel vehicles

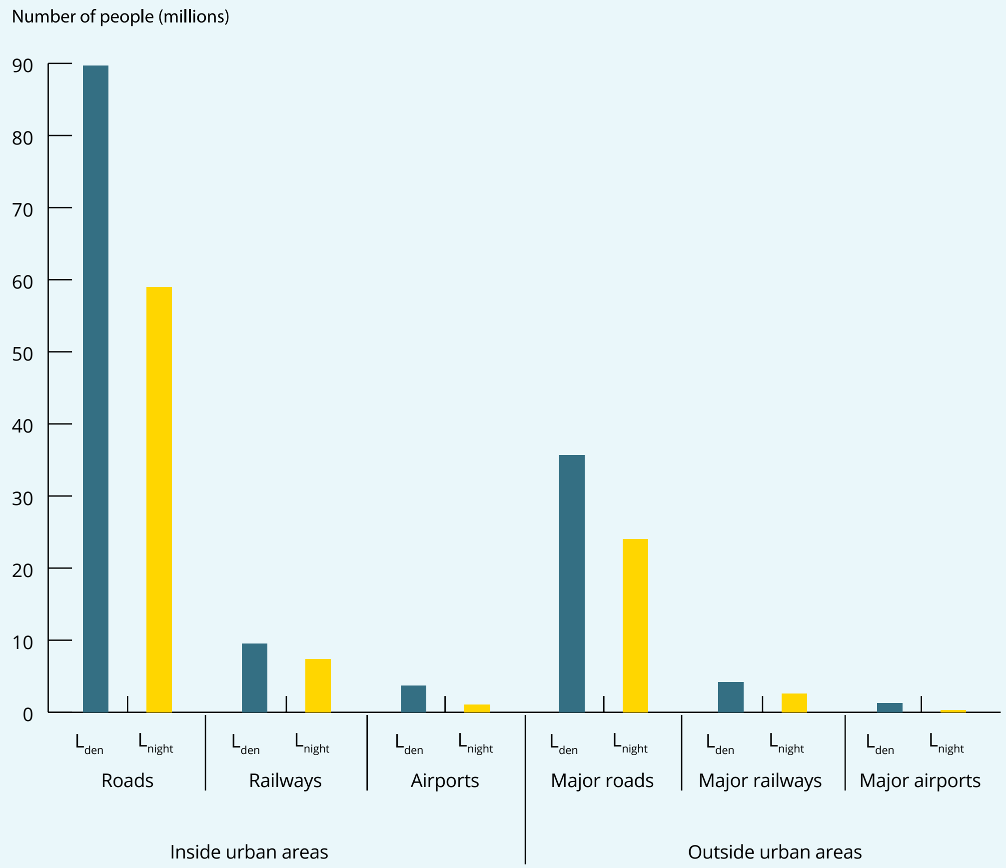


Source: Based on www.fueleconomy.gov.

Noise from road transport

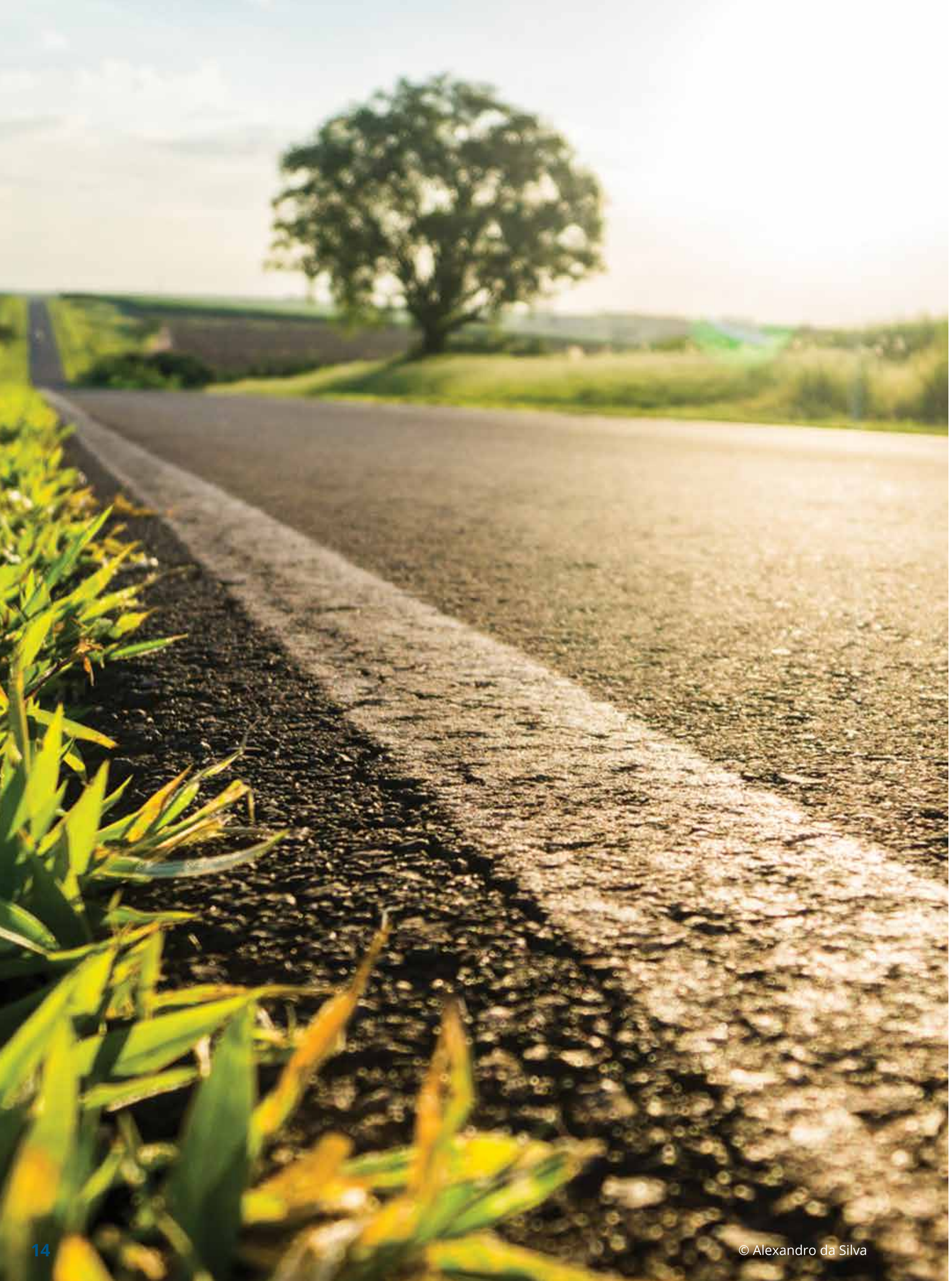
Road traffic is, by far, the greatest source of traffic noise in Europe, both inside and outside urban areas. High levels of noise harm human health and well-being. Two of the main indicators used for monitoring noise levels are L_{night} and L_{den} (day–evening–night). L_{night} is the average sound level measured overnight between 23.00 and 07.00. L_{den} is a weighted noise level measured over a 24-hour period, with a decibel penalty being added to night time noise levels; these penalties reflect people's greater sensitivity to noise during the night and the evening.

Exposure to high levels of noise from road transport is a major concern. In 2012, almost 90 million people living in cities were exposed to long-term average road traffic noise levels exceeding 55 dB L_{den}. At night time, over 83 million people were exposed to road noise levels exceeding 50 dB. On major roads outside urban areas, around 35 million people were affected by high levels of noise during the day time and 24 million people at night (EEA, 2014a).



Recently, new legislation limiting the sound levels allowed from motor vehicles and of replacement silencing systems was adopted (EU, 2014a). Its main elements are:

- new international testing methods to better reflect driving behaviour;
- limit values for passenger cars, buses and light trucks, and for heavy-duty vehicles;
- additional sound emission provisions in the vehicle type approval procedure and revision of existing derogations for certain vehicle types;
- a minimum noise level ('Approaching Vehicle Audible Systems') for electric and hybrid electric vehicles;
- requiring provision of information on noise levels at vehicle dealerships.



Regulating vehicle emissions in the European Union

Over the last 25 years, Europe has put in place a number of policies to reduce the emissions of greenhouse gases and air pollutants from vehicles.

Carbon dioxide emissions

The EU is committed to reducing fuel consumption from road vehicles in the effort to reduce GHG emissions from transport and improve energy security. To this end, two important regulations have been introduced in recent years for new passenger cars and new light commercial vehicles (vans) sold in Europe. In 2009, an EU Regulation was agreed (EU, 2009) that established mandatory annual targets for average CO_2 emissions from new passenger cars sold in Europe. New cars registered in the EU-28 must achieve an average emissions target of 130 grams of CO_2 per kilometre (g CO_2/km) by 2015. A medium term target has also been established: by 2021, phased in from 2020, the average emission to be achieved by all new cars is 95 g CO_2/km.

Following the legislation for cars, two years later, a separate Regulation was introduced setting targets for vans (EU, 2011). New vans registered in the EU must meet an average emissions target of 175 g CO_2/km by 2017. For 2020, the target is 147 g CO_2/km.

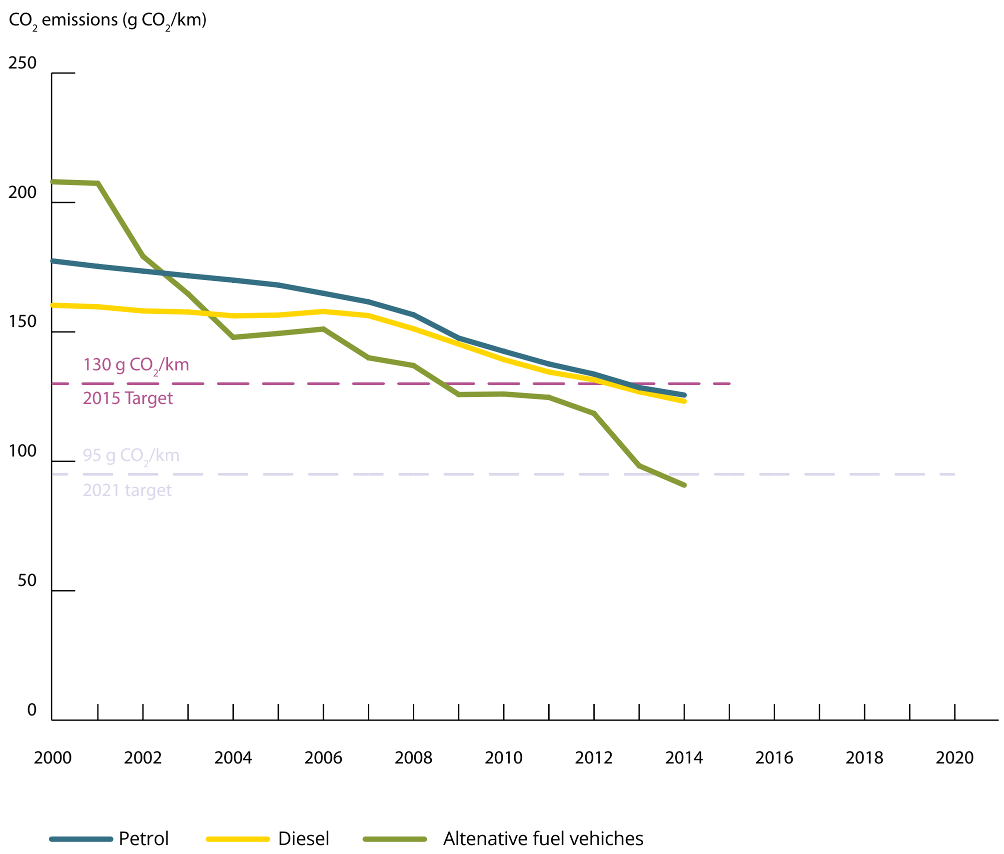
The data that EU Member States have reported to the EEA and the European Commission, based on standardised laboratory emission tests, show that CO_2 emissions from new passenger cars have steadily decreased since 2000. As a result, new cars sold in 2013 already met their CO_2 target ahead of the 2015 deadline (EEA, 2015b). As observed for passenger cars, official CO_2 emissions from vans have also decreased over the last three years and already met their 2017 target in 2013 — four years ahead of the deadline.

Air pollutants

Since the 1970s, the key mechanism by which vehicle air pollutant emissions have been regulated has been through the setting of exhaust emission limits. As with CO_2 measurements, vehicle conformance with the required limits is checked on the basis of standardised laboratory emission measurements. The first European Council Directive that specified measures against air pollution from motor vehicles was in 1970 (EU, 1970). Around 20 years later — in 1992 — the 'Euro' emission standards were introduced, starting with the 'Euro 1' step, followed, generally, by successively stricter standards: Euro 2 to Euro 6. At present, in 2016, only Euro 6 vehicles can be sold in the EU.

The increasingly tighter emission limits have led to the introduction of new vehicle technologies, and there have consequently been some significant reductions in vehicle emissions in Europe over the last 40 to 45 years. As an example, the latest technology Euro 6 diesel car must emit almost 97 % less PM when tested than a 20 year older Euro 1 vehicle.

Change in officially reported CO_2 emissions from new petrol, diesel and alternative fuel passenger cars sold in the EU



Note: The value for alternative fuel vehicles includes pure electric, liquefied petroleum gas (LPG), natural gas (NG), ethanol (E85), biodiesel, and plug-in hybrid vehicles.

Source: EEA, 2015b.

Emission limits (g/km) of the successively introduced Euro emission standards for passenger vehicles

Diesel	Date	CO	NMHC	NO_x	HC + NO_x	PM	PN
Euro 1	July 1992	2.72	–	–	0.97	0.14	–
Euro 2	January 1996	1.0	–	–	0.7	0.08	–
Euro 3	January 2000	0.64	–	0.50	0.56	0.05	–
Euro 4	January 2005	0.50	–	0.25	0.30	0.025	–
Euro 5a	September 2009	0.50	–	0.180	0.230	0.005	–
Euro 5b	September 2011	0.50	–	0.180	0.230	0.005	6.0×10^{11}
Euro 6	September 2014	0.50	–	0.080	0.170	0.005	6.0×10^{11}
Petrol	**Date**	**CO**	**NMHC**	**NO_x**	**HC + NO_x**	**PM**	**PN**
Euro 1	July 1992	2.72	–	–	0.97	–	–
Euro 2	January 1996	2.2	–	–	0.5	–	–
Euro 3	January 2000	2.3	–	0.15	–	–	–
Euro 4	January 2005	1.0	–	0.08	–	–	–
Euro 5	September 2009	1.0	0.068	0.060	–	0.005	–
Euro 6	September 2014	1.0	0.068	0.060	–	0.005	6.0×10^{11}

Notes: NMHC, non-methane hydrocarbons; PN, particle number.

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How are vehicle emissions measured?

Testing vehicle emissions is complex. Standardised measurements in laboratories are used to check that vehicles meet the official requirements for exhaust emissions. However the official procedures currently used in Europe are not representative of real driving conditions. This problem has led to the development of new measurement procedures as well as portable emission measurement systems to obtain better information on real driving emissions.

Measuring emissions under European Union legislation

According to Europe's laws, before being sold, vehicles must be tested to verify they are compliant with the required environmental, climate, safety and security standards. As it is not practical to test every single vehicle, one production vehicle is tested — with this vehicle considered representative of the 'type' — and, if all standards are respected, 'type approval' documentation is issued. In Member States, type-approval authorities have been granted responsibility for all aspects of the approval of a type of vehicle. This includes issuing and withdrawing approval certificates, as well as appointing the technical laboratory services that run the tests and verify whether the vehicles conform to the relevant European legislation.

As part of the testing, all light-duty vehicles — whether passenger car, light commercial vehicle, moped or motorcycle — have to be tested on a 'chassis dynamometer', also known as a roller bench. A chassis dynamometer is designed to operate a vehicle indoors on a stationary platform to simulate real-world vehicle operation. The vehicle is driven on rollers, following a predefined driving pattern, with the dynamometer simulating the inertia of the vehicle, as well as the air drag resistance and the friction on the vehicle (known as the 'road load'). The level of resistance on the dynamometer is adjusted for each specific vehicle tested to simulate the level of resistance that the vehicle would encounter if operated on the road, including:

Vehicle aerodynamic resistance, a factor affected by the vehicle's size and shape, which determines how much air the vehicle has to push out of the way as it moves — the more resistance there is, the more energy has to be expended;

Tyre rolling resistance, a factor related to tyre design that determines how much energy the vehicle has to use to overcome the resistance caused by the interaction between the tyres and the road.

To set the road load and to properly reflect the actual vehicle characteristics, an initial 'coast-down' test procedure is first performed. The coast-down test consists of coasting the vehicle from a certain speed outside of the laboratory with the engine ungeared, while simultaneously recording the speed and the travelled distance until it stops. The test allows the values of the resistant forces acting on the vehicle at certain speeds, as well as the road conditions, to be evaluated, so that they can be reproduced in the laboratory when the vehicle is subsequently tested on a chassis dynamometer.

To determine its emissions and fuel consumption, each vehicle follows a pre-defined 'driving cycle' on the chassis dynamometer. 'Driving cycles' are pre-defined cycles of accelerations, gear changes, steady speeds, decelerations and idling. A trained driver is employed to follow the driving cycle on the chassis dynamometer within defined tolerances.

While the vehicle is being driven on the roller bench, all emissions from the vehicle tailpipe are collected in sealed bags and subsequently analysed. The emission results, measured in grams of pollutant per kilometre driven, are then determined.

Emission levels primarily depend on vehicle-related factors such as model, size, road-loads, fuel type and technology. In addition to the vehicle configuration, the driving dynamics — including vehicle speed, acceleration, idling time and gear selection — have a very significant effect on emissions. Hence, the type of standardised driving cycle used for testing is an important factor in determining vehicle emissions.

A vehicle being tested on a roller bench

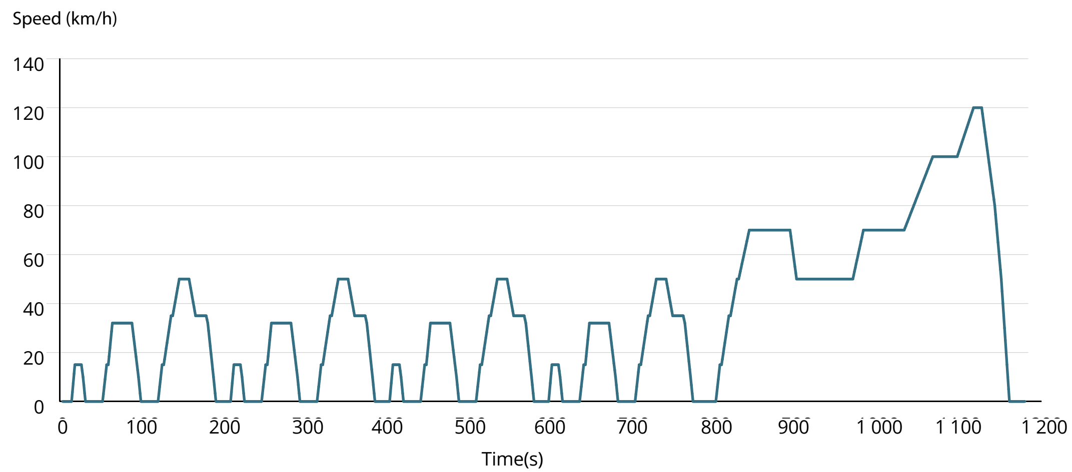
To measure its evaporative emissions, the car is placed into a completely sealed chamber, called a Sealed Housing for Evaporative Determination (SHED). The SHED is equipped with a heating/cooling system for temperature control in the chamber and uses software and analytical equipment to determine the level of evaporative HC emissions of the vehicle.

The current European Union type approval driving cycle

The New European Driving Cycle (NEDC) is presently used under EU legislation for assessing the emissions and fuel economy of light-duty vehicles during type approval. It was first introduced in 1970 to represent typical driving conditions of busy European cities; it was then updated in 1990 in an attempt to better represent more demanding, high-speed driving modes. The NEDC now consists of an urban and an extra-urban driving part. The NEDC speed profile, which shows the speed of the vehicle during the test, is illustrated below.

The NEDC was originally developed when vehicles were lighter and less powerful than those available today. For these reasons, the test involves only a simple speed pattern with low accelerations, constant speed and many idling events that typically under-load modern day engines. Nowadays it is widely accepted that the NEDC is outdated, with much evidence available from the scientific community and vehicle users clearly showing that the emission values and fuel consumption measured in the laboratory largely understate the actual levels obtained under real-world driving conditions. This difference occurs for a variety of reasons, including deficiencies of the NEDC testing procedure itself, but also due to certain deficits in the associated measurement protocols. These issues are explained and discussed in the next chapters.

Speed profile of the NEDC driving cycle



Source: GFEI, 2015.

Test cycles designed to better reflect real-world driving

Because of the known deficiencies of the NEDC, a number of alternative driving cycles have been developed in Europe and elsewhere for research purposes and to inform policy development where improved knowledge of real-world driving emissions is needed. One such example is the Common Artemis Driving Cycles (CADC), that are frequently used in Europe to provide information on 'real-world' emissions necessary for modelling actual road transport emissions. The development of these alternative driving cycles has been based on statistical analysis of a large database of European real-world driving patterns. The cycles include three driving schedules: urban, rural road and motorway. Results of vehicle emission measurements tested using CADC are incorporated in real-world road transport emission models, such as the COPERT model (see the box page 31 on COPERT model).

Compared with the NEDC, the CADC is considered much more dynamic, with higher average and maximum speeds, more accelerations and braking, less driving at constant speed and less idling. As a result, CADC imposes a higher and more realistic load on the car engine. The following table shows a comparison of the main characteristics of NEDC and CADC driving cycles.

Comparison of NEDC and CADC driving cycle characteristics

Characteristic	Unit	NEDC	CADC
Distance	km	10.931	50.886
Total time	s	1180	3143
Idle (standing) time	s	267	230
Average speed	km/h	33.35	58.3
Maximum speed	km/h	120	130
Cruising	%	38.8	19.3
Accelerating	%	23.6	38.8
Decelerating	%	17.3	34.5
Braking	%	16.9	21.1
Idling	%	20.4	7.32

Other legislative driving cycles

In addition to the European NEDC, other driving cycles have been developed and are used in different parts of the world to determine fuel economies and pollutant emissions (GFEI, 2015).

United States Environmental Protection Agency test cycles

Federal Test Procedure (FTP)-75 is used for emission certification and to determine the fuel economy of light-duty vehicles in the USA. Since 2000, vehicles have also had to be tested on two Supplemental Federal Test Procedures (SFTP) designed to address shortcomings with the original FTP-75 in representing demanding, high-speed driving and the use of air conditioning.

Australian test cycles

The Composite Urban Emissions Drive Cycles (CUEDCs) was commissioned by the Australian National Environment Protection Commission in 1998 as part of the Diesel National Environment Protection Measure. CUEDCs were created with the intention of closely replicating actual Australian on-road urban driving. CUEDCs are used for chassis-based dynamometer testing of both heavy and light vehicles. They are composed of four distinct drive cycle segments for describing different driving conditions: congested, minor roads, arterial and highway.

Japanese test cycles

The Japanese 2005 emission regulation introduced a new chassis dynamometer test cycle (JC08) for light vehicles (< 3 500 kg gross vehicle weight). The test represents driving in congested city traffic, including idling periods and frequently alternating between acceleration and deceleration. Measurements are made twice, with a cold start and a warm start. The test is used for emission measurement and fuel economy determination for both petrol and diesel vehicles.

Example of a PEMS unit mounted on a car

Note: The vehicle shown in the figure is for illustrative purposes only and does not correspond to any of the test results shown in this report

To illustrate the importance of the chosen test cycle on the final measured emissions, it is possible to show the ratio between NO_x emissions measured on NEDC and the more representative CADC cycles (see following figure). For both diesel and petrol vehicles, the CADC emissions are higher than the NEDC ones. Particularly for diesel vehicles, the ratio has greatly increased over time as the different Euro technologies have been implemented. For Euro 1 vehicles, NO_x emissions measured using the CADC cycles were already up to 40 % higher than the NEDC; by Euro 6 vehicles, NO_x emissions over the CADC cycles were almost five times higher than the corresponding NEDC measurements for diesel.

Measuring emissions on the road

It is possible to directly measure emissions from vehicles as they are driven on roads. A Portable Emissions Measurement System (PEMS) is a transportable measurement system containing a variety of instruments that can be carried on board a vehicle to monitor the real-time emissions of selected pollutants. As PEMS are specifically designed to measure emissions during the actual use of a car in its regular daily operation, they have to be small, lightweight and compact enough to fit into any vehicle size and be quick and easy to install.

PEMS is still a relatively new technology, but is considered rather simple and inexpensive to purchase and maintain compared with a chassis dynamometer. Its main limitations

Ratio of NO_x emissions measured on the NEDC and more representative CADC cycles for different vehicle Euro categories and engine technologies

Ratio CADC/NEDC	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
PETROL	1.07	1.38	1.88	1.62	1.96	1.50	n.a.
DIESEL	1.22	1.13	1.64	1.88	3.16	3.52	4.80

Source: INFRAS and TUG, 2015.

are the reduced range of pollutants that can be measured during a test compared with laboratory testing, as well as the mass (30–150 kg) it adds to the vehicle, which can affect the fuel consumption and hence measurements of the different pollutants. Furthermore, the lower repeatability of measurements encountered when testing, owing to real-world sources of variability, can be challenging to ensure consistency of measurements between different vehicles tested.

Findings from a European Commission study (JRC, 2011a) confirm that current laboratory emissions testing fails to capture the wide range of potential on-road emissions and that PEMS can assist in filling this gap.

Past PEMS results show for example that average NO_x emissions of diesel cars, for the then-latest technology Euro 5 cars, substantially exceeded the Euro 5 emission limit by a factor of 4 to 7. By comparison, on-road NO_x emissions of petrol vehicles, as well as CO and HC emissions of both diesel and petrol cars generally, stay within their emission limits. NO_x emissions were found to be the highest during uphill–downhill driving (rural) and during motorway driving at high speeds, i.e. at higher engine loads. This also provides an indication that the exhaust aftertreatment devices (the devices responsible for controlling exhaust air pollutant emissions) are under-performing under these operating conditions.

CO_2 emissions tested with PEMS were also found to be higher (by 21 % on average) than laboratory tests for petrol and diesel cars. The magnitude of this discrepancy varies depending on vehicle type, operation mode, route characteristics and ambient conditions.

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The gap between real-world and test cycle emissions

For certain pollutants, there is a significant discrepancy between official emission measurements and real-world vehicle performance. This gap has increased over past years. For NO_x, the latest Euro 6 diesel vehicles can emit up to 7 times more in real-world conditions than in official tests. New vehicles similarly can emit up to 40 % more CO_2 under real driving conditions than official measurements would indicate. The reasons for this discrepancy include the outdated measurement procedure used to test vehicles, the optimisation of permitted flexibilities by manufacturers during vehicle testing, as well as differences in driver behaviour under real driving conditions.

Real-world emissions

Nitrogen oxides

Real-world NO_x emissions from petrol cars in the EU have decreased significantly since 2000, in line with the increasingly stringent emission limits. In significant contrast, the emissions from diesel cars have not improved much over the same period, meaning reductions from diesels have not been as large in reality as originally foreseen in legislation. For example, average real-world NO_x emissions of new Euro 5 diesel cars are of the same size as earlier Euro technologies and are even of a similar size as pre-Euro cars.

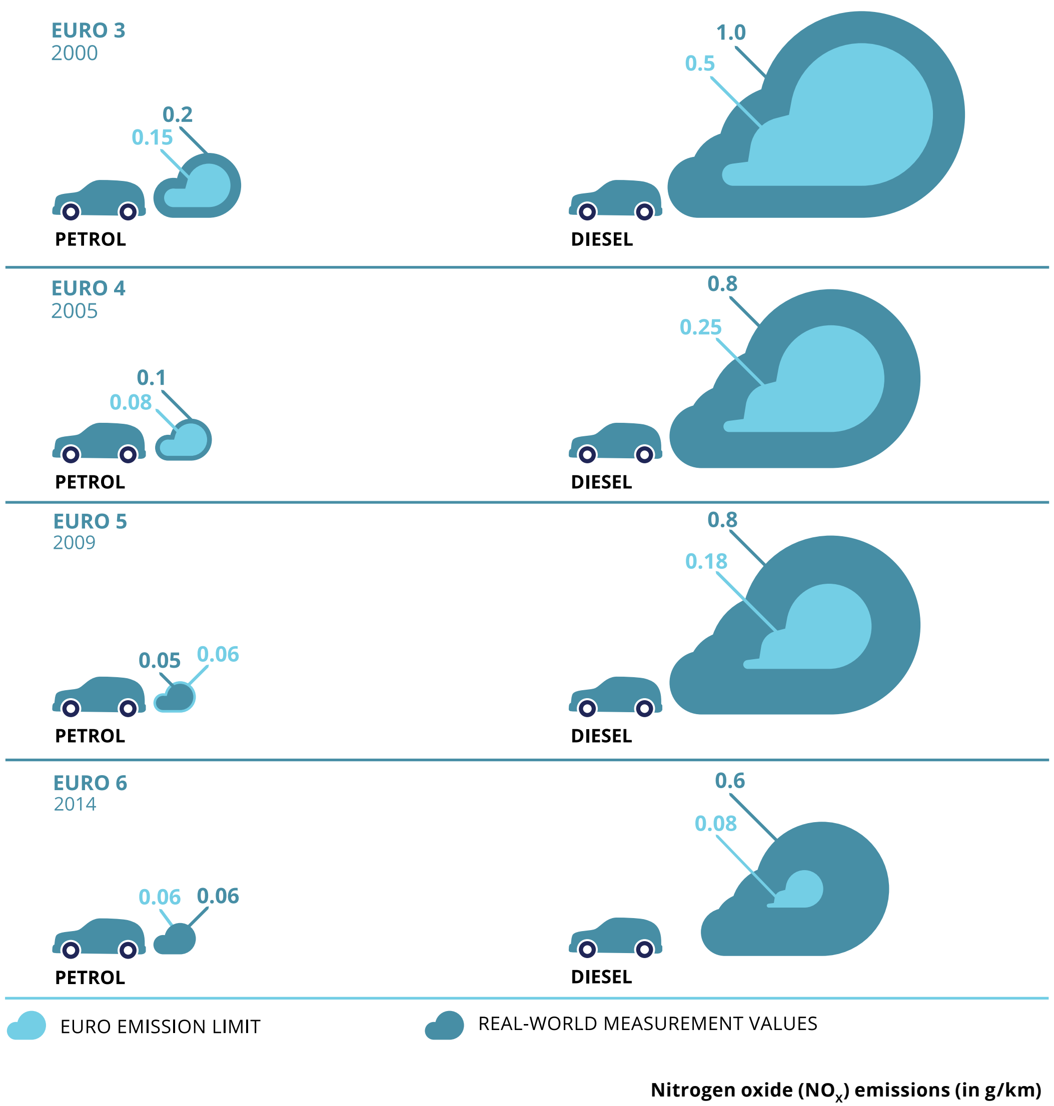
The lack of progress in reducing real-world NO_x emissions is especially notable, given that, until the very latest Euro 6 standards, diesel cars were already permitted to emit three times more NO_x than petrol cars.

A series of recent studies have provided evidence that even the latest Euro 6 diesel vehicles do not seem to perform much better, despite the tightening of the NO_x emission limit value from 180 to 80 mg/km. A study conducted on behalf of the Dutch Ministry of Infrastructure and Environment (TNO, 2013) found that Euro 6 vehicles produced around 500 mg NO_x/km in real-world driving, an amount very similar to that produced by the earlier Euro 4 and Euro 5 vehicles.

Similarly, a more recent study conducted by the International Council on Clean Transportation (ICCT, 2014c) based on on-road tests performed on the latest technology diesel Euro 6 cars found that, on average, real-world NO_x emissions were around 560 mg/km, or seven times higher than the limits set by the Euro 6 standard. Other similar findings have also been reported by other organisations, including the Association for Emissions Control by Catalyst (AECC) and Allgemeiner Deutscher Automobil-Club (ADAC) — Germany's largest automobile club.

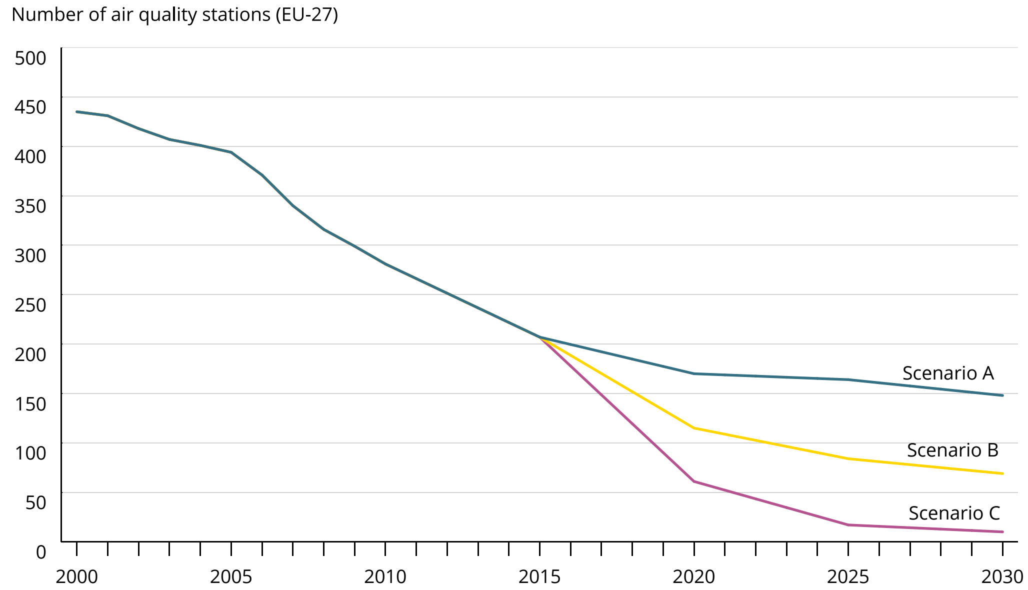
Quickly reducing NO_x emissions from diesel cars is very important in meeting European air quality targets. The chart on the following page shows the expected impact of the Euro 6 diesel NO_x emission standard on the number of exceedances of EU air quality limits. In principle, this shows that Euro 6 alone can significantly influence the future evolution of air quality in cities (at least in terms of NO_2) if all vehicles were just to deliver the required emission limits under real-world driving conditions (IIASA, 2012).

Comparison of NO_x emissions and standards for different Euro classes



Source: Adapted from: ICCT, 2014a; Emisia, 2015.

Different scenarios showing the reduced number of monitoring stations exceeding EU air quality NO_2 standards with different assumptions on the future effectiveness of Euro 6 passenger car NO_x standards



Notes:
- Scenario A: assumes that real-world emissions from Euro 6 diesel vehicles are only 30 % lower than those of the previous Euro 5 generation and thus deliver similar reductions to Euro 4 vehicles;
- Scenario B: assumes that Euro 6 vehicles are introduced in 2015, but only deliver the same emission reduction as the ratio of Euro 5 real-world emissions to test measurements;
- Scenario C: assumes real-world Euro 6 diesel NO_x emissions are the same as the test cycle emission limit value of 80 mg/km from 2015 onwards.

Source: IIASA, 2012.

In response to the need to deliver real improvements in air quality, the European Commission has recently introduced a future requirement for PEMS to be used to measure in-use emissions of light-duty vehicles, the so-called real driving emissions (RDEs) (see section 6).

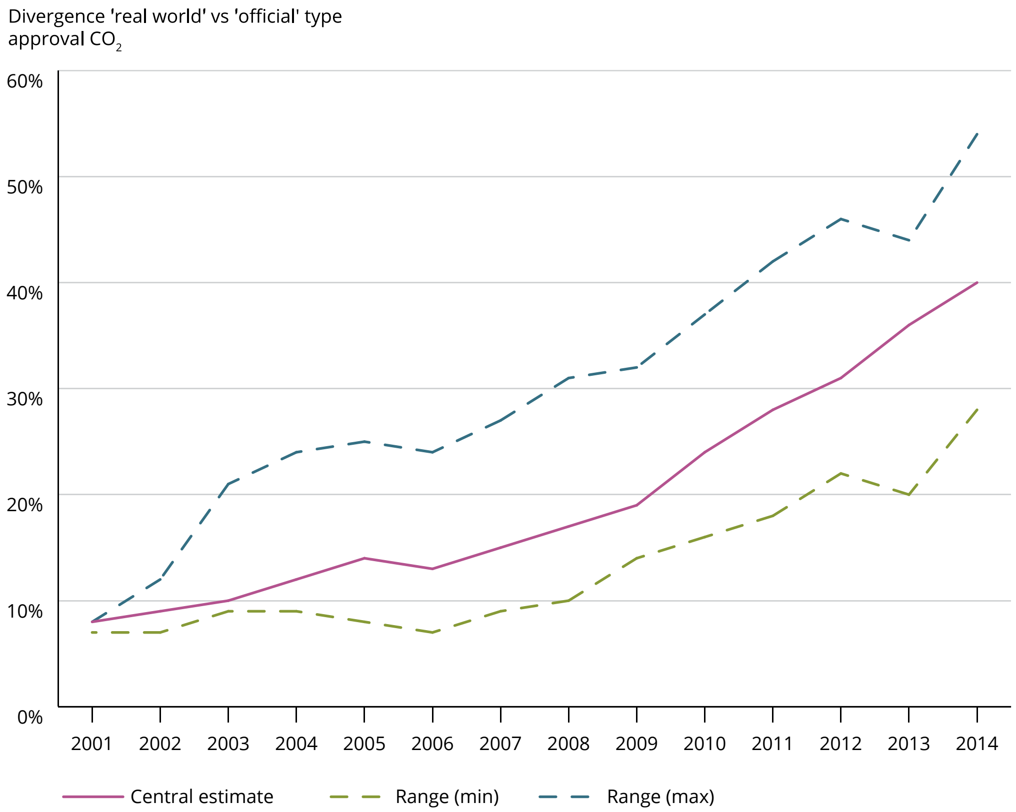
Carbon dioxide

As for NO_x, it is also clear that there is currently a significant gap between real-world and type approval fuel consumption and CO_2 emission levels. In particular, for fuel consumption — and hence also for CO_2 emissions — this gap has two important consequences:

- It can provide a distorting impact on national CO_2 based vehicle taxation systems;
- Customers complain that official fuel economy values are misleading, which raises the issue of consumer rights. As a result, consumer confidence in the automotive industry can be harmed if advertised values systematically fail to meet reality.

A comparison of fuel consumption data from more than half a million private and company vehicles across Europe has shown how this discrepancy between type approval and real-world values has grown over the last 12 years (ICCT, 2014b; ICCT 2015a). In particular, the gap has increased considerably since 2007, when the binding EU average CO_2 target for passenger cars was first proposed. While the average discrepancy between type approval and on-road CO_2 emissions was below 10 % in 2001, by 2014 it had increased to around 40 %. Moreover, while the average discrepancy between type approval and real-world values was initially similar for diesel and petrol vehicles, since 2010 the difference between the two technologies has increased: for conventional diesel vehicles, the gap is 5 % greater than for conventional petrol vehicles.

Divergence of real-world CO_2 emissions from manufacturers' type approval CO_2 emissions



Source: ICCT, 2015a.

The biggest difference was observed for hybrid cars. Data for hybrid vehicles are available from 2010 onwards and the discrepancy between type approval and real-world CO_2 emissions is about 40–45 %. This larger difference may be explained, to some extent, by the fact that hybrids usually have automatic transmissions, which the study showed tend to consume about 40 % more fuel under real-world conditions than under type approval testing. The average difference for vehicles with manual transmissions was 33 %.

Several other European studies have shown the magnitude of the gap between NEDC legislative and real-world CO_2 emissions. All studies confirm this gap: the average discrepancy between type approval and on-road CO_2 emissions is in the range of 10–40 % (ICCT, 2013; JRC, 2011b; ICCT, 2014b).

The COPERT model: estimating road transport emissions:

COPERT (COmputer Programme to calculate Emissions from Road Transport) is a widely used software tool for calculating real-world air pollutant emissions (CO, NO_X, VOC, PM, NH_3, SO_2, heavy metals) and GHG emissions (carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4)) from the road transport sector (Emisia, 2015). Supported by the EEA and the EU's Joint Research Centre (JRC), it is used by many countries both inside and outside Europe for estimating and reporting official emissions data from the road transport sector.

COPERT calculates emissions as a product of activity data (i.e. mileage) and speed-dependent real-world emission factors. Emissions factors are separated into exhaust emission factors — split into those produced during thermally stabilised engine operation (hot emissions) and those occurring during engine start from ambient temperature (cold-start and warming-up effects) — and diffuse emissions factors, i.e. non-methane VOC emissions due to fuel evaporation and non-exhaust PM emissions from tyre and brake wear.

Emission factors for more than 240 individual vehicle types are included in the model, including for:

- passenger cars;
- light-duty vehicles;
- heavy-duty vehicles (including buses);
- mopeds; and
- motorcycles.

Emission control technologies (e.g. 'Euro' standards) are included for each of these vehicle categories — additional user-defined technologies can also be included.

Explaining the gap between real-world and legislative emissions

The existing gap between real world and test cycle emissions is mainly due to three factors (T&E, 2015; TNO, 2012):

- An outdated test procedure that does not reflect real-world driving conditions, as described in earlier sections;
- Flexibilities in the current procedures that allow manufacturers to optimise the testing, and thereby achieve lower fuel consumption and CO_2 emission values;
- Several in-use factors which are driver dependent (e.g. driving style) or independent (e.g. environmental conditions).

Test flexibilities

Flexibilities exploited by manufacturers during the NEDC test cycle can be broadly grouped into two categories: those relevant to the initial coast-down test and those relevant to the type approval test itself.

As described earlier, the coast-down measurement involves driving a vehicle up to a certain speed, and decelerating it in neutral gear until it stops. The vehicle's speed and travelled distance are constantly recorded during the test. Coast-down testing is used to determine the appropriate resistance levels (or 'road loads') to use on the dynamometer for a given vehicle model in the type approval test.

For this coast-down testing, a number of flexibilities exist:

Wheel and tyre specification. The legislation allows some flexibility in the choice of wheels and tyres that are to be used during the test. This flexibility may be used to optimise rolling and aerodynamic resistances of the vehicles by selecting low-rolling resistance tyres and low-width wheels and tyres.

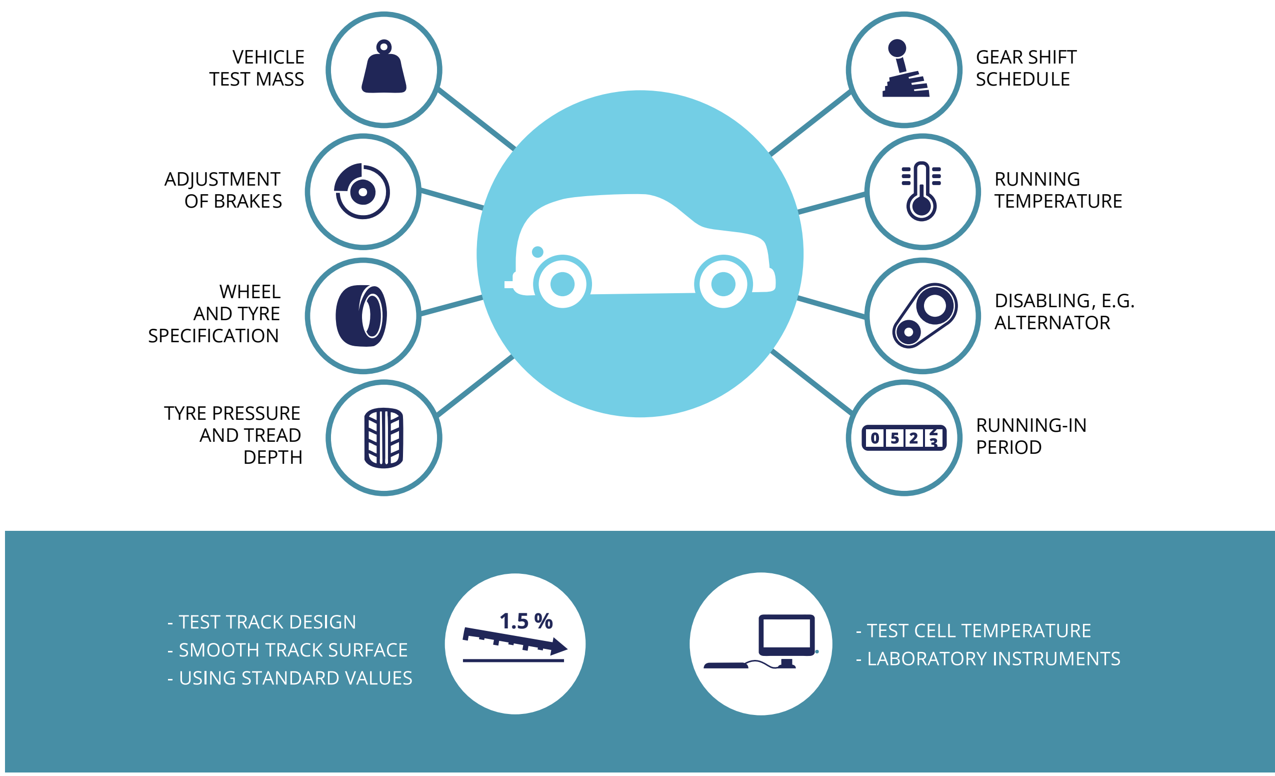
Tyre pressure. The legislation specifies that tyre pressure should be set according to the manufacturer's specifications for the use considered and should be set when the tyres are 'cold'. However, the exact temperature is not specified in the legislation. Therefore, there is some flexibility, which allows manufacturers to overinflate tyres compared with 'normal' use, resulting in a lower rolling resistance.

Adjustment of brakes. The legislation allows some adjustments to vehicle brakes in order to eliminate 'parasitic drag', namely losses from unintentional braking. This flexibility may be used to further improve coast-down performance.

Vehicle preconditioning. The legislation specifies that the vehicle should be brought to normal running temperature in an appropriate manner. This 'normal running temperature', however, is not defined. Hence, there is some flexibility, which allows manufacturers to optimise vehicle temperature during the testing, resulting in a lower rolling resistance.

Running-in period. The legislation specifies that the vehicle should be tested after having been run-in for at least 3 000 km. The tyres should be run-in for the same distance or have a tread depth between 90 and 50 % of

Flexibilities in the NEDC test approval procedure



Source: T&E, 2015; TNO, 2012.

the initial tread depth. Hence, there is some flexibility, which allows manufacturers to use tyres with minimum tread depth to reduce rolling resistance.

Test track design. The legislation defines the characteristics of the road on which the vehicle is tested. The road surface is, however, not specified; hence, there is some flexibility in optimising the road surface, as a smooth surface results in lower rolling resistance than a rough surface.

Using all the above flexibilities, an improved coast-down result leads to reduced resistances over the NEDC test and hence lower fuel consumption. Test results from a recent study conducted for the European Commission (TNO, 2012) show that the estimated CO_2 benefit from utilising all flexibilities within the allowable limits relating to the coast-down test is about 4.5 %. The reduced resistances are also likely to help manufacturers reduce NO_x and PM emissions during the NEDC testing.

Volkswagen and 'defeat devices'

In September 2015, the United States Environmental Protection Agency (USEPA) announced that it had issued a notice of violation of vehicle emission limits against Volkswagen. This occurred after the USEPA, together with the Californian Air Resources Board, had investigated a variety of four-cylinder diesel passenger cars manufactured by Volkswagen and found that the on-road performance of these vehicles emitted up to 40 times more NO_x than permitted by the US emission standards.

Volkswagen subsequently admitted to using 'defeat devices' in the USA to artificially lower NO_x emissions during testing of these diesel vehicles. The defeat devices comprise computer software that can identify when a vehicle is being tested by monitoring various parameters such as speed, engine operation, air pressure and external conditions (i.e. temperature and humidity). When the engine software recognises the vehicles is undergoing a test, engine operation and the performance of the vehicle catalyst change to ensure that the pollution standards were respected. However, once on the road, the emission control systems were reduced or switched off resulting in significantly higher emissions under 'normal' operating conditions. Volkswagen has subsequently confirmed it has also sold diesel vehicles in Europe containing the same defeat device software.

Subsequently in early November 2015, the USEPA issued a second notice of violation after discovering certain additional larger diesel vehicles manufactured by Volkswagen Group also appeared to use defeat devices. Separately, Volkswagen Group has also publicly confirmed that the fuel consumption and CO_2 emission values it has published for some models are incorrectly stated. The company is presently reviewing which models are specifically affected.

At the time of writing, several Member States have announced that they plan to independently investigate the on-road emissions of Volkswagen diesel vehicles, as well as those from other manufacturers. The new real emissions testing procedure (RDE), which will be adopted soon in the EU, will also provide a valuable check to the on-road performance of vehicles compared with laboratory testing.

Optimising NEDC test conditions — changes in emissions of selected pollutants

Fuel type	CO_2	NO_x	PM	CO	HCs
Petrol	↓	↓	↓	↑	↑
Diesel	↓	↓	↓	↑	↑

For the NEDC type approval test itself, the main permitted flexibilities that manufacturers may take advantage of are:

Vehicle test mass. The reference mass is the mass of the unloaded vehicle increased by 100 kg, which corresponds to the mass of the driver and the fuel. The definition of reference mass depends on which parts of the vehicle are considered to be fitted by the manufacturer and which are fitted at a later stage as aftermarket or car dealer options. This flexibility allows manufacturers to reduce vehicle testing mass by specifying items as dealer-fitted optional extras, resulting in lower resistances in the chassis dynamometer.

Wheel and tyre specification. The legislation specifies that standard wheels, tyres and tyre pressures should be used. There is some flexibility in defining what are standard wheels and tyres for a specific vehicle model. This allows manufacturers to optimise the overall vehicle configuration for testing, for example by selecting low-rolling resistance tyres and a high tyre pressure and specifying that this is the standard vehicle setting.

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Laboratory instrumentation. The legislation specifies the measurement accuracy and tolerances for a range of instrumentation equipment. These tolerances can be used for calibrating the equipment towards one end of the allowable range. Examples are the temperature, atmospheric pressure and humidity of the test cell, accuracy of the gas analysers, etc.

Test cell temperature. The legislation specifies a range of temperatures in the test cell before and during the test. A higher temperature generally reduces friction in the engine and vehicle components. This flexibility in temperature selection improves efficiency, thus reducing CO_2 emissions.

Dynamometer load. Use of the coast-down curve is not the only option for simulating road load during the type approval test. The legislation provides the option of using standard 'table values' commonly referred to as the 'cookbook' method. This method does not include a measurement of aerodynamic or rolling resistance for the vehicle being tested, but contains only typical factors. This flexibility allows manufacturers to use the 'cookbook' for testing vehicles that have relatively high aerodynamic and/or rolling resistance, for example vans or all-wheel drive vehicles.

Gear shift schedule. The legislation defines the gear number and shift points of the NEDC test. However, the use of higher gears is allowed if a vehicle cannot reach a speed of 15 km/h in first gear. The use of higher gears generally decreases fuel consumption, as higher gears allow the engine to operate more efficiently owing to lower engine rotational speeds.

Driving technique. It is very difficult for a driver to exactly follow the speed trace of the NEDC. To account for this, the legislation allows a tolerance of ± 2 km/h between the actual and the target vehicle speed. This flexibility allows experienced drivers to use these limits to their benefit, by following the lower limit at constant speeds and by achieving smoother accelerations.

Other reasons for divergences

The different flexibilities of the type approval test discussed above are not the only factors responsible for the observed differences between laboratory measurements and real-world emissions. Other factors, discussed below, also contribute to this effect.

The use of on-board electrical equipment, such as heated seats, window defrosters, air-conditioning units for cabin heating and cooling, and entertainment systems, may require significant additional amounts of energy to operate. All of these systems are switched off during the type approval test and hence their impact is not taken into account in the fuel consumption reported by car manufacturers.

The condition of the vehicle in real-world driving might also be completely different from when the vehicle is type approved, and lead to increased fuel consumption and hence emissions. For example:

- additional passengers and cargo result in the vehicle becoming heavier, reducing fuel economy;
- accessories for carrying cargo such as roof racks or rear-mount cargo boxes increase wind resistance — the additional resistance increases with vehicle speed;
- lower than recommended tyre pressure increase rolling resistance.

Driving behaviour and conditions have a significant effect on fuel economy. Although 'normal' driving is difficult to define, 'aggressive' driving (speeding, rapid accelerations and braking) will use significantly more fuel. Speeds above 90 km/h increase fuel consumption substantially. Other external factors, such as fuel quality, weather conditions and road surface, can also affect fuel economy.

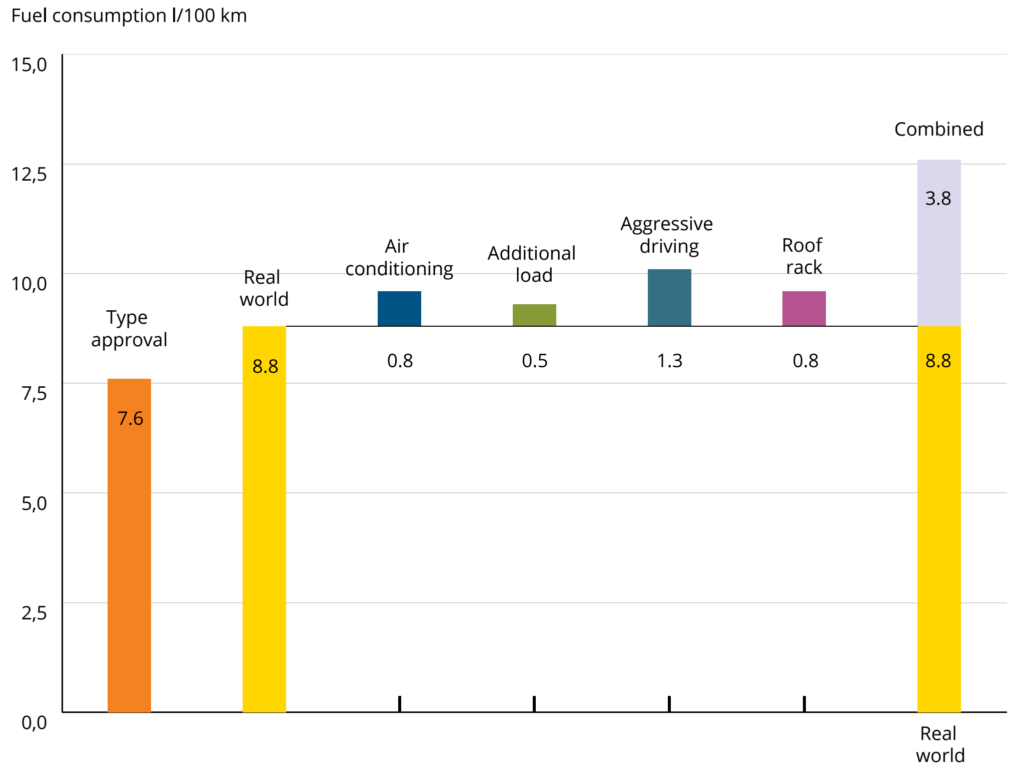
- Engine and transmission friction increases at low ambient temperatures owing to cold engine oil.
- Hot and humid conditions increase the power demand of the air-conditioning unit.
- In winter, it takes longer for the engine to reach its most fuel-efficient temperature. This affects shorter trips more, as the car spends more of the trip at less-than-optimal temperatures.

The following figure shows the potential impact on fuel consumption of selected factors for a typical mid-sized petrol car (AVL, 2015). While clearly representing a 'maximum' driving scenario, it serves to illustrate the significant penalty in fuel consumption that different vehicle and driving conditions can have. Such a vehicle, having an official fuel consumption value of 7.6 L/100 km, is estimated to have a real-world fuel consumption of around 8.8 L/100 km, i.e. 16 % higher than the official value. In addition, the effect of selected parameters can also be estimated using vehicle simulation software:

- turning the air-conditioning unit on;
- the additional load of four passengers and luggage;
- demanding driving with a 30 % increase in average speed and rapid accelerations and braking;
- adding a roof rack, resulting in a 15 % increase in aerodynamic coefficient and another 20 % increase in frontal area.

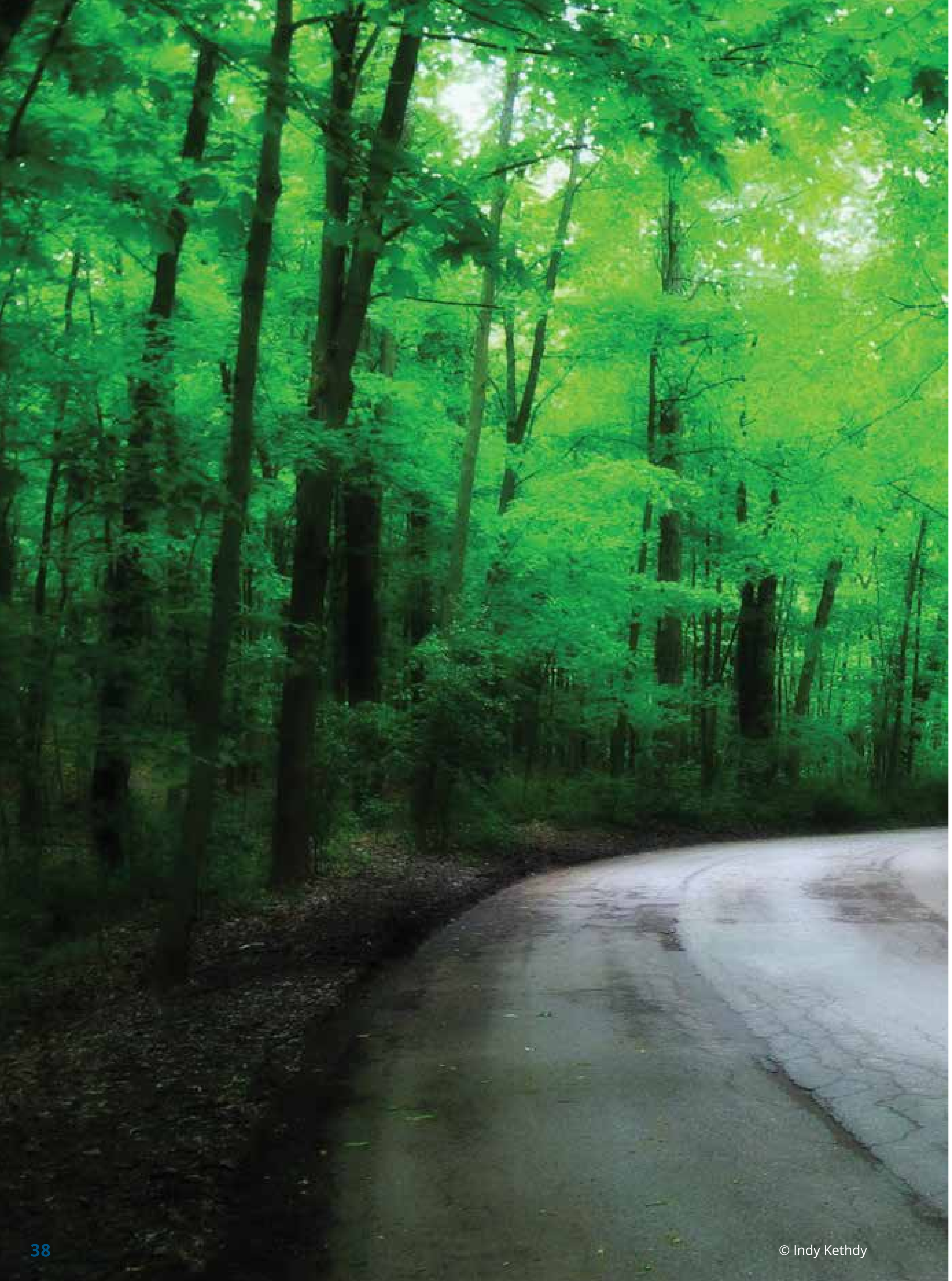
Overall, under these operating conditions, real-world CO_2 emissions for this vehicle might be as high as 12.6 L/100 km, around 65 % higher than the tested measurement.

Impact of selected vehicle and driving conditions on fuel economy for a typical mid-sized petrol car



Note: The combined value of all these parameters does not equal the sum of the individual values, as their effects are non-linear.

Source: AVL, 2015.



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Progress in reducing emissions from Europe's vehicles

The need to improve fuel efficiencies and the introduction of progressively stricter European standards over the past decades have greatly contributed to technological development in the European vehicle manufacturing industry. Innovations include the development of electric and hybrid vehicle technologies, eco-innovations, and improvements in conventional engine and exhaust technologies.

Electric vehicles and hybrids

Over recent years, a number of alternative engine technologies have been introduced on a commercial scale by vehicle manufacturers. These technologies include hybrid and electric vehicles.

A **hybrid vehicle** combines an internal combustion engine and an electrical motor to power the wheels. The combustion engine runs off fossil fuels as for a conventional vehicle, and a battery provides additional electric power that assists the conventional engine during, for example, vehicle acceleration. The battery is typically charged during the braking or slowing of the vehicle. Hybrids deliver certain benefits compared to conventional technologies, as they reduce fuel consumption and CO_2 emissions by up to 35 %, as well as reducing air pollutant emissions (ICCT, 2015b). The size of the emissions reduction varies with the sophistication of the hybrid system. Petrol hybrids are amongst the cleanest commercially available vehicles with regard to regulated pollutants (JRC, 2012).

Plug-in hybrid vehicles, similarly contain both a conventional and an electrical motor which provide power to the wheels. The difference compared to a normal hybrid is that the batteries can be charged by 'plug-in' to the electricity grid. The environmental impact of plug-in hybrids depends on their operation mode — the all-electric mode of plug-in hybrids results in effectively zero tailpipe emissions in urban conditions, but relying on the conventional engine can lead to emission levels comparable to those of normal vehicles.

Pure electric vehicles have only an electrical motor and no internal combustion engine. Electrical motors have an efficiency that may exceed 80 %, and they offer substantial GHG and air pollutant reductions compared to conventional vehicles. However the higher cost, infrastructure needs, and battery capacity are still factors that limit the public uptake of electric vehicles (JRC, 2012).

Eco-innovations

To encourage development of innovative vehicle technologies to reduce CO_2, the concept of 'eco-innovations' has been introduced into EU vehicle legislation. This allows a manufacturer, or supplier, to apply for the approval of innovative technologies that reduce CO_2 emissions but which are not measured during the standard test cycle. To date, eleven eco-innovations have been approved. For each of these, the CO_2 emissions saving is higher than 1 g CO_2/km.

Examples of approved vehicle eco-innovations

Eco innovation	Description
Use of ambient energy sources	Photovoltaic panels in the roofs of vehicles
Efficient lighting systems	Use of LED lighting
Improved electrical components	High efficient alternator
Engine compartment encapsulation	Additional insulation component to keep the heat in the engine compartment, which reduces the loss of energy
Energy storage systems	Use of the potential energy of the roads to recharge vehicle batteries


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Improving conventional engine efficiencies

Only about 18–25 % of the energy contained in fuel is actually used to move vehicles. There remains, therefore, a significant technical potential to increase vehicle efficiencies.

The extent to which this can be achieved, however, depends on several factors, including, for example, the engine compression ratio [2] or the mixing timing. Engine efficiency has steadily improved over the last decades as a result of, for example, improved engine design and more precise ignition timing. Some of the main technologies put in place over the last 20 years that have delivered improved engine performances are outlined below.

Direct fuel injection

In conventional petrol engines, petrol and oxygen are mixed outside the combustion area. In direct injection systems, petrol is injected directly into the cylinder, so that the timing and the amount of fuel can be precisely controlled. This results in higher compression ratios and more efficient fuel intake, which deliver higher performance with lower fuel consumption.

Variable valve timing and lift

Valves control the flow of air and fuel into the cylinders and the flow of exhaust gas out of them. When and how long the valves open (timing) and how much the valves move (lift) both affect engine efficiency. Optimum timing and lift settings are different for high and low engine speeds. Traditional designs, however, use fixed timing and lift settings, which are a compromise between the optimum for high and low speeds. Variable valve timing and lift systems permit the valve opening and closing times and the valve lift to be varied to the optimum settings for each engine speed.

Cylinder deactivation

This technology deactivates some of the engine's cylinders when they are not needed. In typical driving at low loads, the car uses only around 30 % of an engine's maximum power. In these conditions, there are only small amounts of fuel needed and the engine needs to work to draw air. This causes an inefficiency known as pumping loss.

Turbocharging

Turbochargers and superchargers are fans that force compressed air into the cylinders of the engine. A turbocharger fan is powered by exhaust gas from the engine, while a supercharger fan is powered by the engine itself. Both technologies allow more compressed air and fuel to be injected into the cylinders, generating extra power from each explosion. This allows manufacturers to use smaller engines without sacrificing performance.

Start–stop systems

These systems automatically turn the engine off when the vehicle comes to a stop, for example at traffic lights or in a traffic jam. The engine is restarted automatically when the driver lifts his or her foot off the brake, or engages the clutch, so that fuel is not wasted for idling.

([2]) The compression ratio of an engine is the ratio between the largest and smallest capacity of the volume of its combustion chamber.

Exhaust technologies

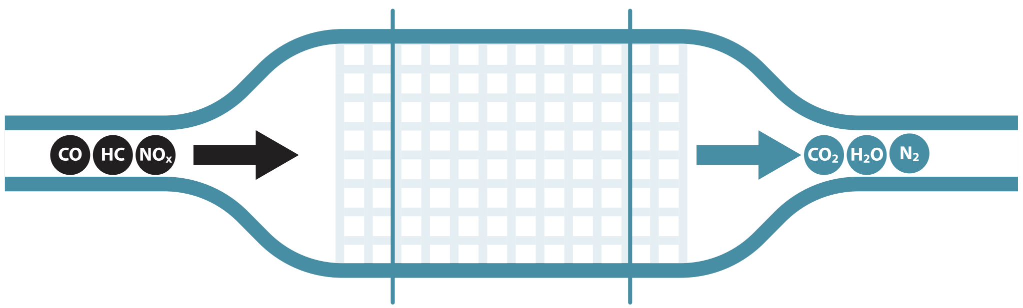
Improvements in engine technology have reduced exhaust emissions, but in themselves have generally been insufficient to meet emission goals. Therefore, the development of additional exhaust aftertreatment technologies has been needed to meet the required emission standards. The main technologies used to remove harmful gases and particles from the vehicle exhaust are catalytic converters, traps and filters.

A catalytic converter is a device that uses a catalyst to convert the main harmful air pollutants in car exhaust emissions into harmless compounds. The catalyst activates certain oxidation and/or reduction reactions, which transform CO, HCs and NO_x into CO_2, water and nitrogen. A converter is typically made of one or more 'honeycomb' bricks, having a typical cross-section of small squares or alternatively triangles.

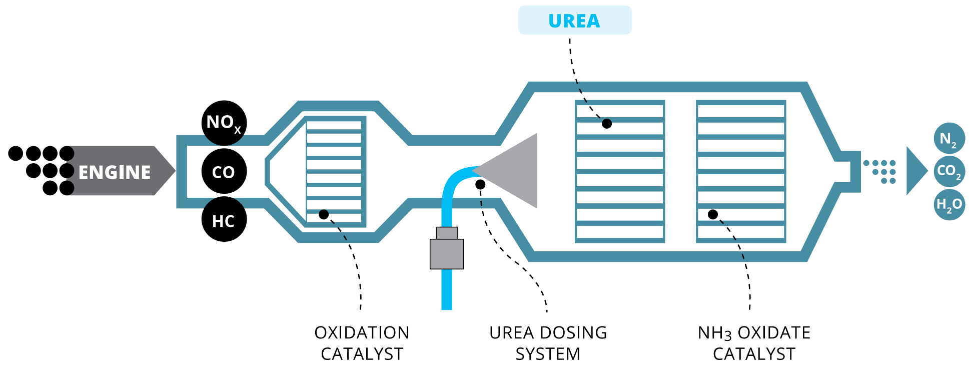
The introduction of Euro 1 emission standards effectively made the use of a three-way catalyst mandatory. Three-way catalysts operate in a closed-loop system including an oxygen sensor to regulate the air to fuel ratio in petrol engines. The closed-loop catalytic control, first implemented in the USA, was a significant technological breakthrough. For the first time, an engine could self-calibrate itself during operation, hence effectively controlling all three major pollutants (CO, HCs and NO_x) under a wide range of conditions. Three-way catalysts are still the main technology used to control emissions from petrol engines.

Oxidation catalysts look much the same as three-way catalysts and their construction and composition is similar, although slightly less complex. Oxidation catalysts convert CO and HCs to CO_2 and water, but have little effect on NO_x. Diesel oxidation catalysts remain a key technology for diesel engines, as they convert CO and HCs but also decrease the mass of diesel PM.

Selective catalytic reduction (SCR) is an advanced emissions control technology system that reduces NO_x by injecting a liquid reducing agent through a special catalyst into the exhaust stream of a diesel engine.



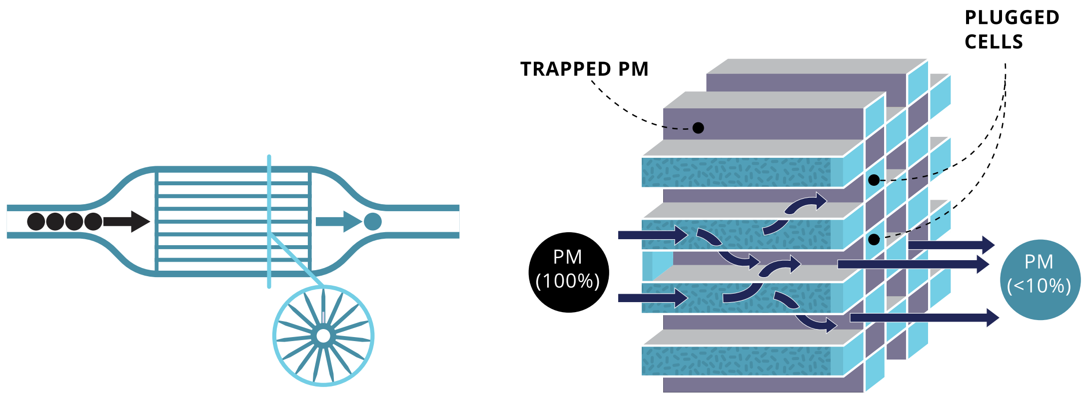
A typical catalytic converter



A selective catalytic reduction system to reduce NO_x

The reducing agent is usually urea, which enables a chemical reaction that converts NO_x into nitrogen, water and CO_2, and which is subsequently expelled through the vehicle exhaust. SCR is a proven catalyst technology capable of reducing diesel NO_x emissions to levels required by current emission standards.

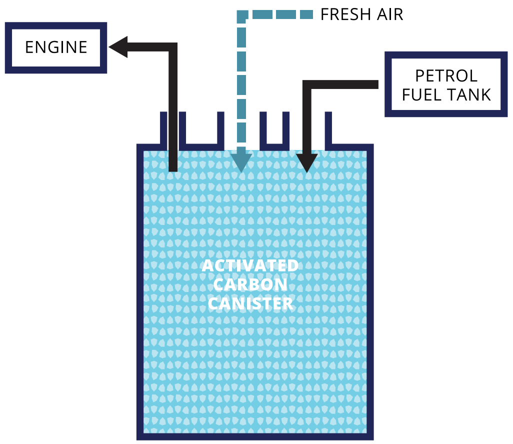
Diesel particulate filters (DPFs) are devices used with diesel engines to remove PM. Based on engine technology and application specificities, different filter technologies may be used to reduce particle emissions. In the most common type (wall-flow filters), PM is removed from the exhaust by physical filtration using a honeycomb structure similar to a catalyst, but with the channels blocked at alternate ends. The exhaust gas is thus forced to flow through the walls between the channels and PM is deposited on the walls. In partial-flow filters, the exhaust gas flow is diverted into adjacent channels and the particles are temporarily retained before being burnt.



A typical diesel particulate filter

Traps and adsorbers are used to control the emissions of specific pollutants — usually NO_x or HCs — when engine operating conditions may not be ideal for conventional catalysts to achieve their full potential. They store the pollutant for a period of time but then release it when conditions are suitable for it to react over the catalytic materials. The two main current examples of adsorbers are NO_x adsorbers (or NO_x traps), used to capture NO_x emissions from diesel engines, and HC adsorbers that are used to 'trim' HC emissions during cold starts.

An activated carbon canister is a trap device used to control evaporative HC emissions from petrol fuel tanks. The canister consists of a plastic case containing the activated carbon, which traps (or adsorbs) the petrol vapour as it is forced out of the fuel tank during heating or refuelling. The adsorbed fuel vapours are then released (or desorbed) into the engine when the car is driven, regenerating the canister. This adsorption/desorption cycle continues for the life of the vehicle.



An activated carbon canister

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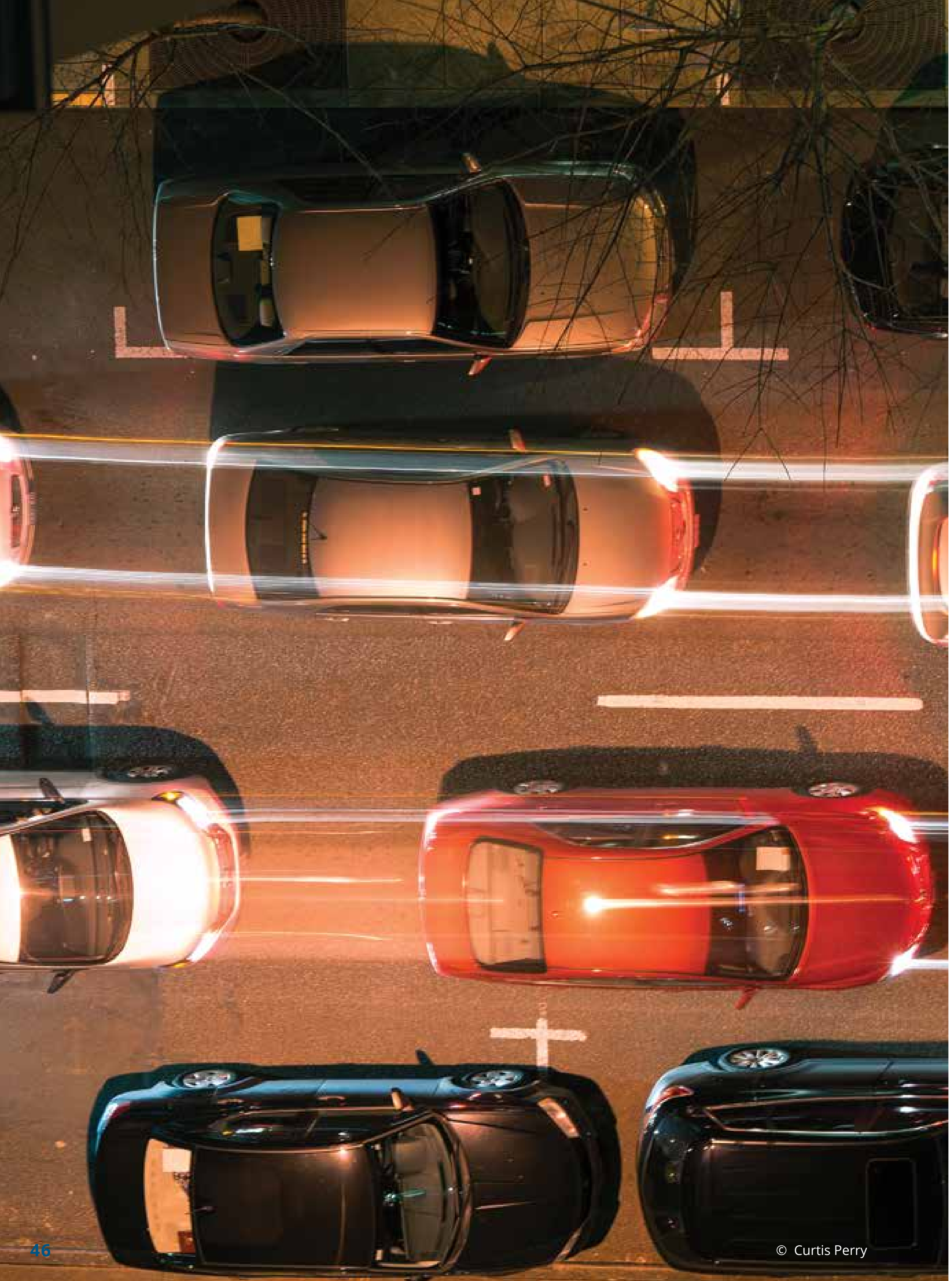

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Looking forward

Two important initiatives are planned in Europe to help ensure an improved future consistency between the official vehicle emissions and real-world driving performance. This includes changing the outdated NEDC official test procedure to one that is more representative of real-world emissions, as well as the introduction of a procedure for measuring the real driving emissions of vehicles on the road.

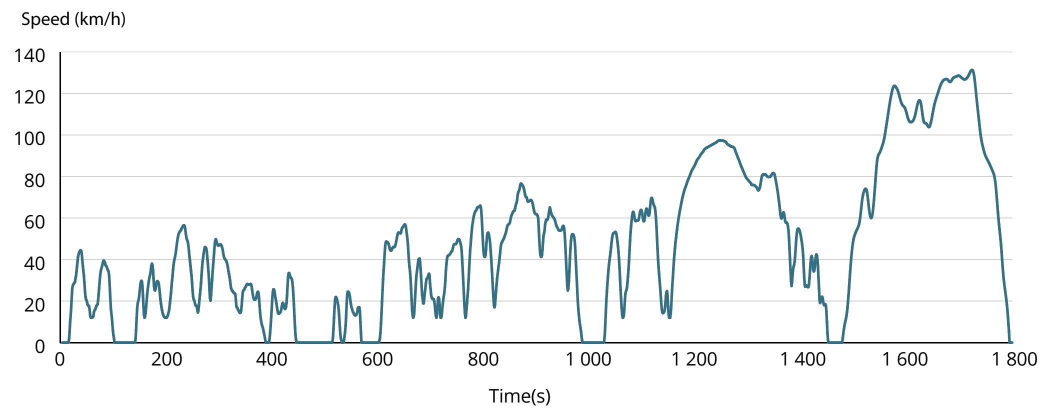
Changes to the EU test cycle

In 2008, the United Nations started work on an updated test procedure, the 'World-Harmonized Light-duty Vehicle Test Procedure' (WLTP). This includes a new test cycle that is more representative of average driving behaviour, and a test procedure that limits the allowed flexibilities and loopholes compared with Europe's current testing system. The European Commission is currently working on introducing the WLTP in the EU with a focus on improving CO_2 emissions testing — the timing of this is still to be agreed.

It is expected that the WLTP will better reflect real world driving emissions compared to the current NEDC test. Compared with the NEDC, the WLTP has:

- a longer testing distance (23.3 vs. 11.0 km) and duration (1 800 vs. 1 180 seconds);
- a higher average speed (46.5 vs. 33.6 km/h);
- a higher maximum speed (131 vs. 120 km/h);
- fewer stops (9 vs. 14);
- less driving at constant speed (66 vs. 475 seconds);
- more acceleration (789 vs. 247 seconds) and braking (719 vs. 178 seconds);
- less idling (226 vs. 280 seconds).

Speed profile of the WLTP test cycle



Source: GFEI, 2015.

The most important differences between the WLTP and the current type approval test in terms of impact on CO_2 emissions can be broadly grouped into the following categories:

Higher driving dynamics. The frequent accelerations and higher speeds of the WLTP require greater amounts of energy, and hence result in higher fuel consumption than the NEDC. In contrast, the better efficiency of an engine at higher loads decreases the amount of fuel needed. The combination of these two effects will lead to an overall higher fuel consumption for the WLTP than the NEDC. In addition, the benefits of stop–start systems (engine shut down during vehicle stops that means reducing idle emissions to zero) will be smaller in the WLTP because of the reduced idling phases.

Vehicle test mass. There is a clearer definition of the vehicle mass in the WLTP, which takes into account optional equipment. For the NEDC test procedure, the mass of the lightest vehicle model version can be used for CO_2 testing. Hence, different versions of the same vehicle model will have higher emissions in the WLTP than the base model with no optional equipment in the NEDC test.

Cold start. In general, driving a vehicle with a cold engine increases CO_2 emissions. However, because the WLTP is longer than the NEDC, the added contribution of cold-start emissions will be distributed over a longer distance and it will not have a significant impact on the total CO_2 emissions.

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Ambient temperature. The test temperature in the WLTP is 23 °C. However, the EU is planning to lower this to 14 °C, which is more representative of European average temperatures. This will result in higher excess fuel consumption because of an increased contribution of cold-start emissions.

The impact of the new test cycle and the associated gearshift procedure on emissions has been evaluated in several recent studies, with a general conclusion being that the dynamics of the WLTP will better reflect the average real-world driving behaviour of light-duty vehicles. It is however unlikely to solve entirely the gap observed between test and real-world emissions. For example, a first estimate of the impact of the transition to the new test procedure on CO_2 emissions for the European car fleet has recently been reported (see table) (ICCT, 2014d). The estimate shown in the accompanying table is based on car testing and simulations and assumes a technology mix of the European car fleet in 2020.

Estimated impact of switching from the NEDC to the WLTP for an expected 2020 vehicle fleet

Regulatory Issue	NEDC	WLTP	Impact on CO_2 emissions
Driving cycle	Operation at low loads with low engine efficiency, higher cold start effect (shorter distance), higher engine speeds (manual transmissions)	Higher speeds and acceleration forces, lower vehicle stop share (stop — start systems)	+ 2.1 %
Vehicle mass	No optional equipment No additional payload	Optional equipment: 70 kg Additional payload: 55 kg	+ 3.5 %
Temperature	Engine start temperature: 23 °C	Engine start temperature: 14 °C	+ 1.9 %
Total Impact 14 °C			+ 7.7 %
Total Impact 23 °C			+ 5.7 %

Source: ICCT, 2014d.

Introduction of Real Driving Emission (RDE) testing

To help address the gap between legislative and real-world NO_x emissions, the European Union has recently agreed a Real Driving Emission (RDE) test procedure for cars and vans. Following its introduction, the EU will become the first region in the world to use on-road emissions testing methods for legal compliance purposes.

The new RDE procedure will measure emissions of NO_x, and at a later stage particle numbers, using portable emission measuring systems (PEMS) attached to the car. The new protocol requires the real driving emissions from cars and vans to be lower than the legal limits multiplied by a 'conformity factor'. This factor expresses the ratio of on-road PEMS emissions to the legal limits. At the time of writing, the NO_x conformity factor has been set to 2.1 (i.e. 110 % above the Euro 6 limit) from 1 September 2017 for new models and two years later for all new vehicles. In a second step, it will be reduced to 1.5 (i.e. 50 % above the Euro 6 limit) from 1 January 2020 for new models and one year later for all new vehicles. These factors remain subject to scrutiny by the European Parliament, and therefore potentially remain subject to change.

Is diesel still a solution for reducing carbon dioxide emissions?

Diesel fuel contains more energy per litre than petrol and, coupled with the fact that diesel engines are more efficient than petrol engines, diesel cars have traditionally been more efficient to run. This means that diesel cars typically have a better fuel economy, producing less CO_2 per kilometre driven. In a number of countries, financial incentives have been used over the past decades to encourage the uptake of diesel vehicles.

However, on the basis of the official test cycle measurements, the efficiency gap between diesel and petrol cars has been decreasing in recent years. In 2014, the average new diesel car registered in the EU emitted 123.2 g CO_2/km, only 2.5 g CO_2/km less than the average petrol vehicle.
By comparison, in 2000, the emissions difference between diesel and petrol vehicles was 17 g CO_2/km.

This diminishing gap can largely be explained by the increase in mass of diesel cars over time. The average diesel car registered in the EU is now about 310 kg heavier than the average petrol car, i.e. around 100 kg heavier than in 2004. This increased mass has largely offset the inherent higher efficiency of the diesel engine, diminishing the average fuel economy benefits of diesel cars.

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Further information

When choosing a new car, consumers are often confronted by conflicting information concerning the relative environmental performances of different vehicles, whether they are looking at petrol, diesel or hybrid vehicles.

There is growing public awareness that the 'official' fuel consumption and CO_2 values advertised on new cars may often be very different, and difficult to achieve, in reality. Similarly, although vehicles in Europe are required to meet the Euro standards for air pollutants, it can be very difficult to find comprehensive reliable information for those wishing to compare details of the typically much higher real-world NO_x and PM emissions for different diesel models. Recent years have also seen an increasing public and media focus on air pollution problems, particularly in cities, where emissions from road vehicles often play a substantial part. Consumers are understandably interested in being better informed on the air quality and climate change impacts of different vehicles.

A number of European non-governmental organisations and consumer associations, national motoring organisations and even media outlets provide online information on real-world emissions of different vehicle types. Based on independent testing and/or reports from motorists, such information sources can be a valuable source of further information should a comparison be sought of the real-world performance of different vehicle models. Examples of organisations and useful information sources describing real-world fuel consumption and emissions include:

Allgemeiner Deutscher Automobil-Club (ADAC)	Germany's largest automobile club
International Council on Clean Transportation (ICCT)	NGO
Next greencar	UK consumer website
Honestjohn.co.uk	UK consumer website
km77.com	Spanish consumer website
Spritmonitor.de	German consumer website
Travelcard	Dutch consumer website
Transport and Environment (T&E)	NGO

For the research and policy communities, it is clear that initiatives that drive vehicle technology improvements and fleet renewal can be one of the main strategies for reducing emissions of both GHGs and air pollutants. However, despite the significant technological progress made over past decades towards cleaner engines, traffic emissions still account for a high proportion of Europe's air and GHG pollution. Conventional-fuelled vehicles can still improve their performance. However, in moving towards Europe's longer term objectives of achieving a low-carbon society, it is becoming clear that incremental improvements in vehicle efficiencies will not deliver the substantial GHG emission reductions needed in the future.

The need for policy coherence across different thematic areas is clear i.e. policies that incentivise lower CO_2 technologies but at the cost of higher air pollutant emissions need to be avoided. In the research area, incentives that support the development of advanced low-carbon technologies will continue to be needed, for example into advanced hybrid, electric and fuel cell technologies.

Measures that encourage development and uptake of future clean technologies in the transport sector will therefore be fundamental for the reduction of transport's impacts on health and the environment and a necessary component of a green economy in Europe.

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References

AVL, 2015, *'AVL CRUISE'* website: https://www.avl.com/web/ast/cruise#tab-1.

EEA, 2013, *Air quality in Europe — 2013 report*, EEA Report No 9/2013, European Environment Agency.

EEA, 2014a, *Noise in Europe — 2014 report*, EEA Report No 10/2014, European Environment Agency.

EEA, 2014b, *TERM 2014: transport indicators tracking progress towards environmental targets in Europe*, EEA Technical report No 7/2014, European Environment Agency.

EEA, 2015a, *Air quality in Europe* — 2015 report, EEA Report No 5/2014, European Environment Agency.

EEA, 2015b, *Monitoring CO_2 emissions from new passenger cars and vans in 2014*. EEA Technical report No 16/2015, European Environment Agency.

Emisia, 2015, 'Copert 4' (http://emisia.com/copert).

EU, 1970, Council Directive 70/220/EEC of 20 March 1970 on the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles, OJ L 76, 6.4.1970, p. 1.

EU, 2009, Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles, OJ L 140, 5.6.2009, p. 1–15.

EU, 2011, Regulation (EU) No 510/2011 of the European Parliament and of the Council of 11 May 2011 setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO_2 emissions from light-duty vehicles, OJ L 145, 31.5.2011, p. 1–18.

EU, 2014, Regulation (EU) No 540/2014 of the European Parliament and of the Council of 16 April 2014 on the sound level of motor vehicles and of replacement silencing systems, and amending Directive 2007/46/EC and repealing Directive 70/157/EEC Text with EEA relevance, OJ L 158/131, 27.5.2014.

GFEI, 2015, 'International test cycles for emissions and fuel economy' (http://www.unep.org/transport/gfei/autotool/approaches/information/test_cycles.asp).

IIASA, 2012, *Compliance with EU Air Quality Limit Values - A First Set of Sensitivity and Optimization Analyses*, ENV.C.3/SER/2011/0009, International Institute for Applied Systems Analysis.

ICCT, 2013, *From laboratory to road. A comparison of official and 'real-world' fuel consumption and CO_2 values for cars in Europe and the United States*, International Council on Clean Transportation, Washington DC, USA.

ICCT, 2014a, *European vehicle market statistics. Pocketbook 2014*, International Council on Clean Transportation, Washington DC, USA.

ICCT, 2014b, *From laboratory to road. A 2014 update of official and 'real-world' fuel consumption and CO_2 values for passenger cars in Europe*, International Council on Clean Transportation, Washington DC, USA.

ICCT, 2014c, *Real-world exhaust emissions from modern diesel cars*, International Council on Clean Transportation, Washington DC, USA.

ICCT, 2014d, *The WLTP: How a new test procedure for cars will affect fuel consumption values in the EU*, No 2014-9, International Council on Clean Transportation, Washington DC, USA.

ICCT, 2015a, *From laboratory to road. A 2015 update of official and 'real-world' fuel consumption and CO_2 values for passenger cars in Europe*, International Council on Clean Transportation, Washington DC, USA.

ICCT, 2015b, *Hybrid vehicles: Trends in technology development and cost reduction*, International Council on Clean Transportation, Washington DC, USA.

INFRAS and TUG, 2015, 'Information from the HBEFA group',.

JRC, 2011a, *Analyzing on-road emissions of light-duty vehicles with Portable Emission Measurement Systems (PEMS)*, Joint Research Centre, Brussels, Belgium.

JRC, 2011b, *Parameterisation of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes*, No 66088, Joint Research Centre, Brussels, Belgium.

JRC, 2012, *Sustainability Assessment of Road Transport Technologies*, Joint Research Centre, Brussels, Belgium.

T&E, 2015, *Mind the Gap 2015. Closing the chasm between test and real-world car CO_2 emissions*.

TNO, 2012, *Supporting analysis regarding test procedure flexibilities and technology deployment for review of the light duty vehicle CO_2 regulations*, TNO, The Hague, the Netherlands.

TNO, 2013, *Investigations and real world emission performance of Euro 6 light-duty vehicles*, No 11891, TNO, The Hague, the Netherlands.

For your notes

Explaining road transport emissions

Road transport is an important source of both greenhouse gases and air pollutants. Despite improvements in vehicle efficiencies over past decades, today the sector is responsible for almost one fifth of Europe's greenhouse gas emissions. Emissions from vehicles also lead to high concentrations of air pollutants above EU standards in many of Europe's cities.

This report provides a summary of the current knowledge on vehicle emissions in Europe. It also explains how emissions are monitored and the common technologies used to limit them.

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