DON'T BREATHE HERE

beware the invisible killer

Tackling air pollution from vehicles

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For more information, contact:

François Cuenot
Policy Officer
Transport & Environment
francois@transportenvironment.org
Tel: +32(0)2 851 02 28 / +32(0)49 134 46 70

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Executive Summary

Urban air in much of Europe is not fit to breathe, and vehicles, especially diesel cars, are the principal cause. High levels of particles, nitrogen oxides and unburned fuel create a cocktail of harmful pollution that is breathed by almost every urban European citizen. The effects are half a million premature deaths each year; a quarter of a million hospital admissions; and 100 million lost working days cumulatively costing over €900 billion. The crisis is taking place despite extensive EU laws that limit ambient air-pollution levels, total national emissions, and emissions from major sources including vehicles. The Commission has acted against 18 EU member states for breaching pollution levels but progress to tackle the problem is glacial. EU limits for air pollution are projected to be breached for at least another 15 years and levels will remain above World Health Organisation no-effect guidelines.

Vehicles are the principal source of exposure because of their ubiquity and the proximity of the exhaust emissions to people. For example, vehicles produce 80% of the particulates and 46% of nitrogen oxides in London[1]. There has been some progress: lead has been removed from fuel; carbon monoxide levels have been reduced; and the introduction of Euro 6 limits on diesel cars is reducing primary particulate emissions. But nitrogen oxides (NOx) remain a key problem especially from diesel engines. These are converted in the air to toxic nitrogen dioxide and ultimately to secondary nitrate aerosol particles and to ozone (when combined with unburned fuel in the air). Particle emissions from older diesels and vehicles with damaged or illegally removed diesel particulate filters remain an issue. There are also problems with gasoline vehicles notably particles from gasoline direct injection vehicles.

The reason for the continuing high emissions from new cars is an ineffective system for testing vehicles that deliver impressive reductions of emissions in laboratory tests but fail to replicate this performance when driven on the road. This problem is extensive for diesel cars and vans that typically emit on average around five times more pollution than permissible limits when driven on the road. But gasoline cars are not exempt – one in five modern petrol cars reportedly fail to achieve emissions limits on the road.[2] Laboratory tests are unrepresentative because the current EU test cycle (New European Drive Cycle, NEDC) is too slow and has insufficient acceleration. The test procedure contains loopholes the manufacturers exploit to get low results. Emissions are only optimised for the tested conditions and there is substantial anecdotal evidence that cars detect when they are tested and deploy "cycle beating" techniques to reduce emissions.

Euro 6 regulations requiring cars to be tested under "normal driving conditions" were adopted in 2007 but the real-world driving emissions (RDE) tests in which portable emissions monitoring systems (PEMS) measure the actual pollution emitted from the exhaust have still not commenced. The test procedure has largely been finalised but there remain important omissions such as failing to account for higher emissions when the engine is cold or when the diesel particulate filter regenerates (cleans itself). Furthermore, agreement must still be reached on when and which 'not-to-exceed' limits (calculated using 'conformity factors') will apply. The test will also initially only apply to diesel NOx emissions yet these are not the only issue.

How long urban air pollution remains a health issue will largely be determined by how effective the new Euro 6 limits and RDE tests are. With full implementation by 2019, non-compliance with NO_2 limit values will be virtually eliminated by 2025. In contrast a later introduction of a weaker

[1] Mayor of London, 2010, *Clearing the air: The Mayor's Air Quality Strategy*
[2] Emissions Analytics 2015, August 2015; *Air quality...it's hotting up*

limit (through high CFs) will lead to more than 10% of monitoring stations continuing to breach current limits in 2030.

There is no technical reason why limits could not be met quickly and urban air pollution rapidly improved. Technology to control emissions is available and affordable. To tackle primary particle emissions a diesel particulate filter (DPF) is now used and is effective – although there are concerns about the impacts of regeneration, especially in urban areas. A similar but simpler gasoline particulate filter could tackle the high particle emissions from gasoline direct injection engines – but because limits are not enforced in real-world tests carmakers haven't fitted them despite their low cost (around €50). Selective Catalytic Reduction (SCR) tackles the diesel NOx issues in combination with other after-treatment systems. But a majority of modern cars continue to use cheaper, ineffective systems to avoid the approximate €200-500 cost of the system. Even where carmakers fit SCR they often configure the system to be ineffective to avoid either needing a large storage reservoir or requiring the driver to refill between service internals. This is because the reagent used in SCR systems (urea) is consumed and requires replacement. By systematically under-dosing with urea, a small bottle of urea can last a year – but the emissions are unnecessarily high.

Cars are not the only issue; Non-Road Mobile Machinery (NRMM), ranging from portable machines like hedge trimmers to large off-road construction machines like bulldozers and engines for compressors, pumps and generators, emit around 15% of urban NOx and 5% of particles. The rules governing their emissions are less strict than for Euro VI trucks and currently omit particle numbers. Tests are often unrepresentative of different use patterns in this very varied sector. The European Commissions has proposed Stage V emissions regulations to address some of these issues and they contain many positive proposals. But the proposed limits fail to align NRMM emissions with those of Euro VI trucks or require the latest abatement technology. The regulation is not technology or sector-neutral with higher limits for gas engines; there are important omissions such as particulate controls on locomotives, smaller barges and large generators. The proposed reforms to testing are also too limited and should be extended to checking in-service emissions using PEMS systems.

The introduction of RDE tests is a key step in tackling vehicle emissions. But tackling the air pollution crisis quickly necessitates not-to-exceed limits to be introduced from 2017 and Euro 6 limits to fully apply two years later. The test must also address the full range of driving conditions and measure emissions from all regulated pollutants from diesels and gasoline vehicles. The emissions checks performed as part of type approval on pre-production cars must be validated by a greatly expanded programme of conformity checks to confirm vehicles sold to consumers also meet these limits and prevent carmakers optimising type approval tests. More in-service conformity checks to confirm pollution abatement equipment continues to operate effectively throughout its lifetime – as successfully undertaken in the US – are also needed and the data should be routinely published.

The Commission must also bring an end to the system in which carmakers select the bodies to test and check their compliance with limits and replace it with a truly independent European type approval authority. This could be funded by manufacturers paying a levy on each new car sold that would be used to finance independent testing. The system of checking that cars continue to meet acceptable pollution limits (Periodic Technical Inspections) is also out-dated, insufficient and in urgent need of improvement. This would ensure that SCR and particle filters function correctly throughout the life of the vehicle. In particular, PTI could be strengthened by setting an expiration date for the type approval certificate. This would ensure that older, more polluting vehicles get scrapped or used to a very limited extent beyond a given age. The Commission must also bring forward proposals for Euro 7/VII emissions limits to end the systems of different limits for diesel, gasoline and natural gas cars and to ensure WHO health guideline limits are met in heavily trafficked locations throughout Europe. Ambitious Euro 5 standards for motorcycles and scooters should equally be agreed to reduce emissions from this sector and promote use of electric two-wheelers.

This required future work programme of the Commission would address much of current crisis but member states must take complementary actions. Diesel taxes should be raised to be equivalent with those of gasoline on the basis of their energy content. This would begin to shift the market in favour of less polluting gasoline, hybrid and ultimately electric cars. CO_2–based vehicle taxes should also include an adjustment to account for higher diesel air pollution emissions. Incentives could also be introduced to encourage the supply of vehicles with emissions significantly below that of Euro 6. This includes supporting through tax schemes and infrastructure the market for electric vehicles that produce zero air pollution in cities. Funding should also be supplied for retrofit programmes to reduce the emissions of older heavy-duty vehicles and NRMMs. National governments should also support and encourage local measures to manage traffic or emissions in pollution hotspots such as: cleaning up municipal fleets; tackling emissions from buses and taxis; establishing pedestrian areas; placing restrictions on vehicular access for all or high-emitting vehicles through low emission zones; and establishing goods trans-shipment centres.

We cannot choose where we breathe so we must stop cars polluting our city air. The technology to clean up vehicle and machinery exhausts is available and costs a few hundred euros. It is a small price compared to the nearly €1 trillion spent annually in health care and lost output and productivity. Cars with engines must be stopped from polluting our air or prevented from accessing our cities. Citizens deserve the right to clean air wherever we need to breathe.

Recommendations for EU action

Euro 6:	Agree an ambitious RDE package that has strict not-to-exceed (NTE) limits for all pollutants, and which includes all engine operating conditions
NRMM:	Align emission limits and testing for non-road mobile machinery with the provisions in place for Euro VI for HDVs
Testing:	Introduce a system of random conformity of production checks and in-service testing overseen by an independent EU Type Approval Authority
Euro 7/VII:	Commission proposal for Euro 7/VII limits for cars, vans and trucks to align limits for diesel, gasoline and natural gas vehicles to enable WHO air pollution guidelines to be met
Motorcycles:	Agree Euro 5 standard for motorcycles and scooters and pro- mote electric two-wheelers within a wider EU strategy on electro-mobility
EU law:	Simplify EU infringement procedure to shorten the steps leading to penalties for non-compliant member states

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The continuing menace of air pollution and the role of transport

Human activities release a large number of different pollutants into the atmosphere, which harm human health and damage the environment. The consequences include: irritation of the skin, eyes, or other sensitive membranes; nuisance caused by noxious smells; acute and long-term toxic effects; and carcinogenicity. Vehicles with internal combustion engines are a dominant source of many of the air pollutants of greatest concern and are, together with construction equipment, the subjects of this report.

Pollution from vehicles is emitted close to where people live and therefore has a much greater impact on human health than more diffuse sources like agriculture or emissions from industry that are widely released high into the air from tall stacks Transport emissions thus lead to higher levels of exposures to the population, as transport activities occurs where people lives, unlike most of the other sources of pollution emissions.

Generally, the evidence of adverse health effects in those living or working close to major roads is growing steadily. However, it has proved difficult to disentangle the individual effects of the many different substances that make up the cocktail of traffic pollution.

Carbon dioxide (CO_2), formed by the oxidation of the carbon in the fuel, does not affect human health in the normal concentrations found in ambient air, so it is not considered a pollutant for air quality purposes. It is however the most important greenhouse gas, and is relevant to some other aspects of this report, so it will be referred to again later.

1. Urban air pollution in Europe

1.1. Exceedances of EU air quality limit values

Air pollution in Europe continues to be significantly above the levels that the World Health Organization (WHO) considers to be a risk to human health. In its latest annual report on air quality[3], the European Environment Agency summarises the current position on exposure to major pollutants across Europe's urban populations as set out in Table 1 below.

Pollutant	**Estimated % exposed above EU reference value**	**Estimated % exposed above WHO guide value**
Particulates ($PM_{2.5}$)	10–14	91–93
Particulates (PM_{10})	21–30	64–83
Ozone (O_3)	14–17	95–98
Benzo(a)Pyrene	24–28	85–89
Nitrogen Dioxide	8–13	8–13
Sulphur Dioxide	<1	36–43
Carbon Monoxide	<2	<2
Lead	<1	<1
Benzene	<1	10–12

Notes: Pollutants are ordered in terms of their relative risk to health, with the highest first.
Estimates are for 2010-12, with adjustments for meteorology, allowed exceedances, etc.

Table 1. Percentage of the urban population in the EU-28 exposed to air pollutant concentrations above EU and WHO reference levels

[3] European Environment Agency - http://www.eea.europa.eu/publications/air-quality-in-europe-2014

According to the WHO guidelines, which indicate the level of pollution at which health effects occur, over 80% of the EU urban population is exposed to unacceptable levels of air pollution. However, only 20% lives in areas breaching EU air pollution limits. EU limit values for many pollutants are unacceptably high and should be lowered to align with WHO Guideline values.

For NO_2 – nitrogen dioxide; an important pollutant from traffic and a major precursor of ozone and particulate matter – around 10% of Europe's urban population is also exposed to above-safe levels designated by the WHO. In addition:

- On average, $PM_{2.5}$ rural and urban background concentrations remained at the same level from 2006 to 2012, while just a small decline was observed at traffic stations;
- There was a flat trend for O_3 concentrations between 2003 and 2012 in 80% of the monitoring stations, and while 18 % of the stations registered a decreasing trend, 2% registered an increase;
- The estimated decrease in NO_x emissions (30% between 2003 and 2012) is not reflected in the fall in measured NO_2 annual mean concentrations in ambient air (of around 18%) in the EU, and the EEA attributes this primarily to increased primary NO_2 emissions from diesel vehicles.

In contrast carbon monoxide and lead pollution from traffic have been largely resolved through changing fuel quality and use of exhaust after-treatment systems.

1.2. The health impacts of air pollution

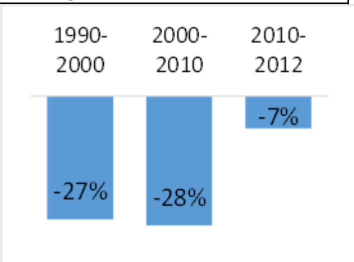
The WHO recently estimated that across Europe, 500,000 premature deaths were attributable to air pollution in 2012[4]. Heart disease and stroke were the most common causes, accounting for 80% of the cases, followed by lung diseases and lung cancer. In addition to causing such premature death, air pollution increases the incidence of a wide range of diseases (mainly respiratory, cardiovascular, and cancer-related) including those listed above, and leads to both long-term and acute health effects.

More detailed modelling by the European Environment Agency (EEA) for the EU-28 countries suggests around 430,000 premature deaths arise from PM2.5 concentrations alone. Germany, having the largest population of the EU-28 countries, has the highest estimate of premature deaths at over 69,000 per year. Italy and Poland (with almost 65,000 and 42,400 premature deaths per year, respectively) are next highest, owing in part to higher levels of exposure to PM2.5. More generally, exposure rates and mortality rates across central and eastern Europe both tend to be higher than the average rates. The most important pollutants from transport are summarised in Table 2 below, and pollutants of lesser concern are summarized in Annex 1.

[4] WHO, 2014, *Burden of disease from Ambient Air Pollution for 2012 - Summary of results*, World Health Organization, http://www.who.int/phe/health_topics/outdoorair/databases/AAP_BoD_results_March2014.pdf

Nitrogen Oxides (NO_x)

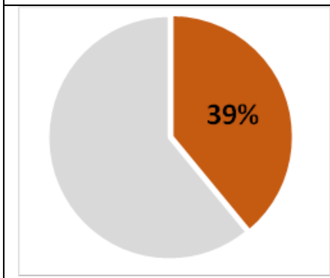
Change in Emissions



Sources: NO_x can be formed in any high-temperature combustion process, but it is primarily formed in vehicle engines and power plants. NO_x, comprising mainly nitric oxide or nitrogen monoxide (NO) and nitrogen dioxide (NO_2), is formed through the chemical combination of nitrogen and oxygen in the combustion process within a cylinder. For most sources, only a small proportion of emissions are primary NO_2, but for diesel engines NO_2 typically makes up most of the NO_x emitted.

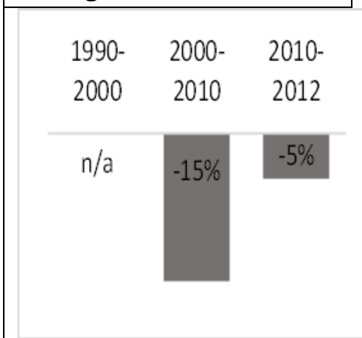
Health Impacts: NO is not a primary pollutant because it is not directly harmful to human health. However, it oxidises in the air to form NO_2, which is a primary pollutant. NO_x also contribute to the formation of secondary particulate matter (nitrate aerosol). Scientific evidence links short-term NO_2 exposures to adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma or other pre-existing respiratory problems. Recent evidence show that NO_2 has an effect on mortality as big as PM2.5[5]. NO_x in the air also reacts with ammonia, moisture, and other compounds to form very small particles.

Transport Share in 2012



Particulate Matter (PM)

Change in Emissions



Sources: PM consists of particles suspended in the air. Sea salt, black carbon from combustion, dust, and condensed particles from certain chemicals can all be classified as PM. During internal combustion engine operation, the combination of unburnt carbon particles with condensed heavy fractions of hydrocarbons and sulphates originating from sulphur in the fuel give rise to particulate matter (PM) in vehicle exhaust. Black carbon particles are particularly associated with diesel engines, and these may have other harmful compounds adsorbed onto their surfaces. Wear on brake pads, clutches, and tyres also contribute to particulate emission and re-suspension.

The smallest particles are of greatest concern. They are measured as PM_{10} (diameter less than 10 micrometres), $PM_{2.5}$ (less than 2.5 micrometres), and UFP (Ultra Fine Particles, less than 0.1 micrometres).. Smaller particles are particularly affected by wind conditions and can travel hundreds of kilometres, but the highest concentrations of them are always found close to busy roads. Working on the background and street PM concentration reduction must be a coordinated effort between local, national, and transboundary emission sources.

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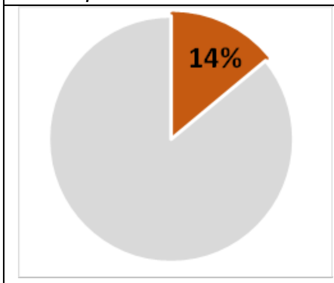
[5] Faustini et al., 2014, Nitrogen dioxide and mortality: review and meta-analysis of long-term studies: http://www.ncbi.nlm.nih.gov/pubmed/24558178

Health Impacts: Small particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory diseases, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and even premature death. The PM component of air pollution is also most closely associated with increased incidence of cancer, especially lung cancer. Indeed, in 2012, the International Agency for Research on Cancer (IARC) reclassified diesel engine exhaust as carcinogenic to humans. There is little evidence to suggest a safe threshold for particulates, and effects can be detected at little more than background concentrations, especially for $PM_{2.5}$.	*Transport Share in 2012* 

Source: EEA and WHO various documents

Table 2. Summary of key air pollutants

According to EEA estimates, ozone exposure causes perhaps several tens of thousands of additional deaths across the EU-28. A further 8% or more of the EU's urban population was exposed to an average annual NO_2 concentration above the limit value and WHO Guideline. Although this is likely to cause both cardiovascular and respiratory mortality and respiratory morbidity, the scale of these impacts has not been quantified by the WHO. Recent evidence suggests that health impacts of NO_2 emissions could have been significantly underestimated.[6]

1.3. *Regulation of air pollution in Europe*

A complete framework of air pollution legislation is now in place in Europe, but weak implementation and standards undermine its effectiveness.

- Regulating air pollution concentration levels: Air quality is measured via a network of air pollution concentration measuring stations around Europe and is subjected to air quality emission limits defined in the Ambient Air Quality Directive (AAQD). However, enforcement of the limits is weak and siting of some monitoring stations is questionable in some instances. The limits which are applied are also significantly above the levels that cause health effects for many pollutants.
- Capping the emission: the National Emission Ceilings directive aims at providing a cap on how much of each pollutant can be emitted in Europe, with emission limits defined by member states via reduction targets to be reached in the coming years. Caps have been set generously high for many pollutants. Others, such as mercury, have even been excluded from the regulatory system entirely.
- Emission source legislation: the pollutant emission from big emitters is regulated where it is released, requiring the implementation of alternative and/or advanced technologies to reduce the emissions. For the transport sector, all vehicles and machines are regulated at the source but the use of obsolete tests means far more pollution is generated on the road than in official tests. Different modes have required different innovations, and emission limit values have improved significantly since the first implementation in 1992. Modes that were introduced later are not facing similar challenges because they can benefit from technologies developed earlier. Nevertheless, some modes (mainly barges and diesel locomotives) are lagging behind (Figure 1).

[6] 60,000 killed annually: UK's misjudged air pollution highlighted in upcoming report, http://rt.com/uk/210335-pollution-deaths-traffic-nitrogen/

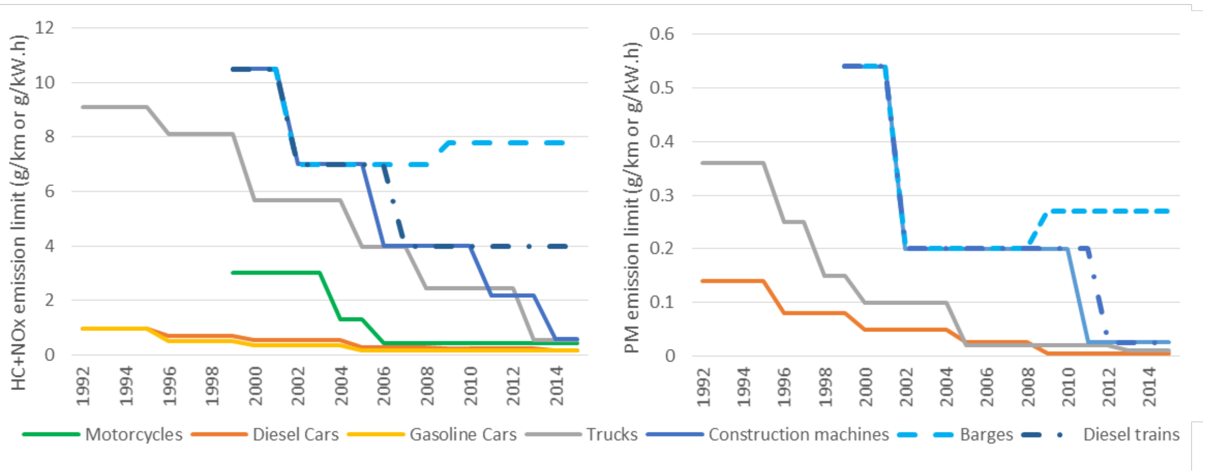


Figure 1. Emission limits evolution over time for PM and HC+NO$_x$, by mode

- The EU Infringement procedure: in the case of any member states not respecting a European law, an infringement procedure is engaged towards the non-compliant member state(s). This is especially true for air quality legislation, with more than half of the member states currently under infringement procedure for not respecting the European law for at least one pollutant (Figure 2).

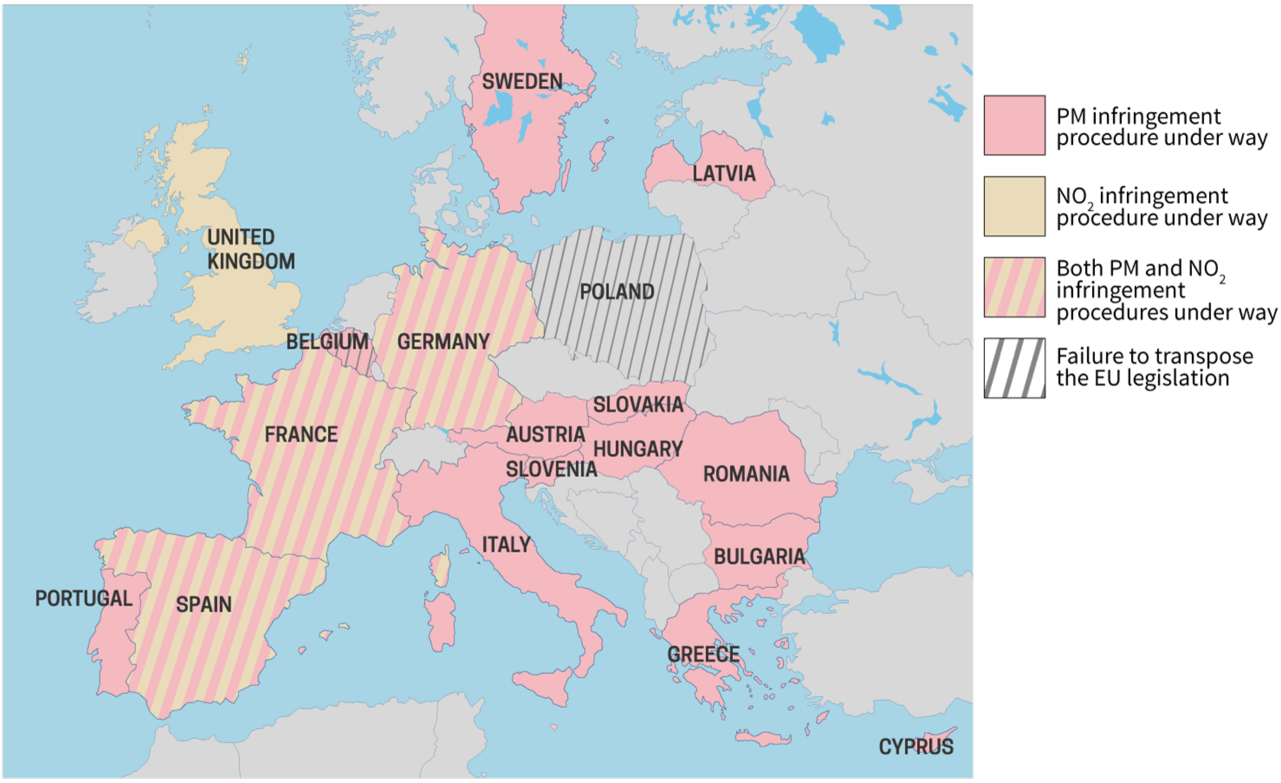


Figure 2. EU member states under infringement procedures on air quality legislation

This set of legislative acts forms what is called the EU Air Quality Strategy. A more extensive description of each legislative tool, with a specific view on transport related issues, is given in Annex 2.

1.4. Road traffic and air pollution

1.4.1. Vehicles' contribution to urban air pollution

Because of its ubiquity and proximity to human habitations and public spaces, road traffic remains a major contributor to many of our air quality problems and contributes an ever-growing share. For example, it produces 80% of the particulates in central London and 46% of all the nitrogen oxide emissions in Greater London[7]. These values are likely to be fairly typical of other large towns and cities across Europe, and remains the case in spite of the efforts outlined above to curb emissions from new vehicles via tighter legislation. The latest data from the EEA's database of air pollution illustrates the impact of traffic on overall air pollution[8].

Some pollutants have been successfully tackled. Figure 3 illustrates a clear 'success story' for vehicle emissions controls - carbon monoxide. Back in 1990, nearly half of all traffic-related monitoring stations registered exceedances of the currently allowed daily maximum value. However, the introduction of the three-way catalytic converter to spark-ignition engines led to a clear and rapid improvement throughout the 1990s, which has been maintained since then. With occasional weather-related spikes, improvement continued through the last decade and non-attainment has now been virtually eliminated at all station types.

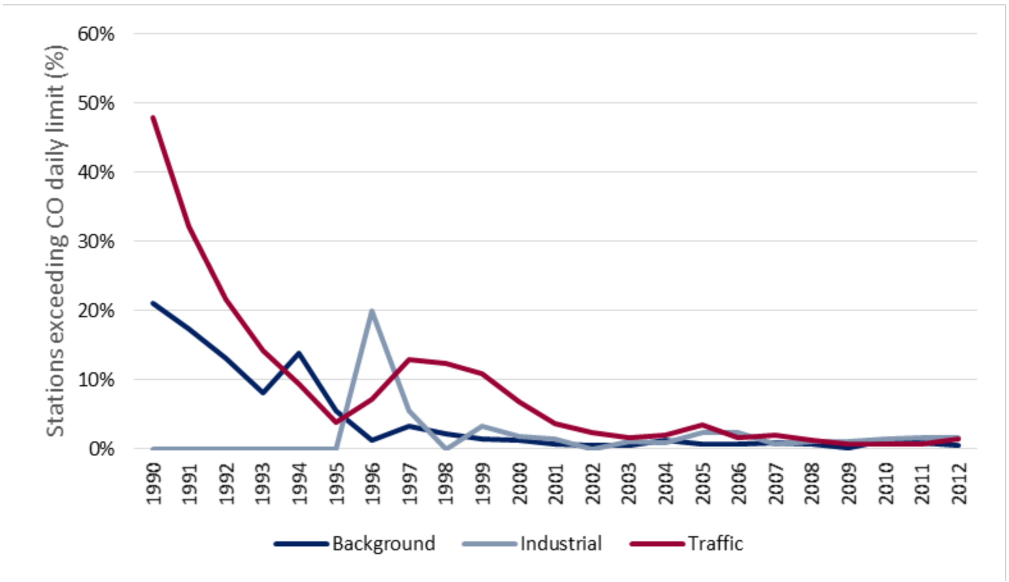


Figure 3. Carbon Monoxide: % of Stations Exceeding Allowed Daily Maximum

[7] Mayor of London, 2010, *Clearing the air: The Mayor's Air Quality Strategy*
[8] http://www.eea.europa.eu/data-and-maps/data/airbase-the-european-air-quality-database-8

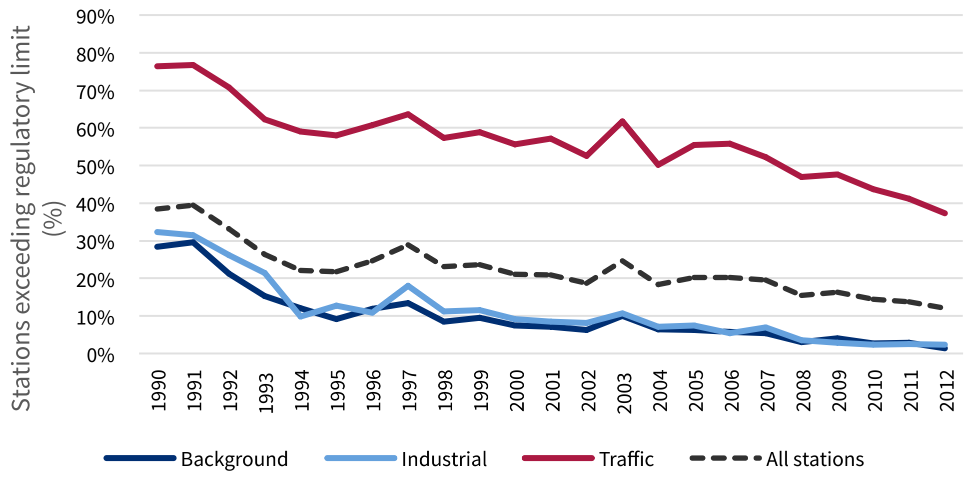


Figure 4. Nitrogen Dioxide: % of Stations Exceeding Allowed Annual Average

As Figure 4 illustrates, however, it is a very different story for NO_2. Background and industrial stations have improved steadily over time, much as they did for CO, and exceedances have now almost been eliminated. Traffic stations started from a much higher level and have improved fairly steadily (but slowly) since the mid-1990s. In 1990, around three-quarters of all traffic stations registered exceedances. Still today more than one in three stations are not attaining the annual average limit value, exposing member states to legal proceedings for exceeding the legal limit.

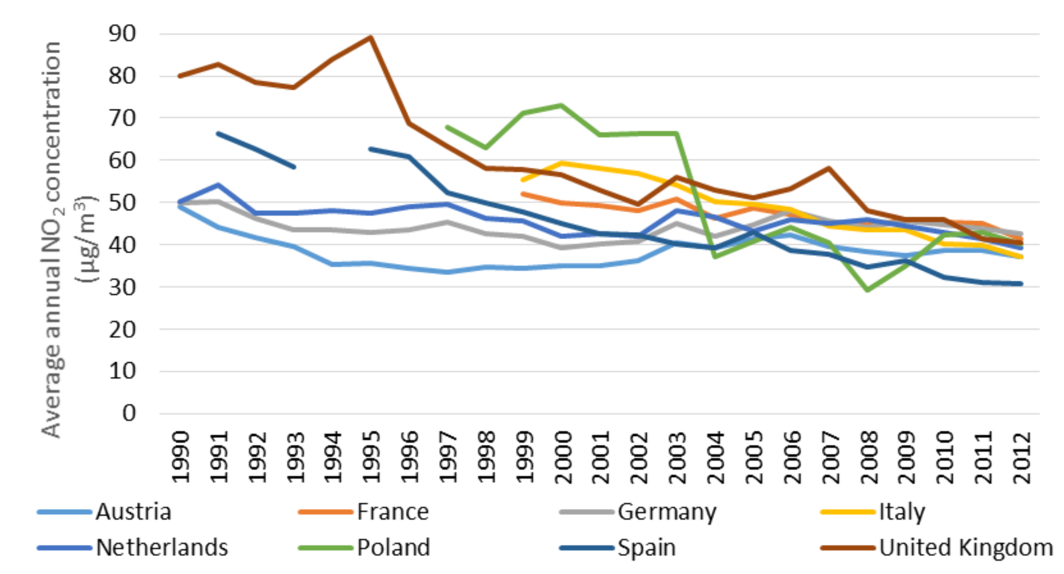


Figure 5. Average NO_2 Annual Mean from Traffic Stations by Country

Figure 5 shows the progress made in reducing average pollution levels of NO_2 at traffic stations for each of the eight largest member states. Most of these States show the same slow downward trend of Figure 4; with Germany being an exception by having showed very limited progress for the last decade. The UK has made slightly more progress than the others but also started from a very high base. Only Spain is now significantly below the limit value of 40 µg/m^3, with others improving gradually but all still averaging around the limit value.

This is clear evidence that the problem of traffic-related emissions has not yet been solved, in spite of tightening limit values for new cars. Furthermore, concentrations of pollutants in vehicles and near roadways are often appreciably higher than those measured at fixed monitoring stations, so these figures may understate the impacts on some motorists and other road users[9].

As noted above, pollution is often at its worst in major conurbations for much the same reasons; that is, the intensity of emissions is greater and the urban landscape impedes their rapid dispersion. Wind, rain, and ascendant air currents are often a great ally in hiding the real face of air pollution in cities. The extent of air pollution in cities is only revealed when the weather conditions offer no dispersion, and this very often leads to long and severe air pollution episodes in cities.

Thousands of people die prematurely in European cities each year because of air pollution. Warm, still weather over Paris in March 2014 and 2015 led to extremely high levels of particulates and concern for citizens' health. This prompted the authorities to ban half of all conventional cars and make public transport systems temporarily free for travel. Looking for a more long-term solution, the mayor of Paris has proposed a ban on diesel cars in the city by 2020 – a controversial suggestion in a country where well over half of all new cars are diesel-powered.[10]

1.5. *Why urban air pollution is not improving – test versus real-world driving*

Predicting future air quality across Europe is an extremely complex task and involves many uncertainties. However, one of the key assumption made in the Clean Air For Europe (CAFE) process (Annex 2) when calculating the likely future contribution of traffic emissions to poor local air quality was that any percentage reduction in new car limit values would lead to a corresponding percentage cut in real-world emissions on the road. As Shown in this report, it turned out to be severely wrong in a number of cases.

In a recent publication[11,] T&E highlighted the growing gap between tailpipe CO_2 emissions and fuel consumption as measured on the official test cycle and the significantly higher levels of fuel consumption of the same cars on the road. This ever-growing 'gap' between real-world driving emissions (RDE) and test results was found to arise because of:

- An unrealistic and undemanding test cycle no longer representative of real-world driving conditions;
- Too many flexibilities and loopholes in the testing protocols that allow carmakers to game the system;
- Lack of transparency in the testing procedures; and
- Growing pressure on carmakers to game the system as regulated limits on CO_2 become increasingly stringent (for CO_2 in particular, substantial fiscal incentives on the lowest-emitting cars added further to this pressure).

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[9] See for example http://www.epa.gov/otaq/nearroadway.htm

[10] http://www.nytimes.com/2014/12/16/world/europe/a-plan-to-limit-cars-in-paris-collides-with-french-politics-.html?_r=0, http://www.lefigaro.fr/conjoncture/2014/12/07/20002-20141207ARTFIG00066-anne-hildago-ne-veut-plus-du-diesel-a-paris-d-ici-2020.php?print=true

[11] *Mind the Gap! Why official car fuel economy figures don't match up to reality*, 2013, T&E, http://www.transportenvironment.org/publications/mind-gap-why-official-car-fuel-economy-figures-don't-match-reality

In the next chapter, we will show that the situation is much worse for regulated pollutants than it is for CO_2; that is, for some kinds of vehicles, the ever-tighter Euro standards have not been matched by similar cuts in actual emissions on the road. Indeed, the divergence between test cycle and real-life emissions levels of regulated pollutants can be even more extreme under certain driving conditions than the fuel economy gap. Driving characteristics can lead to a 'spike' in emissions much more dramatic than any impact on fuel and CO_2. These sorts of effects can largely or totally counteract the tightening of limit values over time, and there is now substantial evidence to back this up.

1.6. How long-term air pollution is expected to remain an issue under different scenarios

Recently-updated projections for the UK by the national environment ministry Defra indicate that some exceedances will persist even beyond 2030[12]. Similarly, for the Paris region it is forecast that at least 750km of road will exceed NO_2 limits in 2020 and 220km will exceed PM_{10} limits[13]. Other EU member states have similar concerns.

Indeed, as all official estimates tend to be based on the assumption of improving levels of real-world emissions from newer vehicles in line with Euro standards, it is likely that even these projections are overly optimistic.

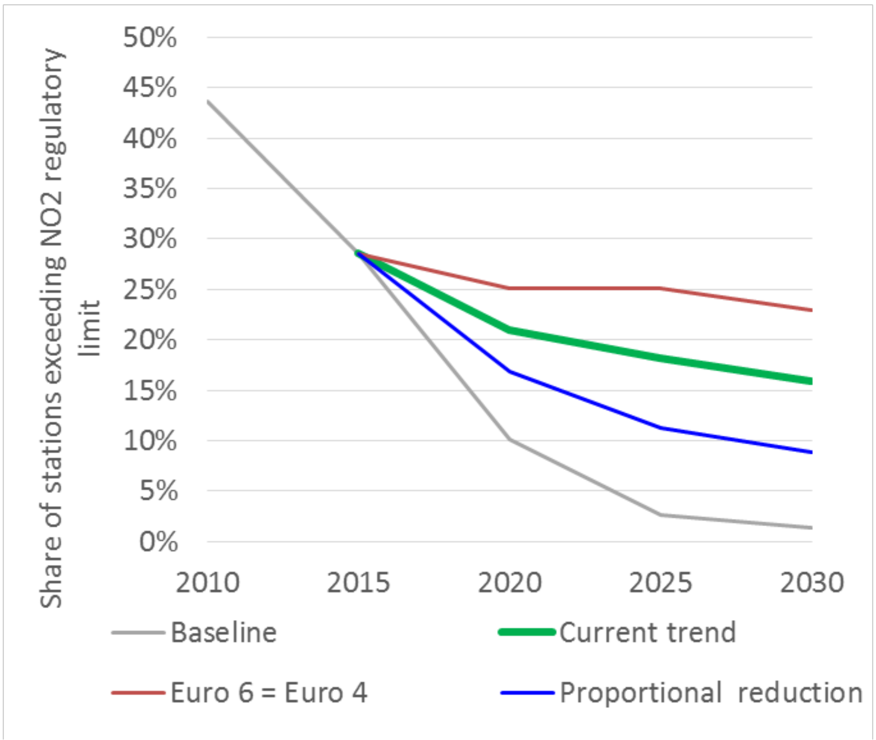


Figure 6. Future NO_2 noncompliance under a range of assumptions

Source: adapted from National Emission Ceiling Impact Assessment[14]

For example, Figure 6 above is adapted from the European Commission's impact assessment of its most recent air quality measures. This illustrates the future trajectory of NO_2 compliance under a range of assumptions about the future emissions from diesel cars under Euro 6. It shows that if future diesel cars deliver significant reductions in NO_x emissions as the legislation intended, noncompliance with NO_2 limit

[12] Defra website: *Updated projections for Nitrogen Dioxide (NO_2) compliance* – http://uk-air.defra.gov.uk/assets/documents/no2ten/140708_N02_projection_tables_FINAL.pdf

[13] *Évaluation prospective des émissions et des concentrations de polluants atmosphériques à l'horizon 2020 en Ile-de-France – Gain sur les émissions en 2015*, 2012, Airparif, www.airparif.asso.fr/_pdf/publications/ppa-rapport-121119.pdf

[14] http://ec.europa.eu/environment/archives/air/pdf/Impact_assessment_en.pdf, Figure 8

values will be virtually eliminated by 2025; and if it delivers only a proportionate reduction in emissions, then noncompliance will be reduced, with about 10% of traffic stations exceeding the NO_2 regulatory limit. If, however, as currently is the case, Euro 6 emissions turn out to be only marginally better than Euro 4, then there will be limited progress in eliminating problems with nitrogen dioxide pollution. If the Euro 6 procedure remains unchanged, a significant share of monitoring stations will still be exceeding NO_2 regulatory limits in 2030.

1.6.1. Non-Exhaust emission sources

Most of the focus on air pollution from transport is on the pollution from exhaust gases. Nevertheless, tyre, brake, and road wear is also emitted pollution into the atmosphere, mainly in the form of particulate matter. Most studies trying to quantify the amount of particulate emissions due to tyre, brake, and road wear offer diverging conclusions[15], and it is therefore hard to determine the individual contributions of these sources. . One such study led by the UNECE PMP IWG is trying to define harmonized test conditions to measure such wear. Recent reports highlight that brake wear could be measured reliably in the near future, but this is not expected to be the case for road and tyre wear[16].

Another source of emission is the re-suspension of particulates already emitted that are lying on the road. Specific road treatment to glue such particulate (with what effect on road friction?) or traffic reduction measures appear to be the most adequate options to limit the re-suspension of particulate.

Chapter 2 now gives further details of the issues surrounding the ‘gap’ between emissions testing limits and emissions under real-world driving conditions.

2. Why Euro standards are failing

2.1. Applying the Euro emissions limits to road vehicles – EU type approval

The emission limits for cars and vans that were outlined in Section 1 are applied through a laboratory test procedure partly designed in the 1970s by the United Nations Economic Cooperation for Europe (UNECE). It is intended to test vehicles under conditions similar to real-world road conditions. Euro standards for cars set limit values for the regulated pollutants (carbon monoxide, hydrocarbons, NO_x and particulates) that must not be exceeded during a chassis dynamometer test using the New European Drive Cycle (NEDC) test cycle. More recently, CO_2 emissions, non-methane hydrocarbons, and particle number (PN) have been added to the emissions tests as variables to be measured.

The New European Drive Cycle (NEDC) test procedure which is used in the EU was designed in such a way that it would be simple and relatively quick to apply, and that the results for tested vehicles could be easily compared and reproduced in repeat tests. To achieve this, the test is standardised to a high degree in its driving conditions, speed profile, ambient conditions, etc. The speed profile of the test cycle is illustrated in Figure 7 below.

[15] http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-vi-road-tyre-and-brake-wear.pdf
http://publications.jrc.ec.europa.eu/repository/bitstream/JRC89231/jrc89231-online%20final%20version%202.pdf
16 http://www.unece.org/fileadmin/DAM/trans/doc/2015/wp29grpe/GRPE-71-23.pdf

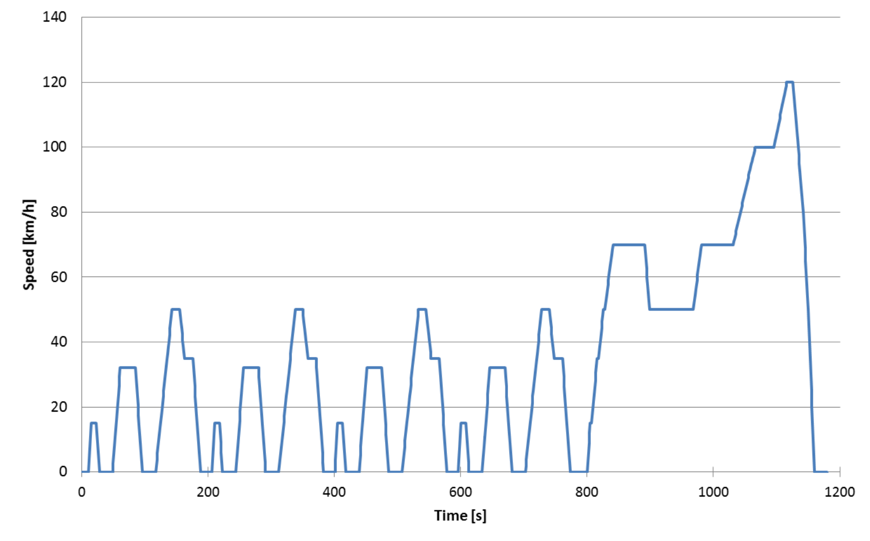


Figure 7. Vehicle speed trace of the NEDC test cycle

The entire NEDC covers a distance of just over 11 km in 1180 seconds (just under 20 minutes) at an average speed of 34 km/h. The test cycle is characterised by low accelerations and a low vehicle speed relative to real-world driving. This also results in a rather low engine load as compared to real-world driving behaviour. Additionally, the vehicle is stationary for 24% of the entire test and decelerating for a further 16%. In fact, this driving cycle was not derived from real driving but developed synthetically into a stylistic pattern with repetitions of the same kinds of speeds and accelerations to facilitate its accurate repetition. Since the late 1990s, cars have become progressively more computer-controlled, enabling car manufacturers to produce vehicles specifically designed to produce low emissions during the laboratory test. The NEDC test cycle is obsolete and entirely unrepresentative of the real-life operations of the tested vehicles.

2.2. The growing gap between test cycle and real-world driving

As a result, the standardised test covers a tiny share of the driving situations and conditions that vehicles would encounter during their everyday driving on the road. To put it more technically, there are only a few limited areas of the entire engine 'map' that are actually engaged during the test cycle. An engine map is the diagram that shows the operating area of the engine with engine speed on the horizontal scale and engine torque on the vertical scale. A typical engine map under the NEDC cycle is illustrated in Figure 8 below for a fairly modest-sized diesel engine.

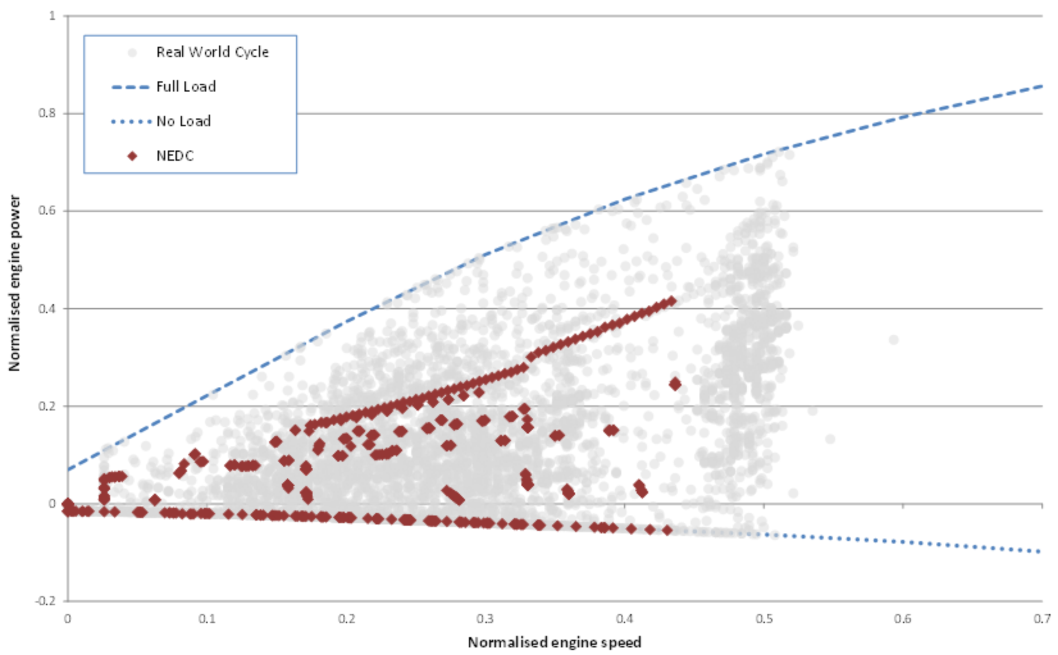


Figure 8. Engine map comparing engine load distribution in the NEDC and 'real-world' driving cycles for a C-segment car with a 80 kW diesel engine

In this diagram, the upper limit of the map is shown by the maximum torque curve – the upper dotted line showing the maximum possible power output at a given engine speed. The lower dotted line is the lower limit, when the engine is under no load because the vehicle is coasting, decelerating, or stationary. For each of the two cycles shown, each dot represents one second of the test. For the real-world test, the numerous grey dots form a cloud that populates most of the engine map up to a given maximum engine speed; for the NEDC, the dots are very sparsely scattered by comparison. Many of the latter lie on the no load curve, reflecting the high proportion of the test spent decelerating or stationary, while the virtually continuously sloping line of dots halfway up the map reflects the regular and repeated accelerations shown in Figure 8. This represents the highest load encountered on the NEDC, but it is still far short of the maximum power output of even such a modest-sized engine, reflecting how gentle the specified accelerations are by modern standards. Elsewhere, the NEDC dots are very sparse and almost all fall within only a small area of the full engine map.

This enables manufacturers to optimise emissions only for the limited areas of the red dots, while outside these areas the engine and/or aftertreatment equipment may be optimised for other engineering goals (e.g. low fuel consumption, driveability, power) at the cost of increased emissions.

Before the 1990s, there was no need to apply complicated engine control measures or after-treatment systems to fulfil the emission standards, as the standards were not very stringent. As a result, the emission performance in the real world was equivalent to the type-approval values in spite of the undemanding test cycle. However, owing to regulatory pressures and other reasons, computerised engine management systems have now become far more sophisticated and can control engine and after-treatment performance with great precision for every part of the engine map. At the same time, engines have become more powerful, so the NEDC populates an ever-smaller part of the whole engine map. Both of these trends make it easier to manage the engine differently in NEDC conditions than elsewhere.

Thus the connection between emissions on the road and during the test has been gradually lost. The laboratory test as it is now is obsolete, and this situation has led to the growing gap between real-world and type-approval emissions for both pollutant and CO_2 emissions.

2.2.1. *Real-life pollutant emission measurement*

The gap between laboratory and real-life emissions is nothing new and emission inventories software have included more realistic emission factors for pollutants for some years now. Tested vehicles are usually a few years old, abecause emission inventories focus on the most popular vehicles in the fleet, so often older than Euro 6. Vehicles are mostly tested on a chassis dynamometer using a more demanding test cycle, such as CADC or Artemis. The data available is now coordinated by the EU JRC in the ERMES group.

2.2.2. *Summary of cycle optimization evidence*

A number of independent studies have now confirmed the chasm that exists between emissions measured in official tests in a laboratory and those emitted in real life.

A summary of the main reports on this topic can be found in Annex 3. All studies show that Euro 6 diesel cars NO_x emissions exceed the legal limit by a factor of 5 to 10, when tested under stringent conditions using a Portable Emission Measurement System (PEMS) on open roads (Table 3). A small number of vehicles nevertheless manage to reach the legal limit in real-life conditions, showing that existing technologies can be up to the challenge of meeting emission limit in real-life conditions.

Author	Year	N° of Euro 6 diesel tested	Type of measurement	Test severity	Average NO_x CF	N° of vehicles reaching the legal limit
EU JRC	2012	1	PEMS	Severe	2.6	0
INFRAS	2013	9	Dyno - CADC	Mild	4	NA
TNO	2010-2015	16	Dyno	Mild	2.9	1
		7	PEMS	Severe	5.2	0
ICCT	2014	15	PEMS	Severe	7	1
ADAC	2015	70	Dyno - WLTC	Weak	2.5	18
Baden Württemberg	2015	3	PEMS	Severe	4.2	0
Emission Analytics	2014-2015	25+	PEMS	Severe	4.5	3

Table 3. Summary of public domain data sources on more stringent Euro 6 diesel NO_x testing

The evidence for passenger cars and heavy duty trucks is now robust, but this is not the case for light commercial vehicles, for which very limited data on real-life measurement have been identified to date. They are nonetheless expected to perform no better than passenger cars .

Approaches to 'real-world' testing undertaken

On-road testing of vehicles will typically give the best and most representative evidence of the size of the emissions gap. In the past, on-road testing of emissions was very difficult to perform, but now vehicle emissions can be quite reliably measured on the road using a Portable Emission Measurement System (PEMS). PEMS is a device that is not part of the vehicle but installed to the vehicle to determine the concentration or the amount of gaseous or particle pollutants, as shown in the picture below.

Even though each on-road test is unique, and can therefore not be easily compared with another test, PEMS testing covers a wide range of operating conditions. Car manufacturers should make their cars resilient to this wide variety of usage patterns instead of trying to make them more uniform.

Tests in the laboratory with a more representative test cycle than the NEDC (such as the CADC) mainly reflect the gap generated by the limitations of the test cycle itself. Such tests are reproducible so the results allow for comparison and verification, but they do not usually reflect the possibility of unrepresentative road-load settings or other weaknesses in the testing procedures, and may therefore understate the full scale of the emissions gap in the real world.
The light-duty vehicle test cycle is expected to switch away from the NEDC towards the World Light duty Test Procedure (WLTP). Even though the WLTP will cover a much broader range of engine operating conditions, it is substantially longer, making the cold phase proportionally less important for emission limits expressed in g/km (see section on WLTP).

2.3. Aftertreatment technologies

The increasing stringency levels of the Euro standards has required vehicle manufacturers to apply more sophisticated engine control systems and calibration strategies and introduce aftertreatment technologies such as those described below to meet Euro Standards. From the outset, the Euro 1 emission standard had the effect of requiring positive ignition-engined (PI or spark ignition – mainly petrol or gasoline, and also natural gas vehicles -NGVs- and liquefied petroleum gas –LPGs) cars to be fitted with three-way catalytic converters. These have become more sophisticated over time but the technology remains the same, proving its effectiveness. As emission limits have tightened, more sophisticated technologies have been needed, particularly for diesel engines. Currently, a vehicle complying to Euro 6 standards will need a combination of different in-engine and aftertreatment technologies.

2.3.1. Gasoline vehicles (positive ignition –PI-engines)

The main regulated emissions produced by gasoline or petrol-engines (and other PI engines such as natural gas and liquefied petroleum gas) are HC, CO and NO_x, plus PM and PN for direct injection gasoline engines.

2.3.1.1. Three-way catalytic converter (TWC)

All PI vehicles certified to Euro standards since 1990 are equipped with a TWC, a very reliable and effective solution for pollutant emission abatement. Essentially, the catalyst promotes three simultaneous reactions that oxidise carbon monoxide and unburnt hydrocarbons to form carbon dioxide and water, while also reducing NO_x to elemental nitrogen. To allow these reactions to take place in the most effective way, the engine needs to operate in a narrow range of air/fuel ratios, slightly above the stoichiometric point at which the amount of air present is exactly sufficient to burn all the fuel in the mixture. To keep the engine at the stoichiometric point, the engine is fitted with an oxygen sensor in the exhaust system that feeds back to an advanced air/fuel control system in the engine. TWCs do not work equally well in all conditions (for example, when the engine is cold), but the evidence still suggests that TWCs now work quite efficiently overall, and the conditions that give rise to excess emissions are limited (for example, at very high speeds where the mixture is richer where excess fuel is used to cool down the TWC).

2.3.1.2. Gasoline particulate filter (GPF)

Emissions of particulates are also generally very low from PI engines, with the notable exception of direct-injection engines, which do produce significant amounts of ultrafine particles. These may therefore need additional emissions reduction technology; for example, a GPF. A filter for a PI engine is similar to the diesel particulate filter described below but is cheaper and simpler to implement[17].

2.3.2. Diesel vehicles (CI engines)

The operating principle of the diesel engine is to inject the fuel directly into the cylinder, in which there is more air available than needed for the combustion (known as lean burning). However, this excess air in combination with a high combustion temperature encourages the formation of NO_x in particular. The fuel directly injected into the cylinder can also lead to PM formation due to incomplete combustion. CO and HC emissions are generally very low in diesel vehicles because of the lean engine operation.

2.3.2.1. Engine management

NO_x emissions can be influenced simply by the timing of the fuel injection in a diesel engine: late injection reduces the engine-out NO_x emissions but at some cost in fuel efficiency and vice versa. This trade-off leads to an incentive for manufacturers to calibrate their engines towards low emissions during the test cycle, while for those conditions not encountered during the test cycle the primary aim is to improve fuel efficiency. To meet Euro 5 NO_x standards, this and other relatively minor adjustments were sufficient, but to meet the increasingly stringent limits, more advanced reduction technologies are needed, as set out below.

2.3.2.2. Exhaust gas recirculation (EGR)

EGR recirculates some of the exhaust gas back into the engine. As a result, there is less oxygen available in the cylinder for combustion, leading to a lower combustion temperature and in turn to less NO_x production. The rate of EGR that can be applied depends on various engine parameters, of which engine load is the most important, as high engine loads require more oxygen. This drawback may tempt manufacturers to apply lower EGR rates (or none) for conditions outside the operating envelope of the NEDC. Improved EGR systems can comply with the existing NEDC Euro 6 NO_x limits in a laboratory by combining two EGR circuits. However, there are numerous reliability concerns regarding the EGR valves getting stuck due to their getting dirty (especially when the EGR loop is high pressure), creating a further incentive to close it outside NEDC operating points. This leads to much higher emissions in real-world use.

2.3.2.3. Lean NO_x trap (LNT)

The lean NO_x trap is a catalytic converter that combines an oxidation catalyst, an adsorber to store NO_2 under lean-burn conditions, and a reduction catalyst. Once the adsorber is saturated, unburnt fuel must be introduced for a short time to deliver reducing compounds such as HC, CO, and hydrogen so that the NO_x is desorbed and reduced to nitrogen. LNT technology is reportedly capable of NO_x reductions up to a level of 70 to 90%, but like most aftertreatment devices, there is a fuel penalty involved for the regeneration cycles.

2.3.2.4. Selective catalytic reduction (SCR)

SCR involves a catalytic converter that can reduce NO_x to nitrogen through the use of an external reducing agent, known in Europe as AdBlue®(mainly made of urea). This is stored in a separate tank in the vehicle and is normally refilled during routine servicing (this requirement is seen as a drawback of SCR by carmakers). The catalyst operates at a high temperature (above approximately 190°C), so it does not work until the engine is warmed up, and it potentially may not work at all during short trips with low engine loads and frequent stops. An SCR system can achieve NO_x conversion rates of up to 80-95%, depending on the rate of application of the AdBlue®. Using the SCR over all operating points would imply a urea flow of around 2 litres per 1000 km. This would require refilling of a typical 16 litre tank at intervals of 6400 to

[17] http://www.transportenvironment.org/sites/te/files/publications/GDI%20Briefing_final_T&E_revised.pdf
http://www.transportenvironment.org/sites/te/files/publications/TUV-Technical_report.pdf
http://www.theicct.org/sites/default/files/publications/GFPworkingpaper2011.pdf

8000 km[18], much more than expected today by most OEMs (the refill is to be done by dealerships during maintenance operation, approximately every 20 000km). For this reason, manufacturers underdose with urea, leading to unnecessarily high emissions on the road.

2.3.2.5. Diesel particulate filter (DPF)

This technology involves a wall flow filter which will physically trap the solid particulate matter in the exhaust gas, including the solid carbon fraction and fine particles. The particulate reduction rates of DPFs are high, reportedly at least 90-95%. All diesel vehicles are expected to be equipped with a closed DPF to meet the Euro 6 particulate limit. The filter has to undergo a regular regeneration process to remove the accumulated particles. Like some of the other aforementioned technologies, this process incurs a small fuel penalty. The DPF must be integrated into the engine control system to ensure reliable regeneration. Regeneration events are nevertheless excluded from the measurement of the emissions in a PEMS and laboratory test. Some evidence shows that the number of particulates emitted during a regeneration is multiplied by a factor of 2 to 10[19]. Those emission are reported nowhere during the type approval process, demonstrating an obvious loophole in the current system that needs to be addressed.

2.3.2.6. Combining solutions

To reach optimum emission reduction, several aftertreatment technologies and devices can be combined, as each NO_x treatment technology applies optimally to different areas of the engine map (Figure 9).

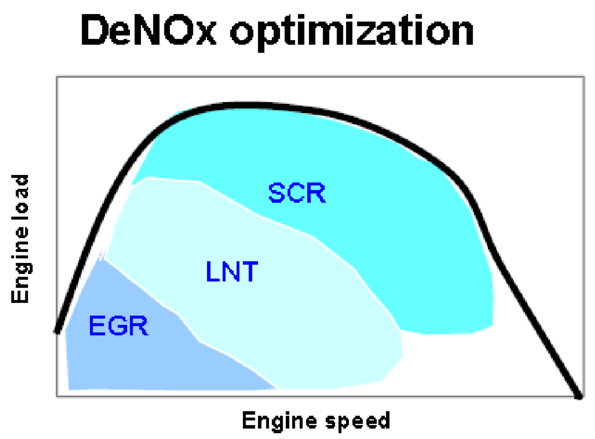


Figure 9. Descriptive technologies effectiveness for DeNO$_x$ optimization[20]

> **Motorcycles and an electro mobility strategy**
> The EU Commission has launched a consultation on the next Euro standards for motorcycles and scooters (L category vehicles). Such Euro 5 standards would be a good opportunity to leapfrog other markets and initiate a massive switch to electric two-wheelers in Europe. Asian countries are leading the electric two-wheelers market, and Europe should not stay behind. Instead, the EU should set low emission limits that would make electric two-wheelers the cleanest and most cost-competitive option for most needs.
>
> Small mopeds and scooters (especially those equipped with two-stroke engines) are disproportionately contributing to air pollution of certain pollutants (including PM, HC, and CO). A

18 http://www.aecc.eu/content/RDE_seminar/06%20%20AECC%20RDE%20seminar%20AECC%20Clean%20Diesel%20RDE%20Program.pdf

19 https://www2.unece.org/wiki/download/attachments/16450001/GRPE-PMP-30-03%20Regeneration%20topics.ppt?api=v2

20 http://www.aecc.eu/content/RDE_seminar/06%20%20AECC%20RDE%20seminar%20AECC%20Clean%20Diesel%20RDE%20Program.pdf

comprehensive strategy to phase out such vehicles should be a high priority. They could be replaced in most cases by electrical bicycles.

The ultimate goal is to have vehicles with zero tailpipe emissions in order to drastically decrease air pollution exposure. Electrification of the transport sector, together with renewable electricity, is the best way forward today, and T&E is calling the EU to adopt such an electrification strategy as soon as possible[21].

Heavy Duty Diesel Engines

Heavy duty vehicles (HDVs – mostly trucks and buses) contribute disproportionately to the overall pollutant emissions from road traffic. That is, they account for only a few percent of the total road vehicle fleet, but in many cases account for a much larger share of total emissions from road transport. They are such major polluters primarily because:

- They have much larger, more powerful engines than light duty vehicles, and therefore consume more fuel and emit more exhaust gases for every kilometre driven;
- They are typically used very intensively; most HDVs travel far greater distances than a normal light duty vehicle over a given period of time.

HDVs are subject to Euro emissions standards similar to those in use for light duty vehicles, with the latest Euro VI limits coming into force in 2013-14. As with LDVs there is a prescribed test cycle, but as HDV engines are so large and the same type of engine could end up in a number of very different vehicle types, engine emissions are measured on a laboratory test bench rather than in a whole vehicle, and are expressed in g/kWh of engine power output. This adds a further layer of uncertainty in mapping from test results to real-world emissions. However, there are, under Euro VI, additional provisions for real-world testing using PEMS, and this is reflected in the results set out below.

The latest test results were summarised and analysed recently by TÜ Graz for the Handbook on Emission Factors (HBEFA) which was released in the summer of 2014. For HDVs certified to Euro VI, SCR and closed DPF are now the norm.

Although it is still early and there are limited real-world performance data, Euro VI-certified vehicles and engines have been found to have very low NO_x levels in most real-world cycles, and only some showed higher NO_x at low loads. The limit values for particle mass and particle number were clearly met in the real-world simulations. This suggests that the additional PEMS tests in Euro VI have now been effective at bringing down real-world emissions in line with the tighter limit values. Unfortunately, most of the data generated by the In Service Conformity (ISC) provision in the heavy-duty legislation remains confidential and cannot be accessed by independent parties to assess the reliability and progress of trucks' emissions.

2.4. *Why vehicles can pass the tests but still poison the air*

In its earlier publication *Mind the Gap!,* T&E described in detail how carmakers are able to claim much-reduced CO_2 emissions for new cars, while evidence from vehicle fuel economy and repeat testing suggests that the improvements are significantly less than is claimed. The same processes, which are outlined below, also account for the generally much larger gap between the limit values and actual emissions of the regulated pollutants.

There are several reasons why the gap for some regulated pollutants (most obviously diesel NO_x) can be much larger than it is for CO_2:

- The NEDC test cycle itself is not representative of real-life driving profiles;

[21] http://www.transportenvironment.org/sites/te/files/publications/2015%2001%2027%20Electrification%20strategy_0.pdf

- Test conditions are optimised by the manufacturer to achieve the lowest possible test results that are not replicated on the road. This includes exploiting flexibilities and loopholes in the protocols that govern the testing process in the laboratory and the preceding;
- Off-cycle parts of the engine map are not optimised for air pollution emissions reduction, leading to emissions.
- On-cycle parts of the engine map are optimised for emissions reduction in a way unrepresentative of that achieved in normal driving. This includes "cycle beating" techniques that detect when the vehicle is being tested;
- Some aftertreatment devices only work when they have properly warmed up, so during cold starts emissions are not properly regulated and may be several times greater than in normal operation;
- When the engine undergoes a sudden transition, such as a rapid acceleration or increase in engine load, the vehicle's control technology can take a moment to adjust to the new conditions, and during this time a large 'spike' in emissions can occur.

2.4.1. Flexibilities in the laboratory testing procedures

Although the NEDC drive cycle itself is a major weakness in the overall type approval process, there are other deficiencies and loopholes in the protocols that specify how the tests are undertaken. Reflecting these, engineers undertaking the test can use a number of 'tricks of the trade' that further increase the likelihood that the tested emissions will fall well below those in the real world:

- **Fully charging the battery before the test and disconnecting the alternator:** Recharging the battery creates a significant extra load on the engine, and consequently a significant increase in emissions, so ensuring that the battery is fully charged or that the alternator is disconnected or disabled helps ensure that the test vehicle has to do less work.
- **Pulling back the brake calipers:** Even when the brakes of a car are not being applied, there is often some contact and friction between brake pads and discs, and this will increase the energy required to go through the test and thus raise emissions. Hence disconnecting the brakes completely or ensuring that the pads are fully retracted can reduce the energy required to power the test vehicle over the test cycle.
- **Losing weight:** Even vehicles of the same model can vary quite a bit in weight, according to engine size, trim, optional extras, and other equipment. It is nonetheless allowed to programme the rolling road with the barest minimum weight class of the most basic version, with everything that can be taken off or taken out removed.
- **Testing the car at 29°C or above***:* The regulations specify that the test must be conducted at an ambient temperature of between 20 and 30°C. The engine warms up faster and runs better (with lower emissions) at a higher temperature, so starting the test as warm as possible helps, even though this is far above the temperatures normally experienced in Europe.
- **Changing the oil:** As the lubricant to be used in the engine and other moving parts is not specified as part of the test protocols, carmakers can use a special test lubricant for the purpose of the test cycle. This too reduces the load on the engine relative to what it would be in a similar production-line car.

2.4.2. Road load and the coastdown test

Test procedures are undertaken on a rolling road or chassis dynamometer, as described above. However, the rolling road cannot simulate all aspects of the test drive accurately without additional information about the vehicle. For example, as the vehicle is stationary, the rolling road cannot accurately reflect aerodynamic drag caused by air passing over and around the vehicle at speed. Equally, it needs to be programmed with the weight or inertia of the vehicle in order to simulate acceleration and deceleration realistically, as well as the rolling resistance, which reflects the amount of energy lost as the vehicle's tyres interact with the road surface. These factors taken together make up a value known as the 'road load', which has to be programmed into the rolling road in order to allow it to simulate a real drive more accurately.

The simplest and most common method of deriving a vehicle's road load is known as a coastdown test. In essence, this involves accelerating the test vehicle to a given speed on a test track, then measuring how far the vehicle travels in coasting to a standstill. This distance is then translated into the road load value that is later programmed into the rolling road.

There are, however, known to be a number of 'flexibilities' in the way this test is conducted that can significantly extend the distance over which the vehicle will coast and hence minimise the road load value. An unrealistically low road load result reduces the emissions measured *under any subsequent laboratory test bed procedure, irrespective of the test cycle used*.

Known 'tricks of the trade' include the following:

- **Removing all optional extras:** Clearly anything that adds weight or drag to the vehicle will cause it to travel less far in the coastdown. Hence, any additional feature that can be easily removed for the test is removed, such as roof racks, additional lights, and even the nearside wing mirror.
- **Over inflating the tyres:** Any vehicle will travel further and faster when its tyres have been pumped up hard, and this practice is not specifically excluded in the test procedure.
- **Using a sloping test track:** The procedures only specify that any slope on the test track must not exceed 1%. An error in the NEDC procedure means the averaging of runs in either direction does not correct for the benefits of the downhill run.
- **Smoothing the way:** A smoother test track reduces the rolling resistance of the vehicle relative to what it would be on a normal road surface. Indeed, the proprietors of one commonly-used test track proudly boast that they have improved emissions and fuel economy figures by between 3.1 and 4.7% since they resurfaced their track in 2009.
- **Improving the aerodynamics:** Another practice that is questionable, but apparently not illegal, is to 'improve' the aerodynamics of the test vehicle and thereby reduce the effect of aerodynamic drag in slowing it down. This is generally done by carefully taping over every indentation or protrusion in the vehicle body, and in particular the radiator grille and the cracks around all the doors and windows and between other body panels.
- **Disconnecting the brakes:** As on the rolling road, disconnecting the brakes completely or ensuring that the pads are fully retracted can reduce rolling resistance and help the car coast farther.

Road load values have a significant impact on the vehicle's emissions. T&E tested 6 vehicles, and removing road load flexibilities on those vehicles led to CO_2 emissions rising more than 10%.[22]

Cycle Beating or Cycle Bypassing?

Terminology is important in this context. One term used to refer to attempts to defeat the emissions control legislation is **cycle beating**. In a case of cycle beating, the engine control system recognises that the vehicle is being tested in a type-approval test procedure and switches to a different engine calibration specifically designed to fulfil the emission standards. With increasingly sophisticated electronic controls and sensors in modern vehicles, it is in principle quite easy to do this; for example, by detecting that the car bonnet is open, that the rear wheels are stationary during the drive cycle, etc. This kind of engine control regimen is referred to as a 'defeat device', and is explicitly prohibited under Euro 6 Regulation EC 715/2007. No carmaker has ever been prosecuted for cycle beating in the EU but anecdotal evidence suggests that it is widespread.

22 http://www.transportenvironment.org/sites/te/files/publications/Road%20load%20determination%20of%20passenger%20cars%20-%20TNO-060-DTM-2012-02014.pdf

Most, if not all, of the techniques listed above do not violate the provisions of the relevant legislation and codes of practice, but exploit flexibilities and loopholes within the current rules. They are not therefore strictly illegal under Article 5 quoted above, and instead can be referred to as **cycle bypassing** strategies. As car manufacturers strictly follow the letter of the legislation and are not concerned by its spirit, each loophole in the legislation has to be closed. This leads to very tedious regulation developments that become very long, as all testing details have to be defined and covered by the legislative texts. Going down that road is not the favoured way forward for T&E; however, trust in car manufacturers can no longer be ensured. Evidence of cycle bypassing is gathered in Annex 3.

2.5. Plugging the gap

In order to help minimise the gap between tested emissions and those found in the real world, two new pieces of legislation are planned for the EU:

- Implementing the upcoming World Light Vehicle Test Cycle (WLTC) and its attendant procedures (WLTP)
- A new Real-World Driving Emissions (RDE) Directive.

2.5.1. Overview of the WLTC/WLTP

For some years the United Nations Economic Commission for Europe (UNECE) has been developing a new light vehicle testing regime to give harmonised and more accurate emissions results. There are two main areas in which refinement of the current testing procedures is being pursued:

- Developing a test driving cycle that is more representative for average driving conditions, built up from actual driving data.
- Developing improved test procedures to reduce allowed tolerances and tighten up on known loopholes or flexibilities, such as those listed above.

The work on WLTP is ongoing, but it is scheduled to be introduced into EU legislation in 2017. The following paragraphs briefly summarise the current state of play.

The new ***WLTC driving cycle*** is far more realistic and dynamic than the NEDC cycle, involving higher accelerations and maximum speeds. The WLTP cycle is 1,800 seconds long (the NEDC being only 1,180 seconds long), so more driving conditions can be tested. The new cycle is illustrated in Figure 10 below.

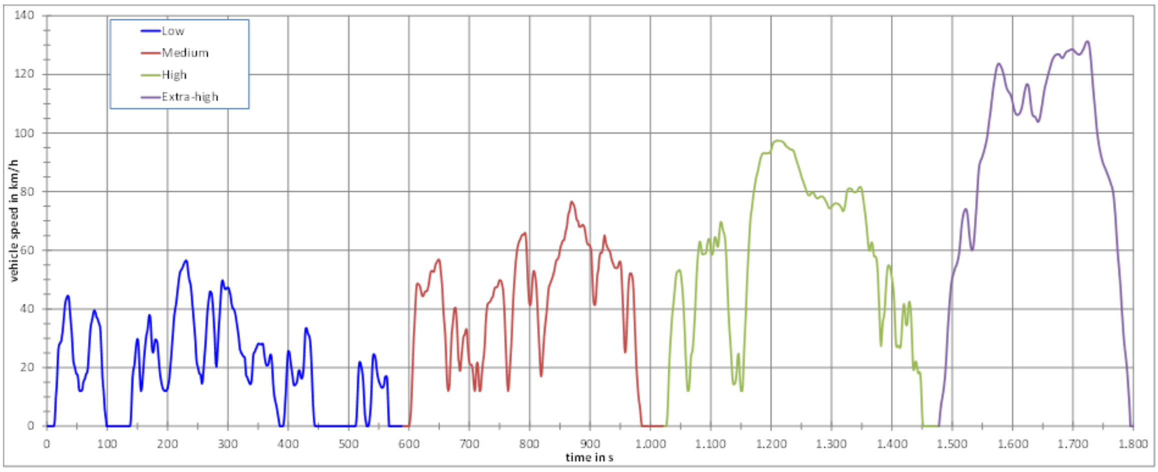


Figure 10. Vehicle speed trace of the WLTC, showing the four phases (low, medium, high and extra-high speed)

Figure 11 below reproduces the engine map from the NEDC test as in Figure 8, but superimposes that of the WLTP. From this it can readily be seen that the green dots of the WLTP load points cover a much larger part of the engine map, including significantly higher load levels than are ever reached under the NEDC. This in itself makes it much harder to defeat the test.

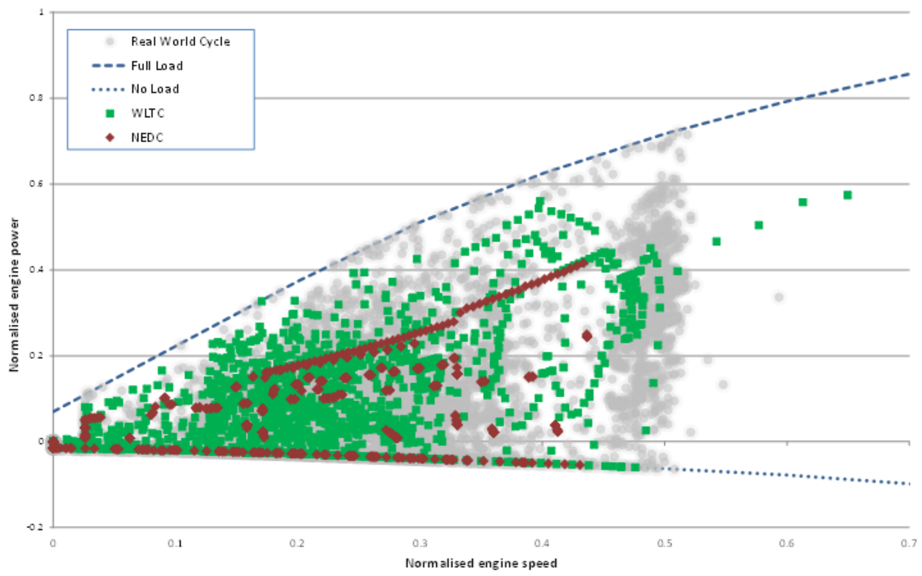


Figure 11. **Engine maps of the NEDC and WLTP compared**

The main **road load issues** that will be addressed and improved by WLTP are to take proper account of the slope in the test track, better and more rigorous vehicle preparation, and using a more representative test vehicle (e.g. in terms of vehicle mass and inertia).

The **laboratory test procedures** will also be tightened up by incorporating state-of-the-art measurement techniques that reflect the capabilities of modern testing equipment; the start condition of the vehicle's battery will be specified; and a smaller test temperature range (23 °C ±3 °C) has been adopted.

Overall, the more demanding and realistic test cycle, the more stringent coastdown procedures leading to higher road load values, and some of the other stricter specifications should lead to more realistic emissions test results. However, because the WLTP is much longer, the emissions during the cold phase that are critical to pollutant emissions (Figure 12) are proportionally less important for emission limits expressed in g/km. A correlation exercise similar to the one that is being performed for the equivalence of CO_2 emissions between the NEDC and the WLTP will lead to lower emission limits on the WLTP than on the NEDC and needs to be urgently developed by the European Commission. Such a correlation exercise should be put in place in the near future in order to ensure that pollutant emissions limits can be meaningfully measured on the WLTP as well.

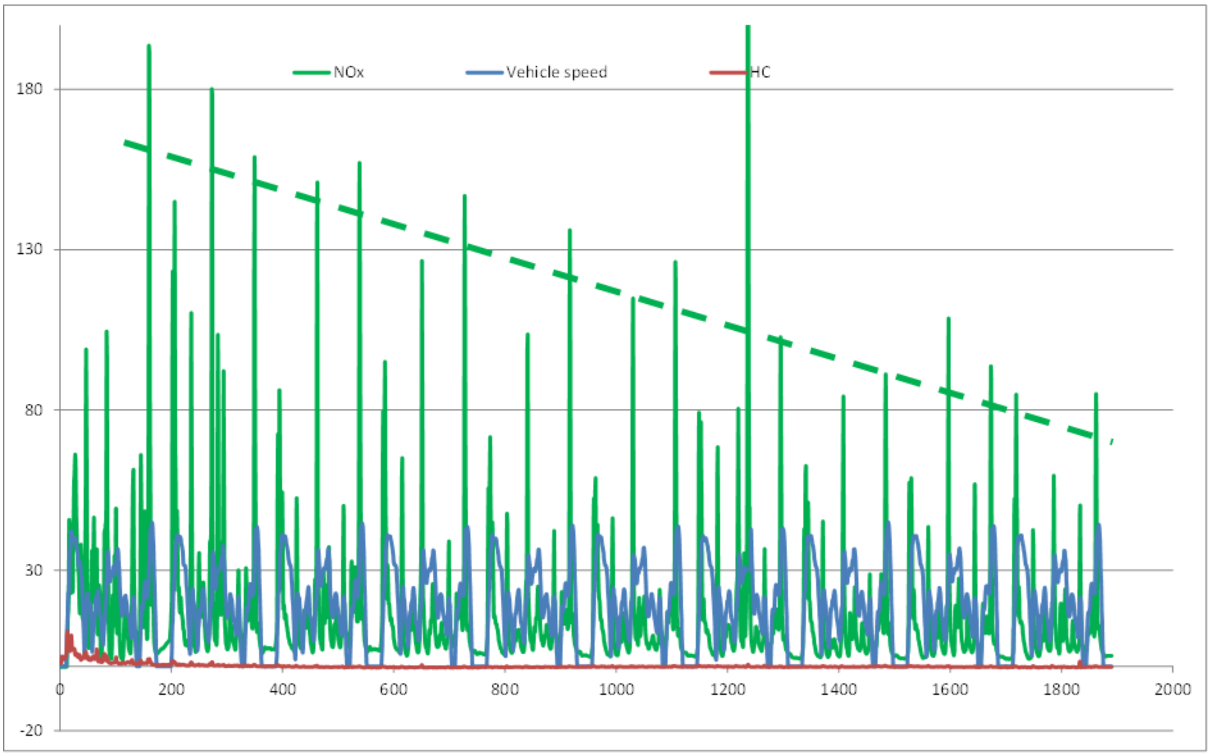


Figure 12. **NO_x emissions on repeated test cycle as engine warms up**

2.6. Overview of the RDE proposal

The future Real Drive Emission (RDE) legislation for Europe should come into force on 1 January 2016and will first be introduced as a monitoring phase that only demands vehicle testing without limit values. Later on (anticipated in 2017) new vehicle types coming onto the market will need to meet 'not-to-exceed' (NTE) limit values which will be defined on the basis of Conformity Factors (CFs) that define the ratio of measured emissions to the corresponding Euro 6 limit value. A second step will lower the NTE emissions to the Euro 6 limit, incorporating measurement uncertainty, at a date to be agreed upon.

The emissions will be measured using PEMS equipment in on-road driving conditions. There is, however, ongoing debate as to how the latter will be circumscribed, so as to be neither unduly extreme nor too undemanding to be realistic. It is envisaged that the test drive will be substantially longer than the laboratory tests (90 to 120 minutes). Data is then post-processed through data evaluation tools; The Commission opted for two distinct tools to be used: EMROAD and CLEAR. Current versions of both tools do not deliver satisfactory results and would need to be significantly improved during the monitoring phase. CLEAR appears to be the most robust tool of the two, but would require a more realistic typical power curve distribution to give more realistic results.

The test procedure and technical characteristics of the equipment and measurement boundaries have been voted on by member states on the 19th of May 2015. In autumn 2015 the regulation will be finalised and will include NTE limits and dates for compliance.

Conformity factors have to reach 1 (=meeting the Euro 6 legal limit) as soon as possible for all pollutants and all light duty vehicles in order to make sure that air quality limits in densely populated areas are no longer exceeded.

2.7. Conformity checking in the EU

As explained above, a vehicle model's emissions are certified in the EU using a single test on a single vehicle. This can be a 'golden vehicle' carefully prepared to give the best possible results, and may not be identical to the production line version because tests are carried out before all details of the final design have been completed.

As such, it is perhaps not surprising that there is the potential for official test results to diverge from real-world values. However, there are ways to keep this divergence in check:

- **Conformity of production checks** can be carried out on vehicles chosen at random off of the production line in order to verify that their emissions do not vary (beyond an agreed-upon margin) from the official values;
- **In-use testing or in-service conformity (ISC)** can be conducted to ensure that real-world emissions do not vary too far from the official values, similar to the NTE tests undertaken in the United States and what is now proposed for the RDE Directive. ISC is already part of the type approval procedure for heavy duty trucks, and is also used retroactively on Euro 5 vehicles. This has lead to drastically lower NO_x emissions on trucks, and heavy duty vehicles today have emission factors (g/km) similar to those for cars[23];
- **Periodic technical inspection (PTI)** procedures should be tightened significantly to detect emission control tampering. About 10% of European taxis are suspected to have removed their DPF, but they still pass their annual PTI with no issues, as the test is not designed to look closely at particulate emissions. PTI schemes should be enforced by using a dual approach involving independent tests during the PTI and monitoring OBD fault codes generated by the vehicle.

In principle, such testing is already carried out in Europe, but the procedures are lax and ineffective. Much of the testing remains in the hands of the carmakers themselves and the related technical services are directly paid for by them. There is little to no independent oversight.

2.7.1. US experience with not-to-exceed (NTE) emission limits

US regulators are far ahead of Europe in their efforts to tighten up on real-world emissions. They began introducing NTE limits as early as 1998 for HDVs and have since extended the approach to other classes of engines and vehicles, including NRMMs. The NTE approach establishes a control area (the 'NTE zone') which defines the area of the engine map that reflects engine speeds and loads expected to be encountered during real-world operation by the class of vehicle in question. Within that part of the map, NTE testing does not specify a particular driving cycle but instead a random period of driving of any type that falls within the bounds of the NTE zone, including operation under steady-state or transient conditions and under a variety of ambient conditions. Emissions are averaged over a minimum time of thirty seconds and then compared to the applicable NTE emission limits, which must not be exceeded for any averaging period.

For light duty vehicles, US regulators have also already applied supplementary emission limits to LDVs that reflect high-speed and aggressive highway driving. Future reform of European testing legislation can benefit from what has been implemented in the US over the last decades.

23 http://www.hbefa.net/e/documents/HBEFA_31_Docu_hot_emissionfactors_PC_LCV_HDV.pdf

2.8. Outlook for WLTP and RDE in Europe

The WLTP and RDE are both important new proposals supported by good evidence and generally robust outcomes. They should help to control the gap that has been highlighted between real-world emissions and laboratory test results, although we cannot yet be certain by how much.

There are also several caveats that need to be kept in mind:

- Neither of these pieces of legislation have yet been translated into EU law, and both will be subject to the usual legislative procedures at the EU level. As a consequence, important provisions might be watered down or removed entirely, thereby allowing existing loopholes to persist or new ones to emerge.
- Carmakers are already seeking a long delay before the introduction of the WLTP into Europe, and are requiring similar delays and very high NO_x Conformity Factors so that the RDE will not exclude many or any gross polluters.
- Much of the envisaged testing will remain in the hands of the carmakers themselves and the commercial testing laboratories who compete for their business. Much more independent scrutiny of these arrangements is needed.

For the future, therefore, several issues should be included in the legislative text.

- Conformity Factors should go down to 1 in the near future and include cold start and regeneration events. Without that, the RDE is likely to be ineffective and diesel cars run the risk of being excluded from the streets, especially in urban areas[24].
- A correlation exercise to determine the pollutant emission level under WLTP should be put in place.
- Put in place a European type approval authority to collect revenue and fund the national type approval authorities to ensure improved independence and the absence of commercial link between car manufacturers and type approval authorities.

3. The Case of Non-Road Mobile Machinery

3.1. Introduction to non-road mobile machinery

3.1.1. What are non-road mobile machines?

The term non-road mobile machinery (NRMM), as applied in EU type approval legislation, covers a very wide variety of machines with internal combustion engines which are intended primarily for purposes other than as road vehicles for transporting passengers or goods.

They range in size from small, portable machines (such as hedge trimmers, blowers, etc.) to large off-road construction machines (such as such as excavators, bulldozers, front loaders, road rollers, etc.) and constant-speed machines (such as compressors, pumps and generators). Railway engines and engines for boats on inland waterways are also included in the NRMM category. Agricultural tractors also are subjected to the same emission limits defined for NRMMs.

The vast majority of these have diesel (compression ignition) engines, although some of the smaller vehicles are likely to have spark ignition (PI) engines.

24
http://www.transportenvironment.org/sites/te/files/publications/2014%2009%2024%20RDE%20-%20a%20last%20chance%20for%20diesel%20cars_FINAL_v2.pdf

3.1.2. Emissions from NRMMs

Weak limits set by the 1997 NRMM Directive and its amendments (listed below), incomplete implementation, and inadequate testing have resulted in the NRMM sector becoming an increasingly important source of air pollution, especially of NO_x and particulates (accounting for 15% and 5% of the total EU emissions, respectively). While the PM share is expected to decrease overtime, the NO_x share is expected to increase to nearly 20% in 2020 as emissions from road vehicles and other sources are reduced.

Machinery used in construction and related fields can be a major source of pollution, especially within cities. Workers close to NRMMs can also be directly exposed to high concentrations of engine exhaust over an extended period of time and are therefore believed to be at greater risk of adverse health effects.

3.1.3. The Regulation of NRMM emissions

In the EU, emission limits for non-road vehicles first came into force in 1999, along with a test procedure to measure such emissions. As with road vehicles, limits were tightened over time in a series of stages, as follows:

- Stage I standard - Directive 97/68/EC
- Stage II - Directive 2002/88/EC
- Stage IIIA and Stage IIIB - Directive 2004/26/EC
- Stage IV - Directive 2012/46/EC

Emissions limits were defined for the same initial set of pollutants as for road vehicles, with separate limits for different categories of engine defined by their power rating. The Stage I emissions were for engine-out limits, i.e. to be achieved before any exhaust aftertreatment device might be fitted. Stage II added engines down to a net power rating of 18kW and tightened the limits for NO_x and PM. With the Stage IIIB standards, a PM limit of 0.025 g/kWh was introduced across all engine classes. This was designed to force the use of diesel particle filters. From Stage III onwards, the emission limits are defined for non-road diesel engines both for the indicated power range and for a small number of differentiated applications, i.e. rail and waterway engines, constant speed engines, and other NRMM engines (mainly off-road vehicles – the category of greatest interest for this chapter). Some of the latter (with a power rating between 56 and 560kW) are now subject to Stage IV standards which primarily tighten NO_x limits.

The emissions were initially measured on the ISO 8178 C1 8-steady-state mode cycle, also referred to as the Non-Road Steady State Cycle (NRSC), which is expressed in grams per kilowatt hours (g/kWh). The emissions are to be measured at eight steady-state load points defined by a combination of normalised engine speed and torque. The test is carried out on an engine dynamometer; that is, the engine is tested on a test bed, in a manner similar to that for engines of heavy duty road vehicles, but is not within the vehicle in which it is to be used. The test cycle is described in greater detail below.

With the Stage IIIB standards, in order to better represent emissions during real operating conditions, a new transient test procedure—the Non-Road Transient Cycle (NRTC)—was developed. The NRSC is still used for Stage I, II and IIIA testing, as well as for constant speed engines at all stages. The NRTC transient cycle can be used for Stage IIIA testing if the manufacturer chooses. Both NRSC and NRTC cycles are used for tests from Stage IIIB onwards for all engines apart from constant-speed engines.

A new Stage V emissions proposal is currently under development and is described below.

3.2. Real-World Emissions from NRMMs

3.2.1. The emissions test cycles for NRMMs – the NRSC and NRTC

Most NRMMs are subject to emissions measurements on both steady state and transient test cycles, similar to heavy duty road engines The test cycles are different for different machines in an attempt to match typical operating conditions. More details about the test cycles are available in Annex 4.

The driving schedule is composed of a series of engine load and engine speed configurations intended to reflect different operation modes of off-road machines; that is, every engine is tested over the same sequence that is intended to reflect all of the major applications in which it might be used, rather than the one in which any individual engine is actually used. Thus, the average obtained cannot be fully representative of any single application of the engine.

3.2.2. Real-world operation of non-road mobile machinery

In a project set up by the Austrian Ministry of Environment, engineers at TÜ Graz tested 17 off-road machines with a PEMS on-board measuring system[25]. During the tests, they performed operations representative of the real-world functions of each machine. The analysis of the engine load clearly showed that different machines during working operation operated in very different patterns and in very different areas of the engine map. Figure 13 shows the typical load points (defined by torque and engine speed) driven during the NRTC cycle set alongside the load points of different types of construction machines in real-world operation, as found in the tests.

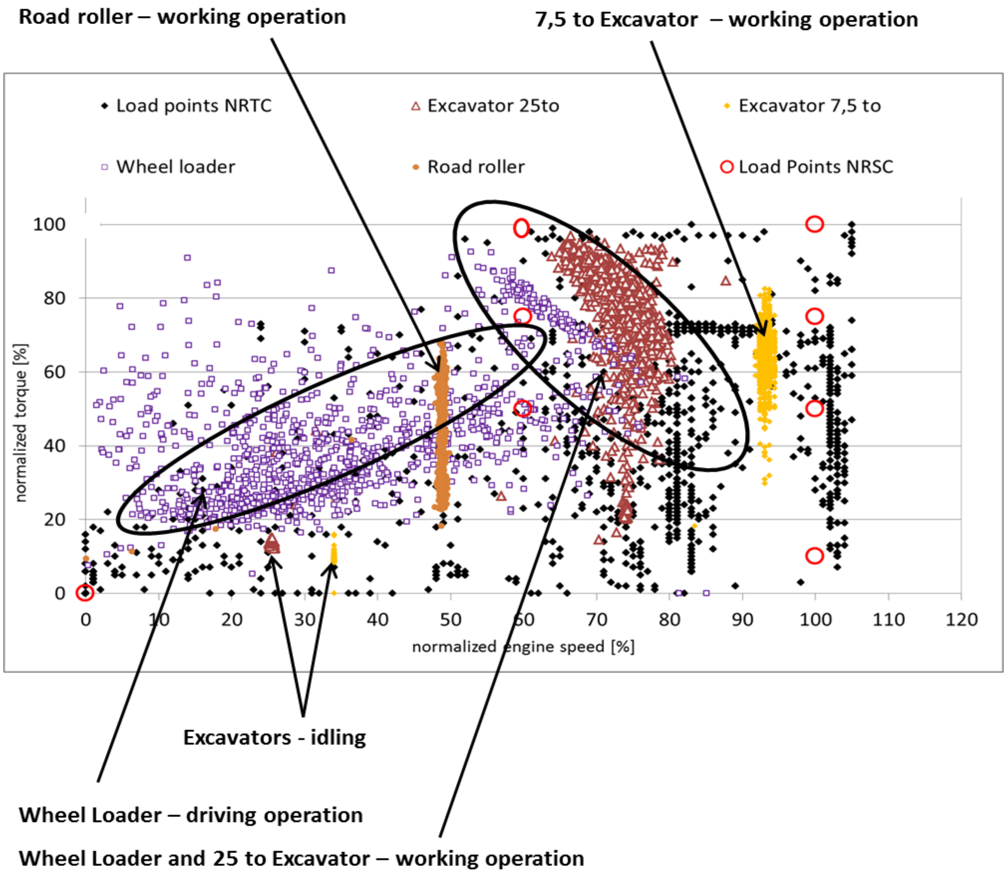


Figure 13. Example for load points in the NRTC and NRSC Cycles and in real-world operation

[25] Blassnegger J, *Emission Factor Model for Construction Machinery Based on PEMS Tests*, Institute of Internal Combustion Engines and Thermodynamics, Graz University of Technology, Inffeldgasse 19, A-8010 Graz, 20th international transport and air pollution conference, Graz, 2014

As Figure 13 illustrates, both the 7.5-tonne excavator and the road roller (the yellow and orange dots, respectively) operate in a very small range of the engine map, and each operate at a constant, though very different, engine speed. The engine load did vary at this working engine speed, but their load points fall in an area of the engine map with low rates of coverage of either NRTC or NRSC load points.

The wheel loader runs very different operation modes, such as mining crushed materials or driving on a road or track. Reflecting this, the load points of this machine cover a wide area of the total engine map, much of it within the area covered to some extent by the NRTC and NRSC load points. The 25-tonne excavator also had a wide but more clearly defined operation, also largely within an area engaged by the two test cycles.

Therefore, it is clear that the NRSC and the NRTC load points, as currently specified, are reasonably representative of some types of off-road machinery, but not all of them. The emissions measured by these tests are not likely to be good reflections of real-world conditions. More PEMS tests should be performed to ensure compliance in real conditions of use, together with strict binding limits that are not to be exceeded.

This is a problem specific to NRMM (over and above the more general issues highlighted in Chapter 2 regarding the NEDC of a rather sparse set of load points in most areas of the official tests). Once again, this allows the possibility for engine operation to be optimised for outcomes other than low emissions in other parts of the engine map.

3.2.3. Real-world emissions from NRMMs

In the programme referred to above, real-world emissions were measured from a range of off-road mobile machines, with a range as representative as possible also across the different emissions control limits from Stage I to Stage IIIB. Owing to the timing of the tests, no Stage IV machines were able to be tested. For some pollutants, such as CO, the progress has been significant, though the emission limit has stagnated for the last few cycles (Figure 14).

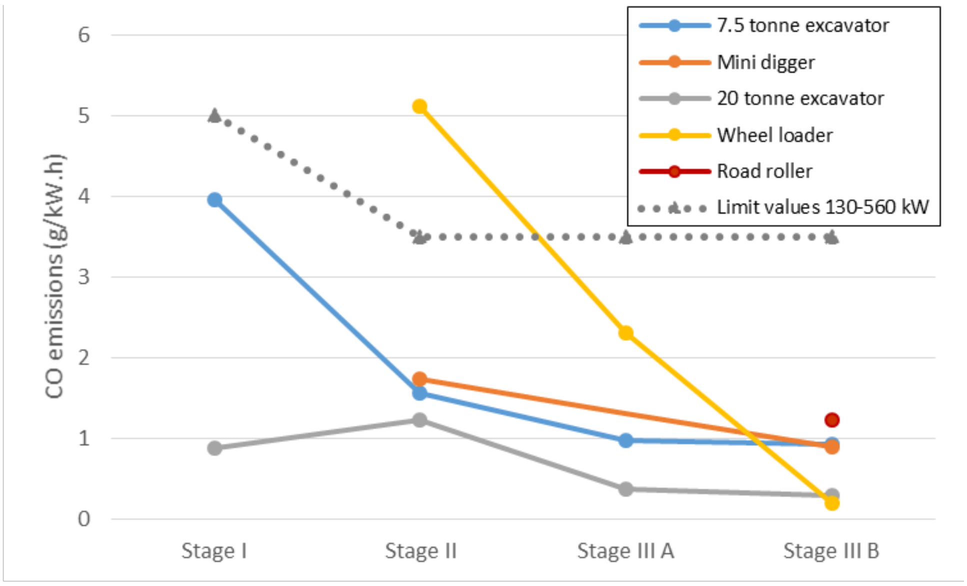


Figure 14. **Average results for all tested machines for carbon monoxide (CO)**

The picture is less clear for NO_x, and the real life emission values are very close in often exceeding the limit value (Figure 15).

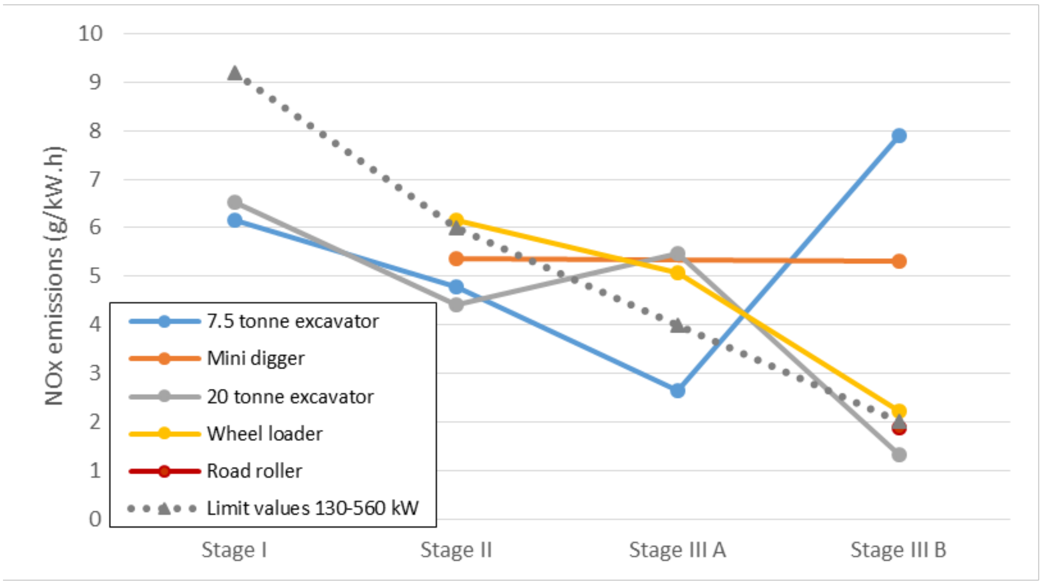


Figure 15. **Average results for all tested machines for nitrogen oxides (NO_x)**

While some classes do show improvements in line with the indicative limit value, others do not. Moreover, this does not give confidence that the much more stringent Stage IV and proposed Stage V standards will be met by machines used in real-life use patterns. Even though similar engines do meet stricter limits in the heavy duty road sector, NRMMs are still equipped with older, cheaper technologies that emit a lot of air pollution.

Given the clear evidence that the test cycles are not adequately representative of all classes of machine operation, it is safe to suggest that there may be a real-world emissions problem for NRMMs analogous to that for on-road diesels.

3.3. The Commission's new proposals

In September 2014, the European Commission proposed Stage V emissions regulations for NRMMs in order to rectify some gaps in regulatory coverage and tighten some limits which had become outdated and no longer reflective of the current state-of-the-art technology. For some classes of NRMMs, new emission stages were last introduced when the Directive was amended in 2004. The proposals are intended to realign EU emissions standards with US emissions standards where relevant.

The proposal introduces a number of important changes, including:

- Widening of the scope of regulated engines to fill some notable gaps in coverage This is accomplished by including compression ignition (CI) engines below 19 kW and above 560 kW and spark ignition engines above 19 kW;
- Lowering the emission limits for some engine categories, such as engines of 19-37 kW and engines of inland waterway vessels;
- Adopting particle number (PN) emissions limits for several categories of CI engines, as has already been done for road vehicles;
- Further lowering NO_x limits;
- Introducing new requirements for in-service monitoring as well as increasing data transparency.

These all appear to be sensible developments, ones which are largely in line with those for on-road vehicles. However, the proposal does not suggest any enhancements to the test cycles and only indirectly addresses the issue of real-world emissions. The lack of ambition of the Commission proposal should be addressed by:

- Harmonising emissions limits of NRMM engines with the ones for heavy-duty trucks; the latest technologies should also be adopted by NRMM.
- Ensuring level playing field among machine types and highest benefit in terms of emission reduction by setting a PN limit for those categories that are currently lacking one (large constructions machines, diesel locomotives and smaller inland shipping vessels)
- Not favouring specific fuel types by allowing higher emission limits: higher HC limits for natural gas engines are not technology-neutral and should be removed. Natural gas engines can enter the market only if they are as clean as other engines types.
- Having only one date for entry into force of all engine types: Entering into force on 1 January 2019 leaves sufficient lead-in time given the fact that technology is already available from other markets, in other modes, or in other countries.
- Making sure the existing fleet also cleans up: develop a retrofit strategy similar to what happened in Switzerland for tunnelling and construction machines. When engines need replacement, make sure the new engines meet the latest emissions limit in place.
- Reforming the test procedure to better reflect real-life operating conditions: more realistic test cycles would allow the delivery of better emissions performance where and when it matters.

3.4. Possible improvements to NRMM emissions testing

3.4.1. Improving the test cycles

Analogous to the work described above to develop the WLTC for cars and vans, improving the test cycles in use to better reflect the real-world operations of NRMMs would bring real-life emissions down drastically.

As outlined above, the actual working engine speed of the machinery in use is not currently well reflected in either the NRSC or NRTC. Therefore, for the future it would be important to better characterise the duty cycle of NRMMs and to embody that in the legislation. This would also be a way to improve the emissions of non-road vehicles in real life, as there would be a stronger incentive for manufacturers to optimise emissions for actual working load conditions rather than the (often unrepresentative) load points from the test cycles.

3.4.2. In-service conformity

The Commission has included in its recent proposals for Stage V limits that a programme of in-service monitoring checks be developed and undertaken using PEMS equipment in real-world operating conditions. The in-service monitoring proposed does not include any not-to-exceed (NTE) values, and therefore only exists to provide information to legislators. This would ideally lead to a conformity factor (as for road vehicles) that would be legally binding, so that machine and engine manufacturers work on reducing the emissions under realistic duty cycles.

In view of the diversity of the machinery covered by this legislation, and also of the results shown above, this programme must be comprehensive in terms of coverage. Such a programme should be used to build up a database of real-world emissions factors for all major types of NRMMs in order to inform future air quality management strategy. Access to raw datasets should also be granted to any interested third parties to better understand the testing conditions and performance of the machines.

3.5. Outlook for NRMM: stopping the rise in emissions share

Several fronts need to be engaged to reduce emissions from NRMMs and reduce NRMMs increasing share of emissions. Specific policies to address this include:

1. More representative test cycles that cover the operating points of the most popular machines;

2. Measuring real-life emissions using PEMS equipment and linking those measurements to binding limits at type approval;
3. Ensuring that the engines are fitted with the best available technologies by setting ambitious emissions limits similar to those for other modes, such as heavy duty road vehicles;
4. Transparently providing data to third parties in order to have independent analysis of the emissions under real-life measurements.

4. Tackling air pollution at an EU, national, and local level

This section discusses the solutions to the problems described in the report. There are many remedies available to manufacturers and policy makers at an EU, national and local level which used in combination will lower pollution levels in hotspots and resolve outstanding issues. Technology has a key role to play – but so does regulation, to ensure that technology is deployed effectively.

4.1. Solutions and issues with abatement technologies

The evidence suggests that diesel NO_x can be reduced significantly with existing technologies that are on the market today. ***Selective catalytic reduction (SCR)*** can deliver low NO_x emissions, especially when combined with other abatement technologies such as EGR and/or LNT. Nonetheless, carmakers are reluctant to fit SCR to all vehicles because of the added cost (up to €500) and instead continue to utilise less effective and cheaper technologies, perpetuating the NO_x problems. When SCR is fitted, it is frequently not properly optimised to work under all normal driving conditions. This is because such optimisation would require regular filling of the urea reagent, a task that could increase the purchase and maintenance costs of a diesel car and add a level of inconvenience, thus potentially discouraging consumers from choosing diesel. The solution to this is an ambitious RDE package, with conformity factors of one, implemented before the end of the decade. In the absence of clean diesel cars, other actions will be inevitable to tackle the problems, such as a ban on diesel cars in city centres.

Ultrafine particles are another serious public health concern. Modern diesels are now fitted with a diesel particulate filter (DPF) to trap exhaust emissions, and retrofit programmes are possible, particularly for heavy duty vehicles and NRMMs. The evidence suggests that DPFs are effective in substantially reducing the volume and number of particulate emissions — even for the ultrafine $PM_{2.5}$ – in real-world driving conditions, especially for heavy duty engines. However, concerns are being raised regarding the effects of catalyst regeneration, which is presently excluded from the RDE test. This is a topic for future research, along with extending the scope of RDE tests to include regeneration events.

DPFs have a given lifetime and will fail and require replacement in the course of a vehicle's life. Sometimes the filters are also deliberately removed to improve performance and fuel economy. An effective system of regular inspections by member states is needed to check that particulate filters are still present on vehicles for which they have been mandated and are working correctly. This is not presently in place, but should be. It should also be illegal to remove such systems, not just to drive a vehicle that has been tampered with.

Modern gasoline direct injection engines also produce fine particulates that can be trapped with an equivalent gasoline particulate filter.[26] These are cheaper and simpler than diesel equivalents as the exhaust gases are much hotter, so elaborate regeneration provisions are not needed. The RDE test must be extended to measure PN from GDI engines. An effective test will ensure the fitting of a GPF, thereby resolving the issues.

[26] http://theicct.org/controlling-gdi-particulate-emissions

4.2. Non-road mobile machines (NRMM)

Similar systems of exhaust treatment are also effective for NRMM, but for this category of vehicles testing systems remain very basic. Specifically, test cycles for NRMM do not properly reflect the real-world use of machinery. A programme of real-world testing of machines using PEMS equipment – as tentatively suggested by the Commission - should be developed in order to establish the scale of the real emissions and develop solutions that will ensure that real-world emissions are controlled and reduced across the whole spectrum of non-road mobile machinery. This will entail developing a database of all the available evidence and then putting in place legally-binding limits that will ensure real-life performance of NRMMs.

4.3. Further actions at the EU level

Air quality problems cannot be resolved exclusively by action at an EU level – but inadequate actions by the EU make resolving problems impossible, both nationally and locally (without draconian steps).

4.3.1. The World Light Duty Test Cycle for pollutant emissions

The work on the WLTC/WLTP is ongoing at the time of writing, but it is scheduled to be introduced into EU legislation from 2017.

The new WLTC driving cycle is far more realistic and dynamic than the former NEDC, with higher accelerations and maximum speeds. It also covers a far larger area of the engine map, making it more difficult to avoid applying emissions reduction strategies in real-world conditions. The main road load issues that will be addressed and improved by WLTP are to take proper account of the slope of the test track, mandate better and more rigorous vehicle preparation, and use a more representative test vehicle (e.g. in terms of vehicle mass and inertia).

At present, work on introducing WLTP is focused on measuring CO_2 emissions. This must be urgently extended to cover all air pollutants. Furthermore, correlation factors between the NEDC and WLTP results need to “translate’’ the current emission limits into new ones applicable for the WLTP. For example, limits under the WLTP would be lower for some pollutants because the cold part of the test would be proportionally less important. The switch to WLTP must not lead to any dilution of the current Euro 6 standards.

An alternative approach would be to end laboratory testing for air pollution as part of type approval entirely and instead use a system of real-world testing.

4.3.2. The Real Driving Emission regulation

The future RDE (Real Driving Emission) legislation for Europe is scheduled to come into force on the 1st of January 2016, and it will first be introduced as a monitoring phase without limit values. It is anticipated from 2017 onwards, new models coming onto the market must meet ‘not-to-exceed’ (NTE) binding limit values that will be defined on the basis of Conformity Factors (CFs) that specify the ratio of measured emissions to the corresponding Euro 6 limit value. Setting conformity factors of 1 for all pollutants measured under the RDE is the only way to drastically reduce the excesses of NO_2 concentration around Europe. Such a CF should be implemented as soon as possible, well before the end of the decade, so that emission reductions accelerate from the mid 2020s as new vehicles enter the fleet.

In RDE tests emissions are measured using PEMS equipment in normal conditions of use. The test methodology has been agreed upon but there is uncertainty regarding how this test will perform in practice. For example, there remain doubts concerning the rigor and consistency of data normalisation tools (CLEAR and EMROAD). Additionally, the current tests underrepresent cold start driving, effectively omitting regeneration events and failing to measure all regulated pollutants. These concerns must be urgently addressed.

4.3.3. *Conformity checking in the EU*

The introduction of real-world tests is a crucial step forward in resolving air pollution problems from vehicles, but it is not a panacea. Tests will still be conducted during type approval processes on pre-production vehicles, leading to the risk that manufacturers highly optimise their test vehicles. To address this limitation, additional checks must be performed to ensure that production vehicles meet similar performance levels and maintain those levels of performance. It is therefore necessary to supplement type approval tests with:

1. Conformity of production checks conducted on vehicles chosen at random off the production line in order to verify that their emissions do not vary (beyond an agreed margin) from the official values; and
2. In-use testing to be conducted in order to ensure that real-world emissions do not vary too far from the official values, similar to the NTE tests undertaken in the US or what is now proposed for the RDE regulation. This should also be extended to vehicles in use some years into their operational lifetimes. Further details are provided below.

4.3.4. *A robust approach to testing*

The current system of testing lacks transparency and independence as manufacturers select and pay for the services of national Type Approval Authorities and testing services that compete for business in a European market. This contributes to a lack of consistency in the way that tests are performed. Creating an overarching European Type Approval Authority would bring a level of independence to the system. Manufacturers should pay a levy on each new car sold that would be used to finance independent testing. Charging 20 Euros per new vehicle sold would raise around 250 million Euros annually to fund such a system and would simply replace the costs currently being incurred. Such a system would be more efficient, as it reduces the number of type approval authorities and cuts down on duplication of services.

The creation of a European Type Approval Authority should be accompanied by a substantial increase in random/targeted testing from vehicles taken from the production line to check for the conformity of production (called the Selective Enforcement Audit –SEA). These tests would make use of PEMS-based measurement to better reflect real-world driving conditions.

Having an ambitious surveillance program – random checks of vehicles straight off of the production line or off of the road after some years of usage would create a major incentive to make vehicles comply under most testing conditions. The EU should find a sustainable and independent financing mechanism to give life to such a programme.

4.3.5. *Periodic technical inspections (PTI)*

Designing tests on production vehicles that are both rigorous and independently-conducted is the only way to ensure that new vehicles' exhaust emissions really are clean and reduce the burden of air pollution. However, there remains a legacy problem with the existing fleet that strengthening the system of periodic vehicle inspections undertaken in member states must address. For example, the tests will need to verify that SCR and particle filters are functioning correctly throughout the life of the vehicle.

PTI could be strengthened by setting an expiration date for the type approval certificate. This would ensure that older, more polluting vehicles get scrapped or used to a very limited extent beyond a given age. For example, a vehicle could only be permitted to continue in use beyond (say) 15 years if it meets modern Euro standards. If it does not meet those standards after the 15-year period, it cannot be on Europe's roads. In practice this would not be viable for most aged vehicles that would be scrapped after 15 years. An exemption could be made for low-mileage heritage vehicles that may continue to be used so long as they were driven for less than (say) 1500 km per year. An adequate transition period could avoid the initial substantial scrappage of older vehicles; for example, by permitting current owners to continue using their cars, but forbidding them from selling them.

4.3.6. Euro 7/VII

This report has demonstrated that Euro 6 is failing to reduce real-world vehicle emissions and improve air quality. There is little doubt that the proposals outlined above will go some way towards improving the situation. However, loopholes and uncertainties remain, and new problems will undoubtedly be exposed. Euro 6 should not be considered the end point of vehicle regulation but Euro 7/VII legislation proposed.

Euro 7 legislation for cars should end the different emissions permitted for diesel, gasoline and natural gas. The legislation should ensure these limits are met in locations throughout Europe including cold northern latitudes; at altitude and on roads with steep gradients. Limits for both cars and trucks (Euro VII) should be set at a level that ensures WHO could be met across Europe – even in heavily trafficked locations.

Discussions on the new Euro 7/VII standards would also be a good opportunity to improve the EU testing architecture as suggested earlier.

4.4. National measures for tackling air pollution emissions

A first and simple step member states can make to help reach their national air pollution targets is to support the Commission's proposals to tighten the type approval procedure by including national RDE provisions. Doing so member states with infringement procedure for breaching air pollution limits will reduce the risk of future fines.

Secondly, nearly all EU member states tax diesel fuel more lightly than petrol in spite of diesel's higher energy density. Many countries are also favouring the purchase of diesel cars through CO_2–based vehicle taxation policies. Such policies have contributed to the dieselisation of the car fleet with new diesel car purchases now outnumbering those for new petrol cars. The larger the proportion of diesel cars on the road the more air quality problems persist. Member states should recognise the higher air pollution emissions of diesel cars in vehicle taxation policies. A more comprehensive system of vehicle labelling that includes both CO_2 and pollutant emissions would also spur a positive change to what defines a "clean car". Labelling dedicated for vehicles that meet more ambitious emissions limits (as is developed in the EULES program in DG Environment) would incentivise both national and local authorities to require such cleaner vehicles in their fleet and encourage their presence on their roads.

Third, owing to the very long duration of the diesel NO_x problem in particular, there are many diesel cars with high real-world emissions already on Europe's roads, and natural turnover will not remove these cars from Europe's vehicles fleets for many years. Member states should therefore consider whether retrofit programmes or limiting registration of used vehicles based on their environmental performance could effectively accelerate the removal of high-polluting vehicles (both light- and heavy-duty) from vehicle fleets. Retrofitted particulate filters, especially for heavy-duty applications, may be beneficial in some contexts, but care would need to be taken to ensure that any such programmes are sufficiently well-targeted and effective.

4.5. Local measures

Local measures to manage traffic or emissions are an essential complements to national and EU action on vehicle emission to address problems in air quality non-attainment. Too often local measures are neglected and poor air quality persists. A very wide range of measures is available to local authorities that would reduce traffic, restrict access to the most polluting vehicles, and achieve modal shift such as:

- **Cleaning up municipal fleets -** Most local authorities run or manage substantial fleets of vehicles for a wide range of purposes. These fleets operate intensively in their respective local areas and therefore can have a substantial impact on local air quality. At the same time, many vehicles in these fleets undertake relatively short journeys in the course of the day, and so are depot-based. As such, many of these vehicles are likely to be suitable for substitution with electric or plug-in hybrid vehicles, or other low emission solutions, through their vehicle procurement programmes.
- **Tackling buses and taxis** - These vehicles operate intensively in town and city centres, and in many cases are old vehicles with high emissions. Local authorities tend to have a high degree of influence over these vehicles as they are often the owners, licensors, and/or commissioners of them. As such, local officials often have the authority to specify that only low emission vehicles may be used in their fleets. Again, the vehicles' modes of operation are often suitable for the use of electric or hybrid technology, and equipping fleets with such technology can dramatically reduce the level of emissions in the town or city centre. An EU fund could help trigger investment in retrofit programmes and help local authorities to "electrify" their fleets.
- **Pedestrianisation or restriction of vehicular access** - Another effective option for reducing emissions in the town or city centre is to create areas in which all or virtually all vehicular access is restricted, either permanently or during working hours. This type of approach offers a wide variety of benefits beyond just better air quality, such as improving the urban environment, encouraging walking and cycling, favouring the local economy, etc.
- **Restricting access for high-emitting vehicles** - Local officials generally have the authority to specify which vehicles may enter their town or city centre. Therefore, they could consider establishing a -low emission zone (LEZ), which would ban or restrict the worst polluters. France released a categorization scheme for light duty vehicles in which Euro 6 diesels are not in the cleanest vehicle category[27].
- **Establishing goods transshipment centres -** An important source of traffic in most town and city centres is the delivery of goods to commercial premises. This is typically undertaken by vans and heavy trucks with diesel engines, both of which are substantial sources of emissions. An alternative pioneered in a few municipalities has been to establish transshipment points at which goods are transferred for the 'last mile' of delivery to smaller and less polluting vehicles, often hybrid vans or even fully-electric vehicles.

Many examples of these and other types of local sustainable transport initiatives can be found on the website www.eltis.org. This website was created by merging the best-practice case studies from the eltis.org and mobilityplans.eu to develop a single, all-encompassing urban mobility observatory.

4.6. Concluding remark

Each year the evidence and estimates of the numbers premature deaths and widespread illness caused by air pollution grows. The problems are predominantly in urban areas and vehicles, especially diesels the dominant source. Once emerging evidence of the effect of nitrogen dioxide are factored into health assessments it is likely 500-750 thousand people will die annually in the EU – equivalent to wiping out the population of Frankfurt each year.

It is entirely avoidable as the technology to clean up exhausts works and is available and costs a few hundred Euros. It is a small price to pay and much less than the hundreds of billions of euros spent in health care and lost output and productivity. Every legislative proposal to tackle the problem meets

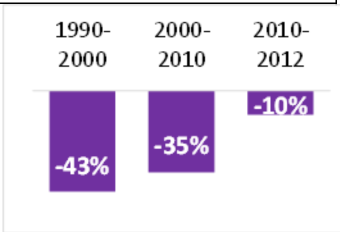
[27] http://www.developpement-durable.gouv.fr/Un-certificat-qualite-de-l-air,43566.html?var_mode=calcul

resistance for carmakers anxious to minimise their costs, have unrestricted car access to all areas and preserve the EU market for diesels. This opposition to tackling emissions perpetuates our polluted air. Cars with engines must be clean or prevented for accessing polluted cities. Citizens deserve the right to clean air wherever we need to breathe.

Annex 1
Main pollutants that are harmful for human health, part 2

Carbon Monoxide (CO)

Change in Emissions

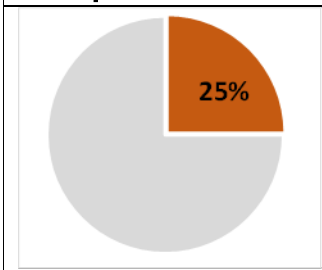


Sources: CO can be formed during the burning of any carbon-rich compound where there is insufficient oxygen available to oxidise all the carbon to CO_2. In internal combustion engines (ICEs). engines (especially petrol ones, this occurs through the incomplete combustion of the carbon in the fuel when the fuel:air ratio is high. Road transport used to be the main source of atmospheric CO, but has declined substantially over the past two decades.

Health Impacts: In high concentrations, CO is lethal, although not at the concentrations encountered in ambient air. However, chronic exposure can give rise to symptoms including tiredness, lethargy, headaches, nausea, dizziness, personality changes, and memory problems.

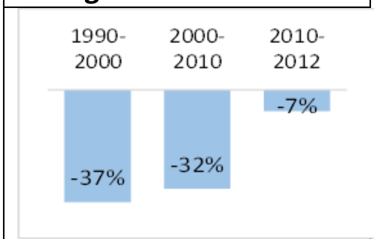
It is particularly likely to adversely affect those with pre-existing illnesses, especially angina and coronary artery disease.

Transport Share in 2012



Volatile Organic Compounds (VOCs)

Change in Emissions

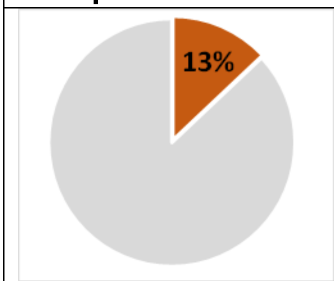


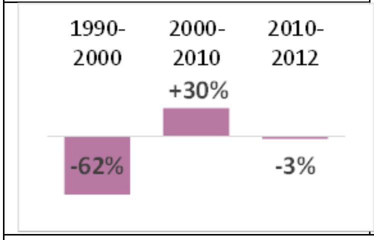
Sources: This is a very large group of compounds formed by unburnt or partially burnt fuel, or by fuel evaporation. It is found particularly in vehicle exhaust.
Methane, forms the vast majority of VOCs and is indirectly responsible for the creation of ozone.
Solvents and other industrial processes are the largest source of non-methane VOCs (NMVOCs) overall.

Health Impacts: A very wide range of substances fall in this category. Health effects can include eye, nose, and throat irritation; headaches; loss of coordination; nausea; and, at high doses, damage to the liver, kidney, and central nervous system. Respiratory, allergic, or immune effects can also be triggered in children who are more susceptible. Some VOCs, including benzene, are also known carcinogens.

VOCs also react with NO_2 to form ozone in the lower atmosphere, which is another common air pollutant that is detrimental to human health.

Transport Share in 2012



<table>
<tr><th colspan="2">Benzo(a)pyrene (BaP)- Non Regulated</th></tr>
<tr><td>Change in Emissions

</td><td>Sources: BaP is an example of a polycyclic aromatic hydrocarbon (PAH) that originates from incomplete combustion of fuels. Main sources include wood and waste burning, coke and steel production, and motor vehicle engines.

In particular, BaP is found in diesel exhaust.</td></tr>
<tr><td colspan="2">Health Impacts: BaP can cause irritation of the eyes, nose, or throat; breathing problems; irritation, inflammation, and infections of the lungs; asthma; reduced lung function; and lung cancer. It is also mutagenic in that metabolytes of BaP can react directly with DNA molecules and distort their structure.</td></tr>
</table>

Source: EEA and WHO various documents

Note: Data on sources are incomplete for BaP

Annex 2 Regulation of air pollution in Europe

The WHO Guidelines

The World Health Organisation (WHO) has the remit of assessing the emerging evidence on the adverse health effects of air pollution and establishing safe levels of pollutants that countries should aim to achieve. These are set out in the WHO Guidelines, which state that air of an acceptable quality is a fundamental human right.

On the basis of the available evidence, the WHO recommends guideline values for both the maximum safe concentration of each pollutant and the safe duration of exposure. A chemical may cause acutely damaging effects after peak exposure for a short period irreversible or incapacitating effects after prolonged exposure to lower concentrations, or both. A time of exposure as short as an hour or less may be specified for acute pollution, and typically a year of exposure reflects prolonged exposure.

EU air quality legislation

The WHO Guidelines are only a guide, and thus have no legal force. Therefore, the EU has gone further in setting mandatory limit values that require the member states to stay under limits for certain pollutants through its Air Quality Framework Directive and a series of 'daughter' Directives dealing with the individual pollutants.

In most cases, the limit values set at EU level follow the WHO guideline values; but, as they are mandatory, they are set at limits that are deemed to be achievable without excessive cost or effort on the part of the member states. In a few cases, this results in EU limits that are less stringent than those established by the WHO.WHO limits remain the mid-term air quality target and would have to be reached by 2030 across Europe. As can be seen from the numbers in brackets in Table 4 below, the annual limit values for PM in the WHO guidelines are significantly stricter than the current EU limit values. In certain cases, a limited number of exceedances of the limit may also be allowed.

The main limits for relevant pollutants are summarised in Table 4 below.

Pollutant	Concentration	Averaging period	Legal nature	Permitted exceedences each year
Fine particles ($PM_{2.5}$)	25 µg/m³ **(10)** **	1 year	Target value entered into force 1.1.2010 Limit value enters into force 1.1.2015	n/a
Nitrogen dioxide (NO_2)	200 µg/m³	1 hour	Limit value entered into force 1.1.2010	18
	40 µg/m³	1 year	Limit value entered into force 1.1.2010*	n/a
PM_{10}	50 µg/m³	24 hours	Limit value entered into force 1.1.2005	35
	40 µg/m³ **(20)** **	1 year	Limit value entered into force 1.1.2005	n/a
Lead (Pb)	0.5 µg/m³	1 year	Limit value entered into force 1.1.2005 (or 1.1.2010 in the immediate vicinity of specific, notified industrial sources; and a 1.0 µg/m³ limit value applied from 1.1.2005 to 31.12.2009)	n/a
Carbon monoxide (CO)	10 mg/m³	Maximum daily 8 hour mean	Limit value entered into force 1.1.2005	n/a
Benzene	5 µg/m³	1 year	Limit value entered into force 1.1.2010	n/a
Polycyclic Aromatic Hydrocarbons	1 ng/m³ (expressed as concentration of Benzo(a)pyrene)	1 year	Target value enters into force 31.12.2012	n/a

**Under Directive 2008/50/EC the member states can apply for an extension of up to five years (i.e. maximum up to 2015) in a specific zone. The request is subject to assessment by the Commission. In such cases, the limit value applies at the level of the limit value plus an agreed maximum margin of tolerance within the time extension period.*
*** Figures in brackets are WHO guideline values that differ from EU standards*
Source: European Commission

Table 4. Summary of EU limit values

The EU air quality monitoring network

In order to establish whether EU limit values are being met across the EU, the member states have been required to construct a network of monitoring stations with equipment designed to continuously measure the levels of all of the main pollutants, including those for which limits have been set. There are now over 2500 stations in the network, although the exact number varies from year to year and for different pollutants.

Stations are categorised into three types, according to their location and the pollution sources that they measure:

1. **Background** stations can be in urban, suburban, or rural areas; they are located away from major sources of emissions in order to indicate the general level of pollution in an area or country;
2. **Industrial** stations are located close to major emitters of pollutants, either in industrial areas or major points of concern such as power stations;
3. **Traffic** sources are located close to busy roads where vehicle emissions are at their highest.

The results of this monitoring are reported to the European Environment Agency, which produces regular reports on progress in cleaning up our air[28].

[28] The latest being http://www.eea.europa.eu//publications/air-quality-in-europe-2014

National Emissions Ceilings (NECs)

In 1999, the then-EU member states, together with other members of the UNECE, negotiated the 'multi-pollutant' protocol under the Convention on Long-Range Transboundary Air Pollution (the so-called Gothenburg Protocol). The commitments under the Protocol are translated into EU law by the National Emissions Ceilings Directive (NECD). This sets out limits for national emissions of the four pollutants responsible for acidification, eutrophication, and ground-level ozone pollution (sulphur dioxide, nitrogen oxides, volatile organic compounds, and ammonia),all of which are also implicated in local air quality problems. The NECD led to significant cuts in emissions up to 2010, but now needs to be amended to focus more on human health by introducing a ceiling for $PM_{2.5}$ and short-lived climate pollutants (black carbon and methane) in line with the 2012 amendments to the Protocol. Objectives including national ceilings must also be extended to 2020, 2025, and 2030. The EU Commission has released a revision of the NEC directives as part of the Clean Air Package which is likely to set more ambitious Emission Reduction Commitments (ERCs) until 2030. However, the Commission proposal is not ambitious enough: the 2025 emission limits should be made binding, and ERCs should reach the 75% gap closure by 2030, as defined to be the most cost-effective by the EU Impact Assessment.

Source regulations: EU emission limits on cars, vans and other sources

In order to bring about improvements in our air quality, ***emission limits*** are imposed on the most important sources of emissions of a particular pollutant. Increasingly sophisticated monitoring and modelling exercises have been undertaken in order to evaluate which sources of pollution are most important and how much their maximum or average emissions should be required to be reduced in order to improve air quality in the most effective and cost-effective way possible (see below).

For most of the common pollutants, emission limits are typically imposed on some or all of the following main sources:

1. Power stations
2. Other large industrial plants
3. Cars and vans
4. Heavy duty vehicles
5. Non-road machinery

Cars and vans have been regulated by a steady sequence of tightening limit values, starting with Euro 1 in 1991 and continuing most recently with Euro 6, which is coming into force between September 2014 (for new vehicle types) and September 2015 (for all vehicle types). These Euro standards limit all of the main pollutants from vehicle exhausts: carbon monoxide, nitrogen oxides, particulates, hydrocarbons and, volatile organic compounds from evaporation. Exhaust pollutant emissions limits are summarised in Table 5 below. Even though emission limits have been tightening over time, the manner in which they are measured is obsolete and needs to be deeply revised to better reflect real-life emissions, as described in the main report.

Euro Stage	Year of entry into force for new models*	CO	HC	$HC+NO_x$	NO_x	PM	PN
		g/km					number/km
Compression Ignition (Diesel)							
Euro 1	1992	2.72	-	0.97	-	0.14	-
Euro 2	1996	1.0	-	0.7	-	0.08	-
Euro 3	2000	0.64	-	0.56	0.50	0.05	-
Euro 4	2005	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009	0.50	-	0.23	0.18	0.005	-
Euro 5b	2011	0.50	-	0.23	0.18	0.005	6.0×10^{11}
Euro 6	2014	0.50	-	0.17	0.08	0.005	6.0×10^{11}
Positive Ignition (Petrol/Gasoline, LPG, CNG, etc)							
Euro	1992	2.72	-	0.97	-	-	-
Euro 2	1996	2.2	-	0.5	-	-	-
Euro 3	2000	2.30	0.20	-	0.15	-	-
Euro 4	2005	1.0	0.10	-	0.08	-	-
Euro 5	2009	1.0	0.10	-	0.06	0.005[a]	-
Euro 6	2014	1.0	0.10	-	0.06	0.005[a]	6.0×10^{11} [a]
Notes:							
* *models already in production must comply typically around one year later*							
a applicable only to direct injection engines							

Table 5. EU Emission Standards for Passenger Cars

As this table illustrates, petrol engines and diesel engines are both subject to separate and sometimes different limits that are slowly converging, reflecting the technical potential for emissions reductions and the willingness to harmonise regulation to achieve technology-neutral fuel policies. This has involved some trade-offs; for example, diesel vehicles have more stringent CO standards but are allowed higher NO_x emissions. For both engine types and for all of the compounds regulated, emissions limits have tightened considerably over more than two decades of EU vehicle emissions regulation. For example, the diesel car limit for carbon monoxide fell from 2.72g/km to 0.5g/km between Euro 1 and Euro 6 (a reduction of 82%) and for particulates from 0.14g/km to 0.005g/km (a reduction of 96%).

For heavy-duty trucks, which are dominated by compression ignition engines, emission limits have tightened in a similar trend but are expressed in a different unit (g/kWh instead of g/km). Recent emphasis has been put on particulate emissions and on reducing NO_x levels, which are difficult to control during the compression ignition combustion process and need to be post-treated in the exhaust line (Table 6).

Euro Stage	Year of entry into force for new models*	CO	HC	NO_x	PM	PN
		g/kWh				number/kWh
Euro I	1992	4.5	1.1	8	0.36	-
Euro II	1996	4	1.1	7	0.25	-
Euro III	2000	3.775	0.72	5	0.13	-
Euro IV	2005	2.75	0.505	3.5	0.025	-
Euro V	2008	2.75	0.505	2	0.025	-
Euro VI	2013	2.75	0.13	0.43	0.01	7E+11

Table 6. Table NN: Heavy duty emission limits

Non-Road Mobile Machinery (NRMM) is also subjected to emissions limits that are engine-specific. Limits depend on application type, engine power, and fuel/ignition type. Progress has been slower on NRMM engines, so such engines are in a position to benefit from leapfrog off of the technological progress made in other modes of transport.

The EU infringement procedures on air pollution

A formal procedure has been put in place to sanction member states that do not respect EU law. This is the case for air quality regulatory limits, and the EU Commission has initiated infringement proceeding against more than half of the member states. Seventeen member states are currently not respecting the PM10 regulatory limit, and one (the UK) is also being prosecuted for NO_2 limit exceedances[29]. When the process reaches the court ruling, member states are exposed to very heavy financial fines which are intended to provide sufficient incentive to put in place ambitious air pollution mitigation policies.

Bringing it all together – EU air quality strategy

All of the above form essential components of the European air quality management system, but how do we know that the limits we set on emissions are sufficient to meet the air quality targets that we set?

All of the above form essential components of the European air quality management system, but how do we know that the limits we set on emissions are sufficient to meet the air quality targets that we set?

The European Economic Community (as it was) first enacted legislation on vehicle emissions limits in Directive 70/220/EEC, but the first major milestones were Directive 91/441/EEC, which effectively required catalytic converters on all new petrol cars, and Directive 94/12/EC, set second stage limits (Euro 2) and separate limits for diesel cars. These measures were, however, hotly contested by the motor industry, consequently a more integrated and holistic approach was developed under the two Auto Oil

[29] http://legal.cleanair-europe.org/legal/eu/infringement-procedure/

Programmes and the subsequent Clean Air for Europe (CAFE) initiative, which culminated in further legislation in 2008. These sought to set subsequent standards on the basis of the most cost-effective approach to meeting air quality standards across Europe through new limits on a range of sectors, including motor vehicles. This was therefore was a deliberative process whereby future emissions limits were meant to be linked to the attainment of the air quality objectives.

In particular, CAFE envisaged a 60% reduction in NO_x emissions by 2020 relative to the year 2000 and a 59% reduction in primary $PM_{2.5}$. This objective in turn gave rise to the new regulation in 2007 that set the standards for Euro 5 and Euro 6 for cars and vans, requiring significant cuts in NO_x and PM emissions. For example, the Euro 5 limit represented an 80% cut in the $PM_{2.5}$ standard for diesels relative to the Euro 4 limit , while Euro 6 required a 68% cut in diesel NO_x from Euro 4. The shortcomings and failures of these emission limits will be covered later in this report.

Annex 3 - Evidence of the growing gap between test limits and real-world emissions

Background

There is now a wealth of evidence indicating exceedances of Euro limit values under real-world driving conditions. This 'gap' between the regulatory limit and real-life emissions has developed over a period of time, and this annex focuses mainly on the gap for cars and vans approved against the current Euro 6 standard. It also focuses especially on NO_x emissions from diesel cars, as this is where the gap between the regulatory limit and real-life emissions appears largest. These are of the most acute concern, together with particulates from gasoline direct injection engines.

Will Euro 6 reduce the NO_x emissions of new diesel cars? Insights from on-road tests with Portable Emissions Measurement Systems (PEMS), M. Weiss et al., paper published in Atmospheric Environment 62, p.657-665, August 2012

On-road tests with a PEMS system were carried out on one Euro 6 diesel vehicle and six Euro 4-5 diesels The tests were carried out on four different test routes designed to reflect typical on-road driving. These results must be taken merely as an indication since only one Euro 6 vehicle was tested.

Their route average NO_x emissions showed that the respective standards were exceeded by 164% for the Euro 6 vehicle, 294% for Euro 5, and 204% for Euro 4 vehicles. The on-road NO_x emissions for the Euro 6 vehicle were on average 0.21 g/km, which is substantially lower than the Euro 4 and Euro 5 vehicles (at 0.76 and 0.71 g/km, respectively) but still almost three times over the Euro 6 limit.

Handbook on Emission Factors for Road Transport, INFRAS, July 2014, http://www.hbefa.net

The HBEFA is based on measurements from more than a thousand cars spanning from the Euro 0 period to Euro 6 period. The relevant data clearly show that NO_x emissions from diesel cars did not drop significantly between Euro 0 and Euro 5, and at some stages even became worse. Furthermore, much more of the NO_x was emitted as primary NO_2 under Euro 3, 4, and 5, making its impact on the quality of air in the immediate vicinity of traffic even worse.

In this case, Euro 6 emissions were found to be much lower, but it is thought that this may be a result of the fact that only 9 diesel car models were available on the market when the testing was undertaken and most of them were from the premium vehicle segment. It is assumed that these early Euro 6 cars were designed to have lower real-world emissions since the OEMs were well aware of the high probability that independent labs would measure the emission levels of these vehicles in great detail. As argued above, it is likely that most production line Euro 6 cars will have higher NO_x levels as long as there is no supplementary legislation to deal with on-road measurements.

For vehicles with PI (petrol or gasoline) engines, the results suggest that more attention will need to be paid in the future to the real-world particle number (PN) emissions. Figure 16 shows the test results for the Euro 5 gasoline cars in the hot start CADC (of which about 40% had direct injection). Most vehicles exceeded the future Euro 6c limit of 6 x 10^{11} particles per km. Since a cold start increases the PN emission levels further (as do high engine loads and transient driving conditions), real-world PN performance is expected to become an issue for PI cars in future.

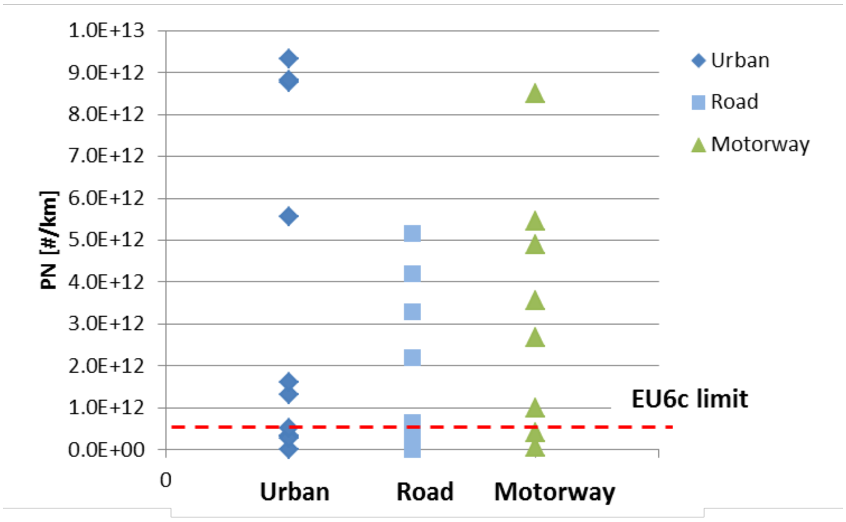


Figure 16. Particle number emissions from Euro 5 gasoline cars in the CADC test cycle according to the ERMES database (status 2012/2013). Each point is the test result of a single vehicle.

Investigations and real world emission performance of Euro 6 Light-Duty vehicles, N. Ligterink et al., TNO report 2013 R11891, December 2013

And

Detailed investigations and real-world emission performance of Euro 6 diesel passenger cars, Gerrit Kadijk et al, TNO 2015 R10702, May 2015

For these study divided on 3 phases, TNO reported data on 16 diesel passenger vehicles. four of these were prototypes (either pre-production Euro 6 or aimed at the US market) and twelve were Euro 6 type-approved. The vehicles were tested on the NEDC and on real-world driving cycles on a chassis dynamometer, and more intensively on many different routes using PEMS and SEMS

The general conclusion of this report was that the real-world CO, THC, and PM emissions of the tested vehicles fell within the Euro 6 limits, but NO_x emissions on a realistic driving cycle were on average more than 6 times higher than the Euro 6 NO_x limit. In on-road measurements, emissions reached 7-10 times above the limit (Figure 17).

Real-world NO_x emissions also varied enormously. In effect, the NO_x performance of Euro 6 diesel vehicles was found to be at a similar level as that of Euro 4 and 5 diesel passenger cars, despite the fact that the limit has been reduced from 250 mg/km for Euro 4 to 80 mg/km for Euro 6.

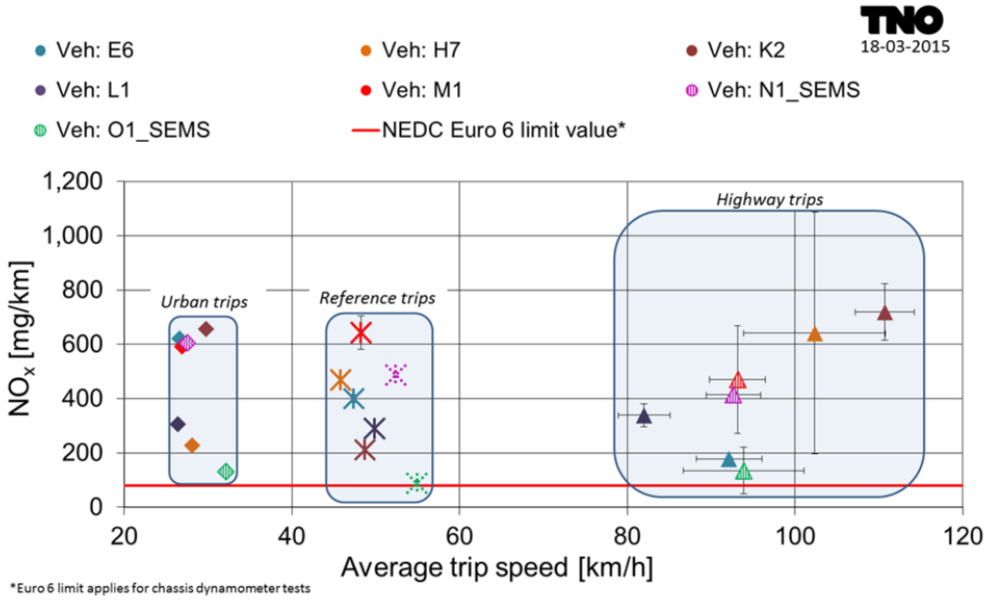


Figure 17. **Euro 6 PEMS tested vehicle at TNO, 2013 and 2015**

The vehicles tested in this study were among the first to meet the Euro 6 standard. Once Euro 6 is mandatory for all new vehicles on the market, it is expected that other (cheaper) abatement technologies may be used for smaller cars in particular, and these potentially will demonstrate poorer emissions reduction performance than the vehicles tested.

Real-world Exhaust Emissions from Modern Diesel Cars – a Meta-Analysis of PEMS Emissions Data from EU (Euro 6) and US (Tier 2 Bin 5/ULEV II) Diesel Passenger Cars, V. Franco et al., the ICCT, White Paper, October 2014

This analysis by the International Council on Clean Transportation (ICCT) is the most comprehensive source found for on-road measurements, as it incorporates results for fifteen Euro 6 vehicles tested for their real-world emissions using PEMS.

In the tests, the Euro 6 diesel cars were found to have low on-road emissions of carbon monoxide (CO) and total hydrocarbons (THC), which were generally within the Euro 6 type approval limits. In contrast, the on-road emissions of NO_x was very high for these vehicles, with emissions averaging 7 times the limit value and with only 10% of the averaging periods below the Euro 6 limit (Figure 18).

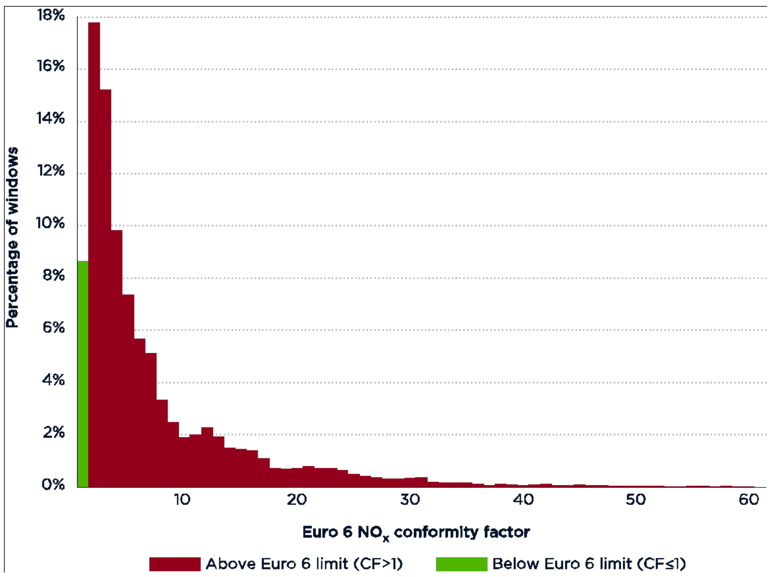


Figure 18. **Histogram of NO_x Conformity Factors (CF) for all windows (source: ICCT - Mock, 2014)**

Further analysis of the results suggests that higher NO_x emissions may be expected from more demanding test cycles in the future, and there were remarkable differences in the emissions performance of the tested vehicles. Only one of the tested vehicles was equipped with a lean NO_x trap (LNT) and 10 were equipped with selective catalytic reduction (SCR). The vehicle with LNT had the second highest NO_x emissions, and the vehicle with the lowest emissions had SCR.

ADAC position on the NO_x emissions of state-of-the-art diesel cars, positioning paper by ADAC, 02.19.7001 – 28275 – STAND 10-2014, 2014

In this study, a total of 18 Euro 6 diesel cars with different emissions reduction technologies were tested by German motoring organisation ADAC in the laboratory on three different test cycles. The NO_x emissions of Euro 6 diesel cars were found to vary greatly between different driving cycles, as can be seen in Figure 19.

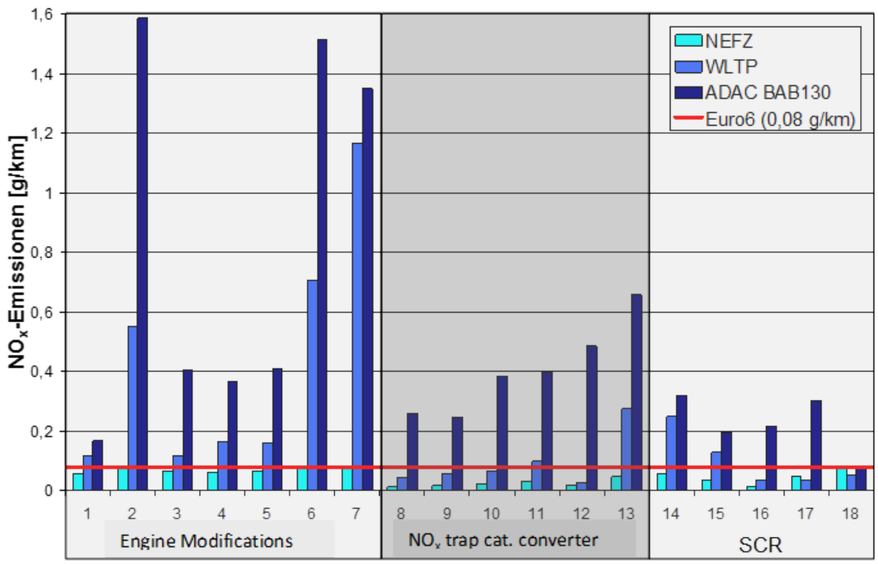


Figure 19. **NO_x emissions of 18 selected Euro 6 diesel passenger cars over the NEDC (NEFZ), WLTP and ADAC test cycles [ADAC 2014]**

The results illustrate that SCR technology has the potential to reduce NO_x significantly on any driving cycle, provided that it is well-calibrated. It also shows that almost all of the Euro 6 diesel cars currently available on the market cannot reproduce the same low-NO_x emission performance from the NEDC on more realistic driving cycles such as WLTC and ADAC Ecotest, and especially not in non-urban traffic conditions. This is related to the absence of harsh accelerations in the NEDC and the associated high engine loads. The ADAC Ecotest contains motorway driving with full-throttle sections, which clearly highlights the differences in the NO_x-reducing potential of the Euro 6 technologies. Engine modifications with no aftertreatment performed particularly poorly in these conditions. On the WLTC, the NO_x emissions were also generally higher, though never to the same extent as on the ADAC test. In general, the Euro 6 vehicles with only engine modifications show the highest emissions in real-world cycles, followed by the lean NO_x catalyst. The SCR technology had the best overall NO_x performance in all test cycles used.

PEMS-Messungen an drei Euro 6-Diesel-Pkw auf Streckenführungen in Stuttgart und München sowie auf Außerortsstrecken, Werner Scholz et al, March 2015

3 Vehicles with different post treatment technologies have been extensively PEMS tested, on different routes. In-depth data analysis has been performed, for example to highlight the NOx instantaneous emission on a Engine speed vs power map, versus the time epnt for each engione point for type approval

test cycles (NEDC, and WLTC). This shows the inadequacy of the type approval test to capture high NOx emissions events (Figure 20).
Report is only available in German.

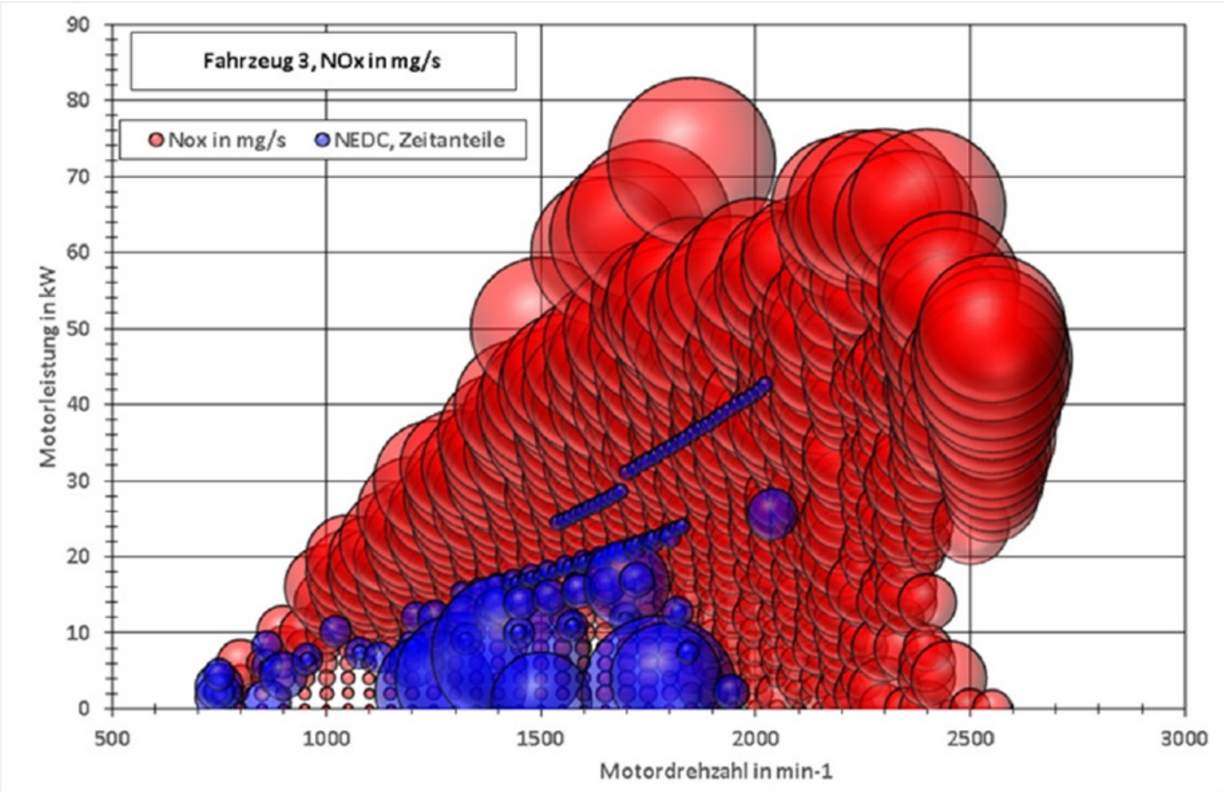


Figure 20. **NO_x emission events on the engine speed vs power map compared with operation points on the NEDC**

Where do Euro 6 cars stand? Presentation from Emission Analytics at the AECC RDE conference, Nick Molden, April2015

Emission Analytics has extensive experience with PEMS measurements, and has tested more than 800 vehicles over the years, primarily for real-life CO_2 emissions measurements.
Additional measurements on some pollutant have been added over time, and more than 25 Euro 6 cars have PEMS-tested and NOx measured over the same route that is kept confidential in order t oavoir optimization from manufacturers.
The route is nonetheless not very demanding, with limited slopes and high speed events. Overall , only 3 vehicles tested by Emission Analytics meet the NOx legal requirement in real-life conditions, and average exceedances factor exceeds 4.5 times the legal limit. Emission Analytics nevertheless recently noticed an improvement of more recent vehicles tested (Figure 21), that would need to be confirmed with future tests, especially as all vehicles will have to comply to Euro 6 as of September 2015.

Figure 21. **Latest trends of Euro96 NOx PEMS teste results**

Conclusions from recent evidence on the real-world emissions gap

The evidence on Euro 6 emissions is still developing, as the standards do not yet apply to all new cars, but some clear conclusions are emerging.

1. Most of the evidence shows limited reductions in real-world diesel NO_x emissions over the whole of the period subject to the Euro limit values, in spite of ever-tighter test limits.
2. More of the real-world NO_x is being emitted as primary NO_2, thereby accentuating the impacts on air quality close to roads with heavy traffic.
3. There is growing evidence that this problem can be resolved by applying good quality selective catalytic reduction (SCR) aftertreatment to diesel engines, but cheaper solutions such as LNTs and engine modifications alone are much less effective.
4. For cars with PI (petrol or gasoline) engines, the evidence suggests that they are now well able to meet Euro standards in real-world conditions for most pollutants, including NO_x. There is concern that particle numbers (PN) are well above the limits for Euro 6, but particle filters are capable of dealing with this problem in a cost-effective manner.

Annex 3 – Test Cycles for Non-Road Mobile Machinery

The ISO 8178 is an international standard and includes a collection of steady-state engine dynamometer test cycles designated as type C1 (commonly referred to as the NRSC and used in the EU for off-road vehicles), D1 (for constant speed engines), and others. These are designed for different types of applications and apply different weighting factors to the various engine modes within the test (defined by normalised engine torque and speed) to reflect, to the extent possible, the different use patterns of broad classes of machines. However, the load points and weightings are the same for all off-road vehicles; so, for example, the differentiation of the load patterns is quite crude.

The NRTC test is a transient driving cycle for mobile non-road diesel engines, developed by the US Environmental Protection Agency (EPA) in cooperation with authorities in the EU. The cycle has a total duration of 1238 seconds and is a transient driving schedule. It is run from both a cold start and a hot start, with an engine soak temperature stabilised at between 20 and 30°C, as for the current NEDC test for road vehicles. The cold start results have a weighting factor of 10% in the EU and 5% in the United States, reflecting the fact that these machines tend to be operated continuously for long periods and hence that cold starts are not a large influence on average emissions.

Table 7 below shows the particular engine modes of the different engine applications used in the NRTC.

NRTC (Nonroad Transient Cycle)								
Application Number	Nonroad Application	Application Duration (seconds)	Application in Cycle Position (#seconds)	Segments from Application Cycle (#seconds)	Segment Name	Segment Duration (seconds)	Cumulative Cycle Time (seconds)	Segment in Cycle Position (#seconds)
					Start/Transition	28	28	0-28
1	Backhoe Loader	206	29-234	52-86	Roading	35	63	29-63
				108-141	Trenching	34	97	64-97
				174-218	Loading	45	142	98-142
				351-442	Grade/Level	92	234	143-234
2	Rubber-Tire Loader	184	235-418	746-822	Typical Operation	77	311	235-311
				531-637	Hi-Spd Transient	107	418	312-418
3	Crawler-Dozer	209	419-627	85-206	Road Bed Prep	122	540	419-540
				376-462	Clearing	87	627	540-627
4	Agricultural Tractor	150	628-777	265-414	AgTractor	150	777	628-777
5	Excavator	35	778-812	319-338	LowerHp (128Hp)	20	797	778-797
				431-445	HigherHp (208Hp)	15	812	798-812
					Transition	3	815	813-815
6	Arc Welder	204	816-1019	1007-1103	Typical Operation	97	912	816-912
				544-650	Hi-Spd Transient	107	1019	913-1019
7	Skid Steer Loader	185	1020-1204	264-365	Typical Operation	102	1121	1020-1121
				150-232	Hi-Trq Transient	83	1204	1122-1204
					Idle/Transition/End	34	1238	1215-1238

Table 7. Allocation of NRTC Test Cycle modes to machinery classes

The load points for both NRSC (red circles) and NRTC (black dots) are illustrated in Figure 13 in Section of the main report.