Real-world Vehicle Emissions

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Abstract

Real-world vehicle emissions differ from the legislative emissions limits for a number of reasons. Emissions can be substantially lower but in most cases emissions in real driving conditions are higher than the type-approval values. This is especially the case for NO_x emissions from diesels. Between Euro 1 and Euro 5 standards the European NO_x limit decreased by a factor of five but real-world NO_x emissions have remained more or less constant. High real-world NO_x emissions from light- and heavy-duty diesels are the main cause of high NO_2 concentrations in cities. Some Euro 6 vehicles now show real-world NO_x emissions close to the limit, but many vehicle models still exceed the limit by a factor of eight in real-world driving conditions. This report outlines the main reasons for the deviations and discusses the implications for managing air pollution. The European situation is taken as example.

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Real-world vehicle emissions

The current state of affairs in Europe[1]

Real-world vehicle emissions differ from the legislative emissions limits for a number of reasons. In most cases emissions, in grams per kilometre, are higher than the type-approval, or factory value. But emissions can also be substantially lower. This report aims to outline the main reasons for the deviations and the implications for managing air pollution. The European situation is used as an example.

In the past attention was directed mainly at the reduction of the emissions of heavy-duty vehicles. However, the latest generation of Euro-VI diesel trucks are very clean. They typically perform better on-road than the type-approval limits. Basically, the average modern 30-tonne truck has a lower Nitrogen Oxide (NO_x) emission than an average modern diesel passenger car. Combined with the increased share of diesel passenger cars in the total fleet attention has shifted to these diesel passenger cars and to light commercial vans. The separation between light-duty and heavy-duty emission legislation lies at 3.5 tonnes in Europe.

Only recently, with the influx of these Euro-VI diesel trucks from 2014 onwards, has the impact of heavy-duty vehicles on the total NO_x emissions declined. Trucks were responsible for more than half the NO_x emissions in many traffic situations on urban roads, despite the small fraction of trucks among the vehicles, 5% or less. The selective catalytic reduction (SCR) emission after-treatment system, used since 2007 on trucks, functioned only in circumstances similar to the European Transient Cycle (ETC) type-approval test. The corresponding on-road circumstances are heavy-loaded driving on the motorway. In urban conditions the SCR system remained too cold to function and the NO_x emissions of Euro-V trucks are typically threefold to fivefold higher than the regulated limit.

With Euro-VI legislation for heavy-duty engines, there are three important changes. First, the new engine test, the World Heavy-duty Transient Cycle (WHTC), uses a lower engine load more comparable to on-road usage. Second, a cold start is included in the test protocol. Finally, and maybe most important for the success of Euro-VI legislation, the in-service conformity (ISC) test is no longer an engine test in the laboratory but an on-road test with the vehicle in normal use. The NO_x emissions of the first Euro-VI trucks were extremely low; in a number of cases close to the bounds of measurement uncertainty. Moreover, with continued testing emissions remain, in general, low for Euro-VI trucks with aging of the first vehicles and with new engines coming onto the market.

There are minor concerns for high emissions in special urban use, such as refuse trucks and inner-city busses, which still operate mainly outside the in-service conformity test regime.

Robust emission control technologies

In the last thirty years there have been two emission control technologies that have changed the landscape for vehicle emissions. These are the three-way catalyst for petrol cars, and the diesel particulate filter for diesel vehicles. Around 1990 the three-way catalyst was introduced for spark-ignition vehicles, such as petrol cars. This decimated the emissions of hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x) of these vehicles (emissions of particulates [PM] were already low for petrol vehicles), and it left diesel vehicles as the main polluters from 1992 onwards. Apart from cold starts, aging and some failures in engine control systems, especially prior to 2000, the emissions of petrol cars have been very low. A catalyst requires time and fuel to warm up. The cold-engine start yields higher initial emissions before the catalyst is warm. For petrol cars these so-called cold-start emissions dominate total emissions, in particular for HC emissions.

The diesel particulates filter (DPF) has been standard for diesel passenger cars since 2009 and for trucks since 2014. The addition to the European regulations of a particulate number emission limit, accompanied with a measurement procedure which can detect particulates accurately in the lower end of the size range, ensured appropriate application of DPF technology. The change in particulate emissions with the introduction of the filter has been dramatic. The particulate mass limit was reduced by a factor of five for diesel passenger cars between Euro-4 (2005) and Euro-5 (2009) standards but the real-world emissions decreased by at least a factor of fifty. Prior to the widespread application of DPFs, the average real-world particulate emissions of diesel cars were somewhat higher than the limits. For vehicles with a DPF the emissions are far below this limit. The actual values are often around 0.5 mg/km, close to the measurement uncertainty, while the limit is 5 mg/km.

The type approval test as the standard for compliance

The type-approval test for light-duty vehicles is executed on the prototype of a new vehicle model, and repeated occasionally in the conformity-of-production tests on new vehicles directly from the factory. The type-approval test is a well-defined protocol, with limited power demand on the vehicle, such that all vehicle models can undergo the same test. Hence the demand on the engine during the type-approval test is only a fraction of the typically available engine power in a modern European light-duty vehicle. If vehicles in use are taken from the road to undergo these tests, the emissions are usually slightly higher but the performance on the type-approval test is generally satisfactory. Occasionally, high emissions from in-use vehicles on the type-approval test occur due to malfunctioning or poor maintenance of the vehicle.

Contrary to light-duty vehicles, the engine demand in the type-approval test of a heavy-duty vehicle is on the high side of the engine demand profile for normal use of trucks. For heavy-duty vehicles the type-approval emission test applies to the engine rather than the whole vehicle, and is based on the rated power of the engine. With the general increase in engine power over the years, the engines have been tested with higher and higher engine loads, while the real-world engine load remained more constant, and unrelated to rated engine power.

Thus the type-approval test for light-duty vehicles is focuses on the weakest link, low-powered vehicles, while the heavy-duty engines are tested on high engine loads matched to engine power. Both type-approval tests therefore cover only a particular part of the engine load spectrum observed in real-world usage.

The two separate worlds of type-approval and on-road in-use testing for light-duty diesel vehicles

In the real world, emissions can be much higher than on the type-approval test. This is particularly the case for light-duty diesel vehicles. Recently, the "dieselgate" scandal with modern vehicles switching to a customised emissions control strategy during type-approval and conformity of production tests caught everyone's attention, but there has been a steady increase in the difference between the real-world emissions of light-duty diesels and the type-approval limits for at least a decade. This increase coincides with the increasing complexity of emission control strategies and the electronic sensor and control systems of the vehicle. Engine control nowadays is related to gear selection, ambient temperature, fuel quality and so on. Within the full span of driving behaviour, vehicle payload and ambient conditions the specific conditions of the type-approval test are a smaller and smaller subset, with an increasing number of parametric dependencies. Optimising emissions control technology on this subset of operating conditions leads to a larger and larger area where emission control is of limited effectiveness. Around the year 2000, high emissions were typically only observed under hard acceleration. Nowadays, temperatures below 20°C, high engine speeds, high engine loads, speeds above 120 km/h, use of running lights can all result in cases where disproportional increases in vehicle emissions are observed.

In particular over recent decades, real-world NO_x emissions from diesel vehicles have remained high, at about 0.6 g/km, despite the emission limit changing from 0.97 g/km (combined NO_x and hydrocarbons [HC]) for Euro 1 legislation in 1992 to 0.080 g/km (NO_x alone) for Euro 6 standards in 2014. Seemingly, the applied emission control technology, which performs excellently in the type-approval tests, has limited effectiveness in any other circumstance than the type-approval test. NO_x emissions from light-duty diesels are high in almost all normal conditions on the road and for all vehicle models until 2016. Very recently some well-performing vehicles have entered the market, with on-road emissions approaching the type-approval limit of Euro-6.

Designed, or optimised, for the type-approval test

Given the precise protocol and the limited demands on engine power in the type-approval test, some technologies can be designed for the type-approval testing that are less suitable for other vehicle use conditions, in particular for higher engine power and dynamic driving. For example, an after-treatment system can be designed for a maximum exhaust gas flow or a maximal amount of pollutants that can be reduced. If this maximum is related solely to values occurring on the type-approval test, the emissions will increase substantially in the real world with higher flows resulting from harder accelerations and higher payloads.

Also engine temperature management is a complex matter, where the optimal operation of an engine, including durability considerations, can be at odds with the emission control system. Most diesel vehicles use exhaust gas recirculation (EGR) to limit the NO_x emissions during combustion. The combination of more inlet exhaust gas and less oxygen (fresh air) in the cylinder reduces the combustion temperature and hence the production of NO_x. The amount of recirculated exhaust gas depends on the power demand, the inlet pressure and temperature and other factors which depend strongly on the precise operating conditions. Therefore, the EGR rate is dynamically controlled, and in the case of high power demand, it can be restricted. NO_x emissions can increase easily by a factor of three or more when the EGR rate is reduced. Such circumstances may not occur in the type-approval tests but can be common in on-road situations. The particulars of EGR control strategies have been key to the high real-world NO_x emissions of Euro-5 diesel cars, sold in Europe between 2009 and 2015. The real-world emissions of these vehicles are on average four times higher than the type-approval limit.

Around 2010 a number of vehicles showed high NO_x emission levels in independently executed type-approval test carried out at a laboratory temperature of 15°C instead of the 20°C to 30°C window prescribed in the type-approval procedure. The rest of the test protocol was identical but the emissions were about three times higher than at 20°C. It was considered an improper emission control strategy to have such a large increase for such limited variation outside the test protocol. On the other hand, there was no implementing regulation which set a precise limit on the acceptable increase in emission while deviating outside the operation region of the type-approval protocol.

With Euro 6 compliant control technologies the situation is even more complex, in addition to EGR most vehicles are equipped with additional after-treatment technology for NO_x reduction. This is typically a lean NO_x trap (LNT) or a selective catalyst reduction (SCR) system. The latter uses a urea solution (AdBlue) to reduce NO_x to harmless components. For most Euro 6 vehicle models real-world NO_x emissions are still very high, but occasionally models are found with low emissions. The reasons why a large number of diesel Euro 6 vehicles perform poorly on NO_x emissions tests in many real-world conditions vary from specific design and optimisation for the type-approval test to the limited robustness of the emission control technology for the circumstances encountered in the real-world tests. In the first case the technology will never work properly in the full spectrum real-world usage. In the second case improvements may be expected. For the petrol three-way catalyst it also took about ten years for the emission control strategy to mature to full robustness, which also copes with emissions during most hard accelerations.

Normal conditions of use as part of type-approval

European legislation already included a provision in 2007 to introduce on-road testing if the regulation based on type-approval tests in the laboratory proved insufficient to yield low real-world emissions, described in the legislation as "normal conditions of use". In 2011 the European Commission started to develop real driving emissions (RDE) legislation because of the failure of Euro 5 cars and vans, sold from 2009 onwards, to reduce the on-road NO_x emissions of diesel vehicles.

The RDE legislation took a long time to develop because of the stakeholders' involvement in the process. However, since 1 September 2017 all new vehicle models should be tested on-road. Since the manufacturer has freedom in the execution of the RDE test with the prototype vehicle, an essential ingredient of RDE legislation is to challenge the declaration of compliance of the manufacturer by doing independent testing in other, possibly more demanding conditions than chosen by the vehicle manufacturer in consultation with the type-approval authority. The change in the regulations on 1 September 2017 is not expected to yield significant change for some time as new vehicle models can be added to existing type-approvals. Only from 1 September 2019 will all new vehicles have to comply with the RDE regulation and RDE tests become unavoidable for manufacturers to sell new vehicles.

There is optimism that RDE legislation will deliver a substantial reduction in NO_x emissions and ensure real-world emissions consistent with the type-approval limits for the foreseeable future. But RDE legislation still lacks two important provisions. First, the final part of the RDE legislation, which covers challenges to RDE type-approval declarations of compliance, has yet to be finalised. Second, there is no provision for reform of European type-approval authorities, which is needed to make pan-European enforcement of vehicle emission legislation possible. Moreover, the finer details of the RDE legislation will determine how robust it is and this will only become apparent as it is implemented.

Impacts of driving conditions on emissions

Driving behaviour, congestion and speed limits can all affect the emissions of a vehicle significantly. For vehicles already in use, influencing driving conditions is one of the few means by which exhaust emissions can be reduced.

The problem with congestion is the low velocity and the high vehicle dynamic range (acceleration and braking). Below 50 km/h most emissions of a modern vehicle are associated with keeping the engine running, rather than propelling the vehicle forward. Below 50 km/h therefore, halving the velocity roughly doubles the emissions per kilometre. Simply said, the engine is operating twice as long if the velocity is halved. The second effect is the higher dynamics associated with congestion. A large number of stopping or braking events means that a larger part of the energy produced by the engine is not used for getting from origin to destination but is converted into heat in the brakes. The low velocity and the increased braking may double the emissions per kilometre in congested urban situations.

Hybrid vehicles are designed to deal more efficiently with the low velocity and high dynamics of congested traffic. In the case of hybrid vehicles the emissions do not increase as dramatically with increasing congestion.

Reducing congestion to reduce emissions is seldom simple. In many cases the bottlenecks in the traffic capacity of a road network are simply shifted in position rather than removed by measures to manage congestion. This will shift the source of the emissions to a new location. In some cases shifting the traffic congestion to another location is warranted, when it can reduce the actual exposure of citizens.

On the other end of the velocity range, above 90 km/h, engine power demand increases rapidly with speed because of the air-drag on the vehicle. From 100 km/h to 150 km/h the fuel consumption typically more than doubles, and given the limited optimisation of the emission control technology for high velocities the pollutant emissions will increase in many cases many times that amount. A factor of five or more increase in pollutant emissions is not exceptional for velocities above 100 km/h.

Altogether, for modern light-duty vehicles driving constantly between 50 km/h and 90 km/h will yield the lowest fuel consumption and the lowest pollutant emissions. In the Netherlands an 80 km/h speed limit on motorways was introduced for the beltways of Amsterdam and Rotterdam to reduce air-quality problems in the neighbourhoods within one kilometre of these motorways. Motorways have a large effect on local air quality due to the 100 000 or more vehicles that can pass per day.

Emission measurement and modelling

The measurement of real-world emissions had to shift from laboratory tests to on-road emission tests because of the elaborate vehicle emission control strategies. Even without an illegal defeat device, vehicles can have very different emissions in normal on-road conditions than in the laboratory. Hence in the assessment of the emissions performance of vehicles it is essential to replicate as well as possible the variety of normal conditions on the road. A shift from a simple test to monitoring of vehicle emissions over a longer time is important for grasping the effects over the full span of on-road conditions.

Since 2009 for heavy-duty vehicles and since 2011 for light-duty vehicles, on-road emissions measurements are part of the determination of the average vehicle emissions for in Dutch air quality models. The official emissions factor model, developed by TNO, is updated annually with the new measurement results from the previous year of emissions testing. Test results from at least ten different common vehicles in the same emissions class are needed to provide a confident prediction of emissions in a variety of circumstances, with as a rule of thumb, each vehicle undergoing at least a day of testing over about 600 km.

Impacts of malfunctioning and tampering

Occasionally a test vehicle performs very poorly because of malfunctioning, tampering, deterioration, or poor maintenance. It is difficult to point to a single factor responsible for high emissions from an older vehicle. Design, maintenance, usage and fuel quality all play a role. Hence, even with a large measurement program it is difficult to have cars banned from the road because of measured high emissions. The manufacturer will point to the user, who, in turn, will point to the garage undertaking maintenance. The garage will point to the annual inspection procedure and the inspection authority will point to the legislation. Eventually, nobody will have full responsibility for a poorly performing car. Unlike safety issues, emission performance seems hardly enforceable in Europe. Even in the aftermath of the scandal around diesel vehicles, and the common knowledge that certain vehicles have extremely high emissions, there has not been a backlash in enforcement. Basically, there is no proper legal framework to deal with violations of emission regulation.

The prohibition of the wilful removal of a diesel particulate filter, the use of inferior replacement parts, or the switching-off of the EGR or AdBlue injection of an SCR system, can be enforced. However, it requires good legislation to separate harmless adaptions of the vehicle from adaptions which increase emissions. Only a technically skilful enforcer can establish if a breach of the legislation has taken place.

This is not a trivial matter as high punitive sanctions are needed to ensure the limited risk of detection yields sufficient deterrence. Measuring emissions reproducibly to establish with confidence a deviation, and its underlying cause, requires a professional inspection service. The typical emission limits in periodical inspections are factors higher than the emission limits in type approval tests.

Tampering exists in Europe, but the magnitude of the problem is largely unknown. There is no proper enforcement against tampering in place anywhere in Europe, unlike the US, where the EPA keeps a full record of the proper state of in-use vehicles, including certification and registration of replacement parts. The reasons for tampering are mainly cost related. The SCR is switched off to reduce the cost of AdBlue refills. Switching off the AdBlue injection is not completely trivial, because of the on-board diagnostics (OBD) control required by legislation. Likewise, the removal of a diesel particulate filter is not a simple procedure. However, drivers, who drive mainly in urban areas below 80 km/h, may encounter maintenance problems because of failed filter regeneration. Such regenerations should take place about every 500 kilometres and they require hot exhaust gas, produced typically with motorway driving. If a vehicle does not enter the motorway often enough, the filter will be clogged and the engine will stop working. Moreover, an uncontrolled regeneration may cause a vehicle fire. The expensive maintenance of clogged filters can be avoided by removing the filter, with high particulate emissions as a result.

Other forms of tampering are the closing off of clogged EGR that requires maintenance and the flashing of the engine control unit for more engine power, probably at the expense of high emissions. These two forms of tampering are usually done together as normal EGR control will not work in conjunction with the power increase.

Impact of real-world emission performance on the effectiveness of local air quality policies

Reducing vehicle emissions with local measures to improve air quality has turned out to be difficult. A decade of mitigation policies in Dutch cities to bring the ambient concentration levels below the European air quality limits has found no silver bullets but instead many demanding measures were implemented, each providing only a small positive reduction in emissions.

Many municipalities have introduced environmental zoning for traffic as a policy instrument for curbing local emissions and improving air quality. In Europe many low emission zones are enforced on the basis of vehicle emission legislation classes, banning older vehicles with higher legislative emission limits. These limits may have little to do with the on-road emission performance of the vehicle, but they can be properly registered and enforced.

The biggest hurdle is that vehicles, once allowed on the road, will be used for fifteen years or longer. Any measure affecting the sales of new cars will not be effective for ten years or longer, as the older vehicles dominate total emissions. The scrappage of older vehicles is usually not very cost effective as a large number of older vehicles, each driven only a limited annual mileage, are together responsible for the high emissions. The replacement vehicle in scrappage schemes may also not bring much improvement. Measures on public transport buses, including fleet renewal or the introduction of alterative propulsion technologies, are often most effective, as these vehicles drive a high mileage in areas where air quality is an issue.

Bringing the velocity of vehicles to a constant 50 to 90 km/h, at least on motorways, is the best alternative that does not affect personal mobility negatively. Expanding the infrastructure capacity to reduce congestion may yield a short-term benefit, but the increased road capacity will generally result in increased traffic volumes within a few years. Road pricing and parking pricing may provide more durable reductions in congestion.

The use of private cars is linked to personal freedom and economic activity. Hence the option to limit the daily mileage of vehicles to reduce the total emissions and improve the air quality is not usually available. Other measures have to be taken to reduce the vehicle emissions. These measures come in four groups. The first measure is a long-term plan: stimulate new vehicles with clean technology possibly enhanced by scrapping the oldest vehicles with the largest impact on air-quality. Second, reduce vehicle use by stimulating clean public transport and alternatives like cycling. Third, enforce proper vehicle maintenance and prevention of tampering. Finally, reduce congestion and bring traffic velocities to a constant 50-90 km/h on motorways. A comprehensive package includes all four items, combined with campaigns to generate public awareness of their personal contribution to public health and quality of life.

Conclusions

The three-way catalyst, introduced around 1990, has reduced the emissions of petrol vehicles to negligible levels compared to diesel vehicles. The widespread application of DPFs from 2009 onwards has reduced particulate emissions of diesels to extremely low levels, well below the emission limits.

Nevertheless real-world pollutant emissions of road vehicles are often significantly higher than the type approval values. This is especially the case for NO_x emissions from diesels. Between Euro 1 and Euro 5 standards the European NO_x limit has decreased by a factor of five but real-world NO_x emissions have remained more or less constant.

High real-world NO_x emissions from light- and heavy-duty diesels are the main cause of high NO_2 concentrations in cities. The fact that newer light-duty vehicles are not significantly cleaner than older Euro classes reduces the effectiveness of local policy measures, like low-emission zones, to reduce the NO_x emissions of traffic. Some Euro 6 vehicles now show real-world NO_x emissions closer to the limit, but many vehicle models in real-world still exceed the limit by a factor of eight.

Given the fleet of vehicles on the road, implementing traffic measures that bring speeds to a more constant 50 to 90 km/h on motorways and ring roads is the most effective measure available to lower tiers of governments for reducing traffic emissions.

Annex 1

TNO has undertaken emission testing for the Dutch government continuously since the 1980's. There are comprehensive programmes to test passenger cars, vans, trucks, buses and two-wheelers. The main purpose of the measurement programmes is to determine the on-road, in-use emission performance of vehicles relevant to Dutch air quality.[1] The emissions factors for different road types and congestion levels are updated annually on the basis of new measurement results. The reports and the results are available on-line. The table below summarises the main results for NO_x and exhaust PM emissions (particulate mass).

Table A1. **Main results of NO_x and exhaust PM emissions**

		Component	**Urban congested**		**Urban normal**		**Rural**		**Motorway**	
			NOx	**Particulates (PM1)**	**NOx**	**Particulates (PM1)**	**NOx**	**Particulates (PM1)**	**NOx**	**Particulates (PM1)**
		Legislation	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]
Passenger cars	Petrol	Euro-1	1.29	0.108	0.72	0.067	0.47	0.0068	0.25	0.0025
Passenger cars	Petrol	Euro-2	0.69	0.0046	0.47	0.0046	0.21	0.0023	0.20	0.0050
Passenger cars	Petrol	Euro-3	0.21	0.0046	0.15	0.0046	0.059	0.0023	0.036	0.0050
Passenger cars	Petrol	Euro-4	0.079	0.0046	0.054	0.0046	0.025	0.0023	0.015	0.0050
Passenger cars	Petrol	Euro-5	0.063	0.0037	0.043	0.0037	0.020	0.0019	0.012	0.0050
Passenger cars	Petrol	Euro-6	0.063	0.0037	0.043	0.0037	0.020	0.0019	0.012	0.0050
Passenger cars	Diesel	Euro-1	1.92	0.372	1.06	0.236	0.45	0.101	0.69	0.081
Passenger cars	Diesel	Euro-2	1.10	0.162	0.80	0.111	0.55	0.045	0.67	0.092
Passenger cars	Diesel	Euro-3	1.23	0.043	0.80	0.031	0.55	0.026	0.70	0.052
Passenger cars	Diesel	Euro-4	0.69	0.051	0.43	0.033	0.38	0.016	0.51	0.035
Passenger cars	Diesel	Euro-5	1.00	0.0005	0.67	0.0005	0.53	0.0005	0.59	0.0015
Passenger cars	Diesel	Euro-6	0.55	0.0005	0.43	0.0005	0.34	0.0005	0.41	0.0015
Passenger cars	Diesel	Euro-6 RDE	0.31	0.0005	0.23	0.0005	0.17	0.0005	0.17	0.0015
Trucks	Light	pre-Euro	12.4	0.971	7.7	0.54	6.4	0.3273	7.0	0.27
Trucks	Light	Euro-1	8.1	0.477	5.0	0.26	4.2	0.1588	4.5	0.13
Trucks	Light	Euro-2	8.7	0.192	5.4	0.107	4.4	0.0771	4.6	0.067
Trucks	Light	Euro-3	10.3	0.224	5.7	0.124	3.9	0.0747	4.2	0.054
Trucks	Light	Euro-4	10.1	0.046	6.3	0.025	3.3	0.0138	3.3	0.0102
Trucks	Light	Euro-5	7.4	0.016	4.6	0.0099	2.8	0.0066	1.7	0.0055
Trucks	Light	Euro-5 with OBD	7.5	0.014	4.7	0.0087	2.7	0.0057	1.8	0.0048
Trucks	Light	Euro-6	0.44	0.010	0.28	0.0061	0.19	0.0042	0.17	0.0037

Table A1. **Main results of NO_x and exhaust PM emissions (continued)**

		Component	Urban congested		Urban normal		Rural		Motorway	
			NOx	**Particulates (PM1)**	**NOx**	**Particulates (PM1)**	**NOx**	**Particulates (PM1)**	**NOx**	**Particulates (PM1)**
		Legislation	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]
Trucks	Heavy	pre-Euro	33.6	2.49	21.0	1.38	15.0	0.82	13.3	0.63
		Euro-1	22.1	1.29	13.8	0.72	9.9	0.41	8.5	0.32
		Euro-2	23.3	0.56	14.6	0.31	10.2	0.19	8.8	0.16
		Euro-3	28.0	0.55	15.6	0.30	9.4	0.17	8.3	0.13
		Euro-4	24.1	0.110	15.1	0.061	7.9	0.031	7.9	0.023
		Euro-5	18.8	0.044	11.7	0.028	6.6	0.021	3.9	0.0162
		Euro-5 with OBD	16.3	0.041	10.2	0.026	5.6	0.017	3.7	0.0131
		Euro-6	1.37	0.030	0.86	0.019	0.56	0.012	0.46	0.0101
Busses		pre-Euro	27.0	2.10	16.9	1.13	12.4	0.65	11.3	0.50
		Euro-1	21.6	0.90	13.5	0.48	9.0	0.31	6.3	0.22
		Euro-2	19.6	0.58	12.2	0.31	8.1	0.28	6.5	0.111
		Euro-3	17.2	0.43	10.8	0.23	6.3	0.19	4.4	0.109
		Euro-4	13.3	0.18	8.3	0.098	4.2	0.043	3.0	0.019
		Euro-5	7.18	0.153	4.5	0.075	2.3	0.051	1.6	0.051
		Euro-6	1.11	0.015	0.69	0.015	0.42	0.0091	0.33	0.007

Notes

[1] For more information and reports see:

https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/emissions-of-nitrogen-oxides-of-diesel-vehicles/
https://www.tno.nl/en/about-tno/dossiers-in-the-news/real-world-vehicle-emissions/
https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/measuring-the-emissions-of-passenger-cars-and-vans/
https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/measuring-the-emissions-of-trucks-and-buses/
https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/emissions-of-particulate-matter-from-diesel-cars/
https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/emission-factors-for-road-traffic/
http://www.ermes-group.eu/web/reports_and_publications

[1] The Dutch national emission inventory can be found at:
http://www.emissieregistratie.nl/erpubliek/bumper.en.aspx
For Europe the European Environmental Agency keeps track of the state of affairs, collecting the data from the member states: http://www.eea.europa.eu/

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