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TNO report

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Uncertainty and development of vehicle emission factors underlying European air-quality models

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Summary

Gatwick Airport Ltd. commissioned TNO to undertake a review of the UK Government's Air Quality Plan - 'Improving Air Quality in the UK – Tackling nitrogen dioxide concentrations in our towns and cities'. TNO was specifically asked to advise on the underlying assumptions on vehicle NOx emissions, which are fundamental to robust and realistic predictions of future levels of NO2. Four aspects were investigated, the reliability of COPERT emission factors, new European legislation; in particular RDE, the effects of urban congestion, and the possible effects new technology.

TNO
TNO is the largest research institute in the Netherlands. TNO advises the Government of the Netherlands on vehicle emissions data used in the modelling of air quality for the Dutch Air Quality Plan. Moreover, TNO assists the Government with technical input to the European Commission on the development of vehicle emission legislation. TNO collaborates internationally with numerous institutes which perform vehicle emissions testing and prepare modelling emission factors for use in air quality plans across Europe.

TNO is particularly well placed to share the latest insight into trends in vehicle emissions, and in estimates regarding the emissions performance of current and future vehicle engine technology.

COPERT emission factors
The assumptions about vehicle emissions in the predictions in the UK Air Quality Plan rely on emission factors from COPERT. COPERT is the most commonly used vehicle emission model in Europe. While COPERT strives to be up to date, it relies on the availability of test data for new legislative vehicle classes. The version of COPERT used in the UK Air Quality Plan's predictions is V4.11 – which relies on vehicle test data that were available in the summer of 2013, prior to the introduction of Euro-6 a year later.

The Netherlands uses an emissions database and model called VERSIT+ in its Air Quality Plan. VERSIT+ is based on actual emissions from thousands of vehicle and engine measurements, which is updated annually to improve the reliability and accuracy of predictions. However, even with the most recent test data from vehicles available in spring 2015, which underpin the 2016 update in the Netherlands, the picture of emission performance for Euro-6 vehicles is as yet incomplete. Not before 2017 is it expected that the performance of Euro-6/VI diesel vehicles, likely to be dominant for NOx emissions around 2022, will be known with reasonable certainty.

The emission factors in COPERT v4.11 are based on very preliminary estimates of the emissions from Euro-6 vehicles carried out on a handful of high end models tested up to 2013. Since 2013 new measurements reveal that the Euro-6 (light duty) and Euro-VI (heavy-duty) factors in COPERT v4.11 are far too optimistic (by approximately 50% for light duty and 30 to 50% for heavy duty vehicles in urban and congested conditions). It is very likely that when COPERT is next updated the emission factors for several vehicle categories will be significantly increased (as

they have been in VERSIT+ in March 2016). This will be particularly important for predictions of urban emissions in the years to come.

Since autumn 2015, the main influx of Euro-6 cars started across mainstream and lower end vehicles, which tend to have higher emissions. Going forwards, therefore, the average emissions expressed in the emission factors are expected to increase even further. Further updates of Euro-6 emission factors are to be expected as COPERT is updated with more extensive data on vehicle emissions across the full range of vehicles.

In addition, COPERT emission factors used in the air quality model are related to average vehicle speeds, so no separate COPERT emission factors are available for specific traffic conditions such as free flow or congestion. Actual driving conditions and behaviour can vary greatly for the same average velocity, leading to substantial variations in emissions, for example in stop-start conditions, starting from cold, or under heavy acceleration. As a result, it is not known how and to what extent congestion is taken into account in the UK Air Quality Model. If this is not taken into account COPERT will underestimate the vehicle emissions..

Improvement of Euro 6 standard
Two further emission standards are to be implemented between 2017 to 2021. The first step, the new laboratory test procedure called the WLTP, will bring very little to improve the real-world NOx performance of vehicles, as official laboratory tests bear little relation to on-road performance.

A second new emission standard, the Real Driving Emission (RDE) standard, will come into operation gradually between 2017 and 2021. This new standard will be based on emissions tests from vehicles in ‘real’ on-road driving conditions. It is hoped that this will bring improvements in air quality where previous standards have failed to live up to expectations. It is very likely that vehicles meeting the RDE standards will only be introduced in large numbers from late 2019, however The 2017 date will only bring a few early adopters if a grant scheme makes it beneficial for the manufacturers. This is not currently foreseen however.

Accordingly, the benefits of this new RDE standard will not start to be known with any real confidence until into the early 2020s as new vehicles enter the mainstream market. Even assuming these vehicles do bring about improvements in air quality, the time it takes for the vehicle fleet to turn over means that the full benefits will not be realised until around 2030, because older cars will be dominant for emissions in the fleet until 2028 and still be in the fleet beyond 2030.

There are also a range of other questions and uncertainties about how effective the RDE standard will prove to be in practice both generally and in particular driving conditions and circumstances, as set out below.

The current RDE standard has a separate test evaluation for urban driving. It is very likely that this will be central to the RDE benefits for urban air quality. The emissions in London driving conditions have been considered in a separate report prepared by Emissions Analytics which notes that vehicles satisfying this future legislation do not exist yet and therefore cannot be tested.

The new and complex emission control technology used in current Euro-6 vehicles, and in oncoming Euro-6 RDE vehicles, have unknown deterioration and failure rates, which may lead to substantial increases in emissions over time. Maintaining vehicle emission control technology during the full lifespan of the vehicle up to the high standard of the type-approval regulation is not fully safeguarded.

Effects on air quality plans

The UK Air Quality Plan uses a Pollution Climate Mapping model to predict levels of NO2 for 2020, 2025 and 2030 in a ‘Baseline’ scenario (without the benefit of new measures contained in the Plan) and in a ‘Plan Scenario’ (which takes into account measures in the Air Quality Plan, including in the case of Greater London modelled benefits of the oncoming Euro 6 RDE standard). It is unclear, however, what these assumptions are. Assumptions made in the Plan about the emissions performance of vehicles currently entering the market, and vehicles which do not exist yet, are central to the accuracy and robustness of the air quality modelling. In contrast to the Dutch Air Quality Plan, where the input and output data are published, and the model is freely available, it is impossible for others to repeat the UK modelling and there is limited transparency of the approach that underpins the UK Air Quality Plan.

Regardless of the assumptions, the introduction date of RDE legislation means that it is likely that the benefits will be seen too late to improve air quality significantly prior to 2025, including in London. It is difficult therefore to accept that compliance will be brought forward to 2025 in London as is predicted.

In Summary

- **COPERT** vehicle emission factors used in the UK Air Quality Plan’s modelling for Euro 6 / VI vehicles, which will form the bulk of vehicles on road in the plan period at least until 2025, date back to data from 2013. They are likely to be too low (TNO current estimates are 30% to 50% higher for urban conditions) and we would expect to see the next iteration of COPERT revise emission factors upwards. Further upward revisions may occur as further data is gathered as the main influx of Euro 6 cars have recently entered the fleet.
- There are many uncertainties about the benefits of the new **RDE** standard, but in any event the true benefits will not be known with confidence until the early 2020s. The time it takes for the vehicle fleet to turn over to vehicles meeting the RDE requirements will not be realised fully until after 2030. Therefore it is unlikely these Euro 6 RDE vehicles will improve air quality materially until the mid 2020s at the earliest.
- Emissions under **congested urban driving** conditions can be as high as approximately 8 times the type approval limit value on average. Underestimating the level of congestion will result in a significant underestimation of the levels of vehicle emissions (NO_x) and will result in a far too optimistic air quality modelling result (NO_2 concentration).
- With complex **vehicle technology**, emission testing of these vehicles also has to evolve. The RDE protocol has been developed for this purpose, but its representativeness for on-road conditions remains unclear. At the moment on-road testing cannot provide better than ±30% accuracy in the emissions for a given trip, with most uncertainties being systematic and not removed by repeating the tests.
- The predictions in the UK Air Quality Plan that all zones except London will meet the limit values by 2020 and London will be compliant by 2025 looks distinctly

optimistic, as there will be only limited benefit from technology improvements before 2025.

- Based on the current NO_2 concentration levels, it is not expected that the whole of London would in fact be compliant until post 2030, without more drastic measures affecting the emission source; i.e. the vehicles on London's roads. This will be difficult in London as a whole and even more difficult in the area around Heathrow Airport, where the airport itself makes an important contribution to local NO_2 concentrations.

Contents

1 Introduction

Gatwick Airport Ltd. Commissioned TNO to undertake a review of the UK Government's Air Quality Plan - 'Improving Air Quality in the UK – *Tackling nitrogen dioxide concentrations in our towns and cities'*. TNO was specifically asked to advise on the underlying assumptions on vehicle NO_x emissions which are fundamental to robust and realistic predictions of future levels of NO_2.

The UK Air Quality Plan itself does not provide much information on the underlying details, and only a short reference to COPERT emission factors is made. Based on the version of COPERT in the Plan, it is clear that somewhat outdated results are used in the UK Air Quality Plan, and that the underlying emission factors are in need of update. The maintainers of COPERT, like most emission factors maintainers in Europe, are in the process of updating the results. The situation for the Netherlands is used to compare with the UK, because with an annual Dutch published update this process is a forerunner to expected changes in COPERT emission factors.

TNO provides and advises on vehicle emissions data that is used by the Government of the Netherlands in the modelling of air quality for the Dutch Air Quality Plan. Moreover, TNO assists the Dutch Government with technical input for Brussels where European vehicle emission legislation is developed and decided. TNO also collaborates internationally with numerous institutes which undertake vehicle emissions testing and prepare modelling emission factors for use in air quality plans across Europe.

The evidence of the higher NO_x emissions on real-world vehicle tests than shown by the official type-approval tests predates on-road testing, RDE, and PEMS. As early as two decades ago engines were optimized and vehicles performed well on the type-approval tests, whereas in other circumstances emissions were much higher. Around 2005 the first signs started to appear that vehicle emission legislation was not bringing what could be expected on the basis of the successive tightening of the emission limits. Also the UK, like other European countries, reported limited NO_2 air quality reductions in the past. This was the background which led to the RDE legislation which is now frequently discussed as the magic bullet to solve all air quality problems. The first step towards this RDE legislation, which makes on-road emission testing compulsory, was taken in 2011, but legislation will not be introduced until 2017 for less strict limits on new vehicle models and 2021 for stricter emission limits on all new vehicles.

It takes typically ten to fifteen years from the development of the initial plans for new vehicle emission legislation to reach a definitive understanding of the real-world emissions performance of vehicles covered by the legislation. Early on in the process estimates are made for the effect on air quality, based on an outline of what the legislation is intended to achieve. The first estimates of reductions are based on the emission limits, but over time as vehicles enter the fleet more information becomes available to update the emission factors for each legislative class. A generic outline of this process is set out in Table 1.

Table 1 The typical time-scale of current and future legislation. A major drawback of RDE legislation is the two year transition period compared with the normal transition period of one year ("year 0", i.e., standard for new vehicle models and "year 1" for all models in the table).

year	**vehicle legislation**	**air quality effect**	**current stage spring 2016**
-10	general layout for future vehicle standard, mandate to the Commission to develop legislation	not taken into account in emission inventories and air quality models	Euro-7 legislation?
-5	legislation text is finished to an extent manufacturers can use it in their development cycle	first estimate of emission factor based on the tightening of the legal emission limit	WLTP legislation and RDE legislation
-2	the first vehicle complying with the new legislation are type-approved	first testing of vehicles; a preliminary emission factor based on initial measurements	COPERT Euro-6/Euro-VI emission factors
0	the new models have to comply, which is usually about half the new sales	subsequent testing may result in an update of the emission factors	VERSIT+ Euro-6/Euro-VI emission factors
1	all models have to comply these usually comprises the big sales volumes which typically have significantly higher emissions	conclusive emission factors	Euro-5 emission factors
2	back sales of stock	no effect expected	
5	deterioration sets in	effect is poorly known: few measurements, some remote sensing data	Euro-1 and Euro-2 updated

Note: In the time schedule above, the first year when all new vehicle models have to comply with new emission legislation is called here "year zero". Typically, the development of new legislation starts 10 years before this introduction year.

Persistent NO_2 air quality problems have been understood for a long time. Moreover, it is also known that diesel vehicles are the main cause of this problem and that vehicle emission legislation since 1992 has done very little to alleviate it. The UK Air Quality Plan must be judged in this light. Based on the fact that NO_x emissions of diesel passenger cars and diesel vans have hardly decreased over the last 25 years, it is uncertain if problems will be solved within the next five to ten years. Even RDE legislation may fail to bring the proper improvement of "real world" vehicle emissions, unless independent control or in-use compliance is organised. Without this independent control, manufacturer's test results will have to be taken at face value, which may lead to the exploitation of the freedom in the RDE test to achieve low type-approval emissions. This part is still to be worked out in the RDE legislation.

This all means that making predictions of vehicle emissions is very difficult. As a rule of thumb it was assumed from Euro-4 (2005) onward that real-world emissions would decrease in the same ratio as the successive legislative emission limits decreased. This has not been the case for NO_x emissions for diesel passenger cars. From Euro-4 onwards the preliminary estimates of the emission factors have always turned out to be too low, and within one or two years of the introduction of a new standard, the emission factors flatten out at the 0.5-0.7 g/km levels achieved by Euro-2. It is too early to tell whether this will be the case for Euro-6. High hopes for light-duty RDE legislation are based on the first generation of extremely well performing heavy duty Euro-VI trucks, with emission well below the legal limit. However, this should not lure one into a false sense of security regarding similar light-duty legislation.

Consequently, any prediction of vehicle performance on the road based on either a few early compliant vehicles, or oncoming legislation must be treated with caution. Normally, the early compliant vehicles are not the standard of what all subsequent vehicles will do (see below), nor can we only rely on the fact that the legislation is effective to establish a reduction in real-world emissions.

The very first measurements on Euro-6 vehicles (“pre-Euro-6” in Figure 2) in 2010 suggested that low real-world NO_x emissions would be achieved in practice. However, these vehicles turned out not to be representative of the Euro-6 vehicles which followed a few years later. Based on the later Euro-6 vehicles, in 2013, the risk of an even further emission increase was incorporated into the Dutch emission factors used from 2014 onwards. The Type Approval limit is exceeded for urban, rural, and motorway driving, by a factor of approximately 3 to 6.

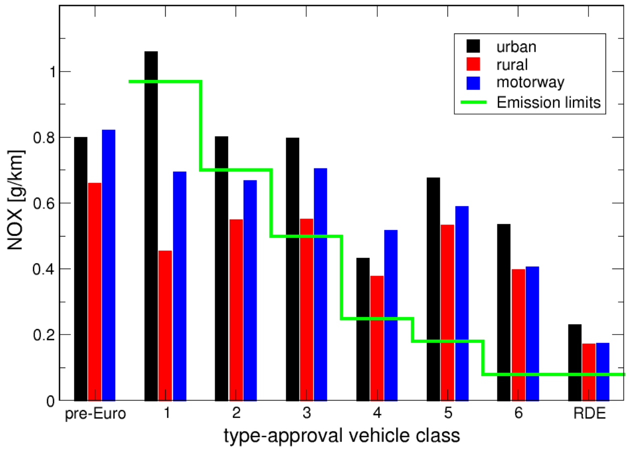

Figure 1 The 2016 Dutch NO_x emission factors of diesel passenger cars from the oldest vehicles (“pre Euro” prior to 1992), to the impending RDE from 1-9-2019. The emission limits have dropped significantly from Euro-4 but emission factors remain stubbornly above type approval limits.

Figure 2 briefly shows the effects of the updates of the Dutch NO_x emission factors. With an increasing number of Euro-6 vehicles available and tested the emission factors have been adjusted upward, year by year. Urban NO_x emission factors have increased significantly with the latest update in 2016. This clearly shows the influence of the latest insight in the performance of current mainstream Euro 6 vehicles. Further adjustments are expected in 2017.

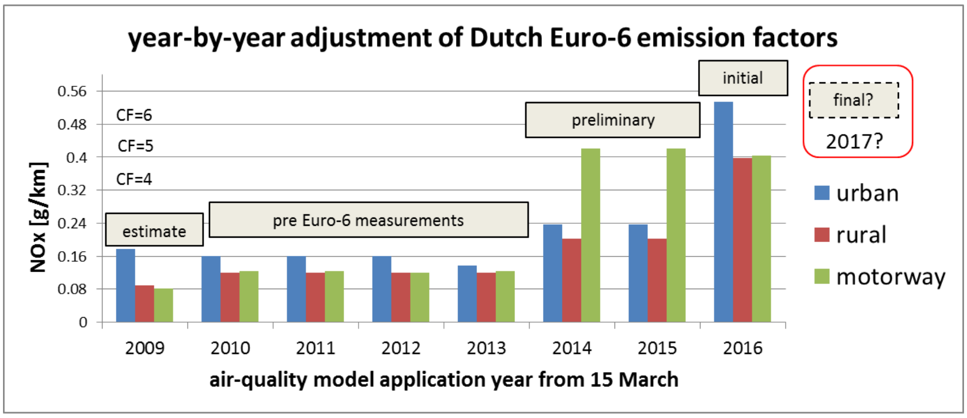

Figure 2 The year-by-year changes in Euro-6 emission factors from the initial estimates in 2009 based on the emission limit of 0.08 g/km, through some well-performing vehicles (“pre Euro-6”) tested in 2009-2010, subsequent testing of a few available vehicles, on to a larger set of Euro-6 vehicles tested in 2014-2015.

In the context of the UK Air Quality Plan, these most recent test results indicate clearly that trajectories based on the early Euro 6 tests are not reliable.

The rest of this report is structured as follows:

- The European vehicle emissions legislation aimed at reducing real-world emissions is discussed in Chapter 3.
- The emission testing across Europe for the determination of emission factors underlying the European air quality models is given in Chapter 4.
- The emission modelling needed to convert these emission measurements to the standardized emission factors is set out in Chapter 5.
- The further uncertainties in the determination of average vehicle emissions for future years are given in Chapter 6.
- Additionally, the experiences with a similar Air Quality Plan in the Netherlands is given in Chapter 7.
- Conclusions are drawn together in Chapter 8.

2 Background

NO_2 air quality problems, usually interpreted as the failure to remain below the European concentration limits, are to a large extent caused by tailpipe NO_x emissions of road vehicles.

The cause of current and future high NO_2 ambient concentrations lies mainly in the NO_x emissions performance of diesel vehicles. Despite tighter regulations, the real-world, or on road, NO_x emissions have not decreased significantly since 1992. In some cases new vehicles, such as diesel passenger cars complying with Euro-5 legislation compulsory from 2009, are actually associated with an increase in average real-world emissions, compared with the previous legislative class; Euro-4. These results were confirmed by several test laboratories in Europe. The indications for Euro-6 are similarly not positive overall.

The recent scandal of Volkswagen has raised public awareness of the disparity between type approval tests and emissions in real driving conditions. In practice, the gap between type approval results and emission performance under real world conditions has been known and investigated for many years in order to derive realistic emission factors for emission inventory purposes.

Since September 2015, the Euro-6 standard has been compulsory for passenger cars. A year before, in September 2014, similar Euro-VI legislation became compulsory for heavy-goods vehicles. In September 2016 Euro-6 legislation will be compulsory for large light commercial vehicles. Thus, at the moment a transition is taking place. Another two transitions are planned in the near future.

- The first transition is the new test protocol, the WLTP in 2017.
- The second transition is the on-road testing of emissions for vehicle legislation, the RDE in the period 2017 to 2021.

This means that the main vehicles which will be dominant for emissions in 2020 (Euro 6/ IV) have only just entered the market, whilst the vehicles which will be important for air quality in 2025 and beyond do not exist yet.

Estimates for the emissions for vehicles which only now enter the market in large numbers are dated. Typically, measurements are collected one to two years before the emission factors are updated in the air quality models. In the Netherlands the source data of air quality models is updated and published annually, such that the air quality models are about one year behind the latest measurements of the latest vehicle models. The other sources of emission factors in Europe, HBEFA and COPERT, rely normally on a three year cycle of updates such that the emission factors trail behind the latest insight on the basis of emission measurements. Generally, this was not considered a problem, because only in three to four years' time will the effect of the influx of new vehicles become important for local air quality. It takes a couple of years for new vehicles to penetrate the market, after which these vehicles are the dominant category of emissions for about five years, after which a slow out flux and a reduced mileage slowly decreases their significance for both total and average emissions. However, predictions of emission factors in 10 or even 15 years from now rely heavily on the quality of the emission factors of the latest and near term future vehicles. These vehicles will dominate the vehicle fleet and therefore the average vehicle fleet emissions in 10 to 15 years from now.

Solving a substantial problem of high NO_2 concentrations in a five to ten years time horizon requires new vehicles, designed to satisfy new emission legislation, to be considered. The few Euro 6 vehicles available for testing in 2013 are a poor proxy for the current influx, and, moreover, they have little bearing on the future influx. The uncertainty in predictions is therefore large. The interplay between wide variation in vehicle categories, available emission control technologies, as well as aspects of the legislation, is complex.

Greater London air quality
On a European scale, air quality problems in Greater London appear to be very large. The NO_2 concentrations are among the highest in Europe. Despite this the UK Air Quality Plan predicts that the Greater London air quality problem will be solved by 2025. In the Netherlands, by comparison, a similar Air Quality Plan (“Nationaal Samenwerkingsverband Luchtkwaliteit”) was set up in 2008, to satisfy European air quality limits by 2015. The year 2015 came and went, and the Netherlands does not fully comply with the air quality requirements as yet, despite the major efforts over the years from all parties involved; central government all the way down to local government. Reducing the NO_2 concentration by a few microgram per cubic metre requires already many drastic measures. The required reduction for Greater London to comply with European air-quality limits, is a much more difficult task by comparison. Moreover, the target seems elusive, with the lowering of European vehicle emission limits repeatedly failing to bring actual reduction of on-road vehicle NO_x emissions.

Given that the Netherlands has a much lower share of diesel passenger cars than the United Kingdom, the optimism of the UK Air Quality Plan to meet targets within a few years, starting from a very high baseline, is very ambitious..

For the realistic prediction of real-world emission performance up to date testing and reporting is needed. Instead, is testing is very limited in the UK and France, the lack of reporting of recent testing in Germany, Switzerland, and Sweden, means that people are looking for alternative sources for the little information that is available from the Netherlands, Austria, and Greece on the real-world emission performance of the latest vehicle models. Commercial parties, not all with thorough validation and robust research to underpin the results, especially when it comes to remote emission testing, and the USA with different vehicle legislation, are now the alternative source of real-world emission information.

For the layman, emissions of vehicles are a simple number in g/km:- the quality of the data, the representativeness of the test, or the vehicle technology beyond the fuel and the vehicle model, are not taken into consideration. In practice, effects of a factor of two or more can be expected from these variations, and it is therefore essential to test or normalize to the representative traffic situation and vehicle usage. Even most of the test data from the European Commission laboratory, JRC, cannot be considered representative by common standards, with a large variation in trips, with many mountainous ones, as understood by the experts from the different emission modelling institutes collaborating in the ERMES executive board: TNO, TUG, INFRAS, LAT, and IVL.

Since Euro-5, the first vehicles complying with a new legislation class seem to perform better than the main influx, a year or so later. Hence, a limited test program at the start of new legislation, required to update the emission factors for the air-quality prognoses, will mainly sample these early vehicles. There is only limited budget and capacity available, in the whole of Europe, to keep testing the new vehicles for their real-world emission performances throughout the full period of legislative dates. For example, only in the case of serious concerns of wrong estimates, does the Dutch government request the testing of older vehicles. The focus in Europe is forward looking towards new legislation and new technologies which can meet this new legislation. Consequently, there is a gap in knowledge on the performance of mainstream vehicle models and the deterioration of emissions over time. Even if all data in Europe is collected and put together there is not enough data to take away the uncertainties. If all vehicles perform the same, only a few need to be tested. However, with modern vehicles there are large variations in the test results for the same vehicle and between different vehicles. Consequently, the emission factors for air quality in Europe have large uncertainties. The three main uncertainties are:

- vehicles satisfying future legislation do not exist yet and they can therefore not be tested.
- the initial testing of the first vehicles satisfying new legislation may not be representative for the average vehicle emission for a legislative class.
- the reduced performance of emission control technology over time, especially for the more complex new technology, is unknown.

2.1 Air quality modelling

A proper model for air quality predictions contains at least the following features concerning vehicle emissions: (Features considered in this report are underlined)

1. Vehicle emission factors:
    a. Sufficient distinction in vehicle categories to differentiate between different emission performances of different vehicles.
    b. Emission factors linked with driving behaviour such as velocity and acceleration/deceleration.
    c. Cold start emissions of vehicles with catalytic emission reduction technology.
    d. Estimates of the effects of emission technology deterioration and malfunctioning.
2. Vehicle fleet model:
    a. Age distribution of the vehicles on the road, with possible distinction between urban fleet and motorway fleet.
    b. The renewal of the vehicle fleet over time, with possible shifts in the fuel type and the popularity of new technology and vehicle categories, such as LCV's.
    c. The payload assumptions for heavy-duty vehicles on the road, combined with the use of trailers by HGV's.
    d. A check on the overall total mileages for the different vehicles summing to the total emissions.
    e. An estimate on the share of heavy duty vehicles and buses on different roads.

3. A driving behaviour model:
    a. The amount of traffic in congestion, possibly distinguishing different levels on congestion. This can be expressed as the average velocity in relation to the speed limit on a particular road.
    b. The degree of acceleration and braking associated with a particular road type and congestion level.
4. A traffic intensity model, comparing:
    a. The spatial distribution of roads.
    b. The traffic intensity, i.e., the number of vehicles passing each road section..
    c. The forecast changes in traffic intensities over time, due to infrastructure improvements and building projects (residential and business).
5. The exposure model:
    a. The distance of the sources from human dwelling areas.
    b. The precise build-up around locations of exposure, which determine the speed exhaust gases are dispersed.
    c. The annual wind distribution affecting the local exhaust gas dispersion.
    d. The conversion rate of NO to NO_2, as the result of ambient temperature, volatile components and ozone, and sunlight.
6. A calibration procedure for incorporating unknown sources and uncertainties into the model:
    a. Background and road side measurement stations with data that spans many years.
    b. Local air quality predictions at the location of measurement stations.

3 Vehicle emission legislation

Every new vehicle type is required to meet a large number of standards, including emission standards, before the manufacturer is allowed to sell the vehicle on the European market. Responsibility for testing of vehicles against the legislative standards lies with the vehicle manufacturers. Manufacturers can perform these Type Approval tests at their own facilities or enlist the help of test houses. Furthermore they need to ensure the appropriate witnessing of the tests by type-approval authorities, such as the VCA, the RDW, and the KBA.

The Type Approval test procedure for vehicle emission testing, including the limit values for vehicle emissions have evolved over time. This section describes the most important developments for the various Euro standards over the last few decades.

Compliance with these standards is based on a standard twenty minute drive cycle test undertaken in laboratory conditions. The very latest legislation for light duty vehicles will see for the first time additional emissions tests carried out in real world driving conditions.

The most recent and future legislative emission standards during the period from now until 2030 are set out in Table 2.

Table 2 The latest and future legislative emission standards, all are part of Euro-6/VI legislation.

	expected introduction dates		
future legislation	**new models**	**all models**	**comments**
Euro-6 passenger cars	1-Sep-14	1-Sep-15	*current influx, preliminary status on emission factors*
Euro-6 heavy vans	1-Sep-15	1-Sep-16	*few vehicle models available, status unknown*
Euro-VI heavy duty	1-Jan-13	1-Jan-14	*very low emission results observed in 2012-2015*
WLTP ("Euro-6c")	1-Jan-17	1-Jan-18	*laboratory test, aims towards CO2 not NOx emissions*
RDE phase 1	1-Sep-17	1-Jan-19	*delayed introduction expected till "all-models" date*
RDE phase 2	1-Jan-20	1-Jan-21	*final stage: likely design criteria for manufacturers*

Testing for real-world emission factors, or the typical on-road emissions of vehicles, is carried out mainly outside the spectrum of the legal requirements. In the development of future legislation there was minimal input from real-world emissions and air quality problems in the development of the future legal limits. Instead the development of future legislation is based mainly on what is technically feasible.

For many years it has been clear that emissions in real world driving conditions are far higher than the laboratory based Type Approval tests. Current and future legislation, which will take effect from 2017, as summarized in Table 2, is intended to change this situation.

Limited NO_2 concentration reductions have been seen in larger cities and real-world NOx emissions of diesel vehicles have been observed to be hardly decreasing. It is necessary, therefore, to understand the uncertainty concerning the effectiveness of future vehicle legislation compared with earlier legislation, especially laboratory tests, but also with compulsory on-road testing.

3.1 NEDC laboratory tests

The Euro-1 legislation in 1992 was the first compulsory European-wide legislation on vehicle emissions. Compliance with this first standard and later legislative standards up to Euro 6 has been based on a laboratory test known as the New European Drive Cycle (NEDC).

This test is the Type-1 test on the first pre-production series of a vehicle model, to ensure that the vehicle emissions control technology meets the relevant emission standards.

The driving cycle is, however, short (lasting for 20 minutes), very stylized, unchallenging, and does not represent real world driving conditions. This means that it is easy to perform the test with all vehicle types, including low-powered vehicles. Subsequent legislation has provided for minor adaptions of the test protocol.

The reduction of NO_x emission limits since Euro-1 and up to the current Euro-6 standard in 2015, as shown in Table 3, has been substantial. Unfortunately these increasingly tighter standards have not led to the expected improvements in air quality because real-world emissions have continued to far exceed the Type Approval standards.

Table 3 Successive tightening of emission legislation, from Euro-1 (1992) to Euro-6 (2015). The relevant emission factors for air-quality are boldface.

Emission limit	NO_x [g/km]		HC [g/km]		HC+NO_x [g/km]		CO [g/km]		PM [mg/km]	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
Euro-1	-	-	-	-	0.97	**0.97**	2.72	2.72	-	140
Euro-2	-	-	-	-	0.5	**0.7**	2.20	1.00	-	80
Euro-3	0.15	**0.5**	0.20	-	-	0.56	2.30	0.64	-	50
Euro-4	0.08	**0.25**	0.10	-	-	0.30	1.00	0.50	-	25
Euro-5	0.06	**0.18**	0.10	-	-	0.23	1.00	0.50	5	5
Euro-6	0.06	**0.08**	0.10	-	-	0.17	1.00	0.45	4.5	4.5

3.2 Additional requirements

Apart from the central Type-1 test, the vehicle model is also required to satisfy other emission criteria, such as cold temperature testing, durability testing, and evaporative emissions testing. This is meant to ensure the vehicle has low emissions in a variety of circumstances and over its useful life. As with the Type-1 test these further tests do not include real-world or on road testing of vehicle emissions.

There is no requirement for monitoring the performance of vehicle models after the Type Approval Test. The durability tests assess how vehicles satisfy criteria on fuel use and maintenance. They are not randomly selected vehicles from users. Furthermore the testing regime applies only to the ‘factory vehicle’, not vehicles that are sold by the manufacturer. ‘Factory vehicles’ and ‘user vehicles’ are therefore separate, and, unlike safety, there is no post-sale monitoring of the environmental performance of individual vehicles due to improper use, adaption, or issues with maintenance. After-sales adaptions, affecting the emission performance, are not necessarily illegal and the regulation and control of replacement parts is limited.

3.3 WLTP laboratory tests

In 2017 the new World Wide Light-Duty Test Protocol (WLTP) will be rolled out for adoption in Europe and will replace the NEDC.

Around 2010, the WLTP was considered to be the solution to the large disparity between emissions from real-world driving and test based emissions. Today, however, the purpose of the WLTP is considered to be more limited, its main purpose being to produce more realistic CO_2 emissions and to remove ambiguities, commonly referred to as “flexibilities” in the test protocol.

In essence the WLTP poses as many problems as solutions for vehicle emissions. Two main problems with the shift from NEDC to WLTP are the cold start and the vehicle medium load. Because the WLTP emission test is more than double the length of the NEDC test it has less than half the stringency of the NEDC when it comes to cold start emissions. For petrol vehicles, the cold start emissions in the first kilometre of the test are dominant in the overall emissions. For future diesel vehicles the relevance of cold start emissions is expected to be similar, with the catalytic emission reduction technology responsible for over half the total emission reduction to reach the required limit of 80 mg/km. The WLTP therefore contains the risk of an increase in real world emissions for both petrol and diesel vehicles, as the less stringent test may result in the application of inferior emission control technology. The medium load ensures a quicker warm-up of the catalyst, compared to the current NEDC test but this is not enough to cover all driving behaviour, especially with medium-powered and high-powered vehicles.

3.4 On-road RDE emission tests for cars

In a simplistic view, on-road testing is the same as gathering real-world emissions data but the reality is more complex. TNO has been testing passenger cars on-road from 2010, and trucks on-road from 2008 using a Portable Emission Measurement System ‘PEMS’ and Smart Emission Measurement System ‘SEMS’. By 2014 TNO had gained enough understanding and experience of on road testing to use the data it has collected for the determination of real-world vehicle emissions of passenger cars.

For trucks it has been more simple and from 2009 TNO relied only on on-road testing for heavy duty emission factors. The bulky PEMS measurement equipment which accuracy made legislative on-road testing possible at the start of Euro-VI in 2014, is not an obstacle for heavy duty testing, and it brought to light many of the finer details in on-road testing and test evaluation of these heavy-duty vehicles.

Few other laboratories have been able to progress their testing of real world emissions to the extent that TNO has for light-duty vehicles. There are several drawbacks, the on vehicle testing equipment being one of them. It adds to the weight and the air-drag of the test vehicle, making the results less representative of normal vehicle usage. Measurement uncertainty and the somewhat laborious and intricate installation and operation means the measurement data must be carefully scrutinised. For example, driving behaviour is a key part in emissions and only since October 2015 are accurate velocity measurements to be obligatory in RDE legislation, after TNO pointed out the typical faults in GPS signal velocities.

This, in part, explains why it has so far taken five years since RDE was first properly proposed to come up with a legislative procedure to test emission on the road.

With the competing CO_2 targets and the on-coming WLTP, RDE was the third major adaption for the type-approval legislation with major consequences for vehicle development. The consequence is that the solution of high real-world NO_x problems may seem to compete with CO_2 targets. The latter requires a proper laboratory test and a major adaption from all parties. This can cause delay for measures to reduce NO_x emissions. The two items are already considered by some stakeholders to be “conflicting measures.”

The legislative RDE emission limit is an average and normalized emission over a trip. Some allowance is given to the variation in the results in the second legislative phase of RDE test from 2020 onwards (See Table 2). In the first phase of RDE, the allowance is based on the best available current diesel vehicle technology. As the data is averaged and normalized this means that in particular traffic situations the emissions are higher. In the Netherlands the effectiveness of RDE is based on the limit, combined with the legal allowance, i.e. conformity factor, combined with the CO_2 increase for each particular traffic situation. For example, in stop and go traffic, fuel consumption and CO_2 emission may be double the average CO_2 emissions. Hence it is assumed that the NO_x emissions in such situations is also double the RDE limit.

3.5 Typical progress of introduction of a new legislative class

In practice, variations of a vehicle model can be added onto existing type-approvals with a limited need for retesting emissions. This means that initially most new vehicles entering the fleet will only meet a new emission standard when a completely new model is introduced. The second legislation date for RDE (in September 2019) “all new vehicles need to fulfil RDE requirements” is therefore far more important than the 2017 first date “only new vehicle types need to fulfil RDE requirements”.

Another factor which slows down the penetration of vehicles meeting the latest emission standards are vehicle stocks. A period of approximately 2 years, from the first date, to sell off existing vehicle stock not meeting the new standards is allowed after the introduction of new emission regulations.

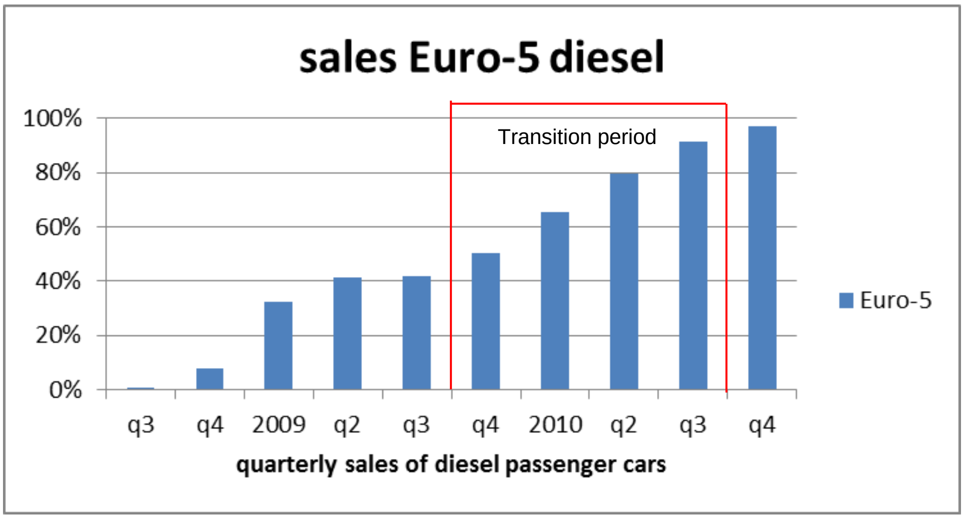

Figure 3 An example of market penetration of vehicles meeting the new emission regulation Euro 5. Starting from the fourth quarter of 2009 the Euro-5 was obligatory for all new vehicle models. However, at that specific time vehicles meeting Euro 5 only accounted for about half the new sales. [TNO 2012]

The flexibility in the regulations of the new emission requirements means that vehicles with more complex and expensive technology will only appear on the market for low-segment and mid-segment vehicle models once the legislation applies to all models. For RDE legislation, this date does not occur until 1^{st} of September 2019. Consequently, it will not be until the period 2020-2022 that any material benefits of RDE legislation even start to occur.

3.6 Other vehicle categories

The expected decrease of emissions in the period 2015 to 2020 in the UK Air Quality Plan is most likely to be due to improved heavy duty legislation - Euro-VI from 2014, than from the light duty vehicle legislation.

Prior to the Euro VI Type Approval test HGV vehicles models over 3500 kg gross vehicle weight were subject only to an engine test (the Roman numeral “V” refers to the heavy-duty counterpart of the light-duty Euro-5 legislation). From Euro-V in 2008 it became clear that this engine test had little bearing on the real-world emission performance of the vehicle. Under Euro-VI the situation has been improved and an on-road vehicle test is required in the type-approval of the Euro-VI engine.

A complete picture of on-road emissions must include all categories’ contribution to the NO_2 air quality problem. Table 4 sets out the different legislative classes. The diesel vehicles are the main cause of high NO_x traffic emissions, and since larger vehicles have a larger fraction of diesel, they contribute more to total traffic emissions. In particular around 2012-2014, Euro-5/V vehicles dominated total emissions, and urban emissions were about ten times the light-duty diesel NO_x emissions. A share of 5% to 10% of heavy-duty vehicles resulted in half of the total emissions, depending on the fraction of diesel passenger cars.

In the Netherlands large vans; N1 Class III (see Table 4) contribute about half of the total NO_x emissions of all light-duty vehicles. This relatively small group of vehicles are mainly diesel, have a higher legislative emission limit than passenger cars, and perform worse compared to the relevant limit than passenger cars. Moreover, the legislative dates lag one year behind that of passenger cars and small vans.

Given that European NO_x emission legislation is based on technological feasibility, larger vehicles have typically less strict emission limits. Any shift from passenger cars to vans, and from vans to HGV's means a twin-fold increase in emissions: a higher share of diesel and more emissions per vehicle. It is therefore important to understand the full fleet with respect to both the share of diesel and the corresponding legislation class. Buses have contributed significantly to the air quality problems in London, for example, even though the number of buses is small compared to the total vehicle fleet based in and around London (in the Netherlands bus service routes and schedules are separately modelled in the air-quality model, because of the large local contribution to urban emissions).

The Euro VI standard led to very low emissions from tests carried in the period 2012-2014 in the run up to 2014 as new HGVs were subject to the first Euro-VI Type Approval. This was because, to be sure of passing the test, manufacturers designed vehicle engines to out-perform the Type Approval standard by some margin.

Later evidence has shown that the engine emission performance of more recent HGV's has not been sustained, perhaps as manufacturers have gained experience. Although HGV's continue to meet the emission requirement in on-road tests, the margin has reduced and they are now closer to the limit.

Table 4 Vehicle categories of emission legislation. Under 3500 kg maximal weight (GVW Gross Vehicle Weight) vehicles are tested, above this weight the engine alone is tested. The former requires a test based on the most low-powered vehicle, the engine tests are based on the rated engine power and are typical at the high end of the normal engine demand.

Category	Description	Category	Mass	Subcategory
Passenger cars and buses				Persons
M	Passenger transport with 4 wheels or more	M1	≤3500 kg	Up to 9
		M2	≤5000 kg	10 or more
		M3	>5000 kg	
Vans and trucks				Reference mass
N	Goods transport with 4 wheels or more	N1	≤3500 kg	Class I: ≤1305 kg
				Class II: 1305< GVW ≤1760 kg
				Class III: >1760 kg
		N2	3500< GVW ≤12000 kg	NA
		N3	>12.000 kg	

In the Netherlands it was decided that the situation with the extremely well-performing heavy-duty vehicles (Categories M2, M3, N2, N3 in Table 4) would not last. Hence, an estimate was made based upon the Euro-VI legislation for the eventual Euro-VI fleet average. This is about double the current NO_x measurement values, and triple the initial measurement results. The recent measurement program of heavy-duty vehicles demonstrates that emissions are indeed higher, and closing in on the conservative estimate made for the Netherlands emission factor database.

The Emission factors for the UK AQ Plan’s air quality predictions from COPERT have not yet been updated to reflect this more conservative outlook on Euro VI, yet it is very likely that with the influx of more Euro-VI vehicles, and also smaller trucks for urban usage, these emission factors will need to be adjusted upward. In addition some Euro-VI buses on urban routes perform poorly, as the Euro-VI legislation does not fully cover the real-world vehicle usage with many stops and a low average speed.

4 Vehicle emission testing in Europe

Real-world vehicle emissions are monitored across Europe. This type of data underpins the national emission inventories, which European member states are obliged to keep. In many member states the same data is used for modelling of air quality needed to ensure European air quality standards are met. Despite these important usages of emission test data, only a limited number of institutes and laboratories gather this vehicle emission data to derive emission factors which represent realistic emission values for specific vehicle categories under specific real world conditions. There are in fact only two main sources of data and three emission models which translate the measurements to the situations on European roads. This limited data base is set out in the section below.

4.1 Vehicle emission data in Europe

In Europe there are a limited number of institutes and laboratories which perform testing for real-world emissions despite the continuing limited reduction across Europe of NO_2 concentrations. The commitment of resource by European member states to ensure sufficient and up to date measurements to keep the emission factors, underlying air-quality models and emission inventories, up to date is decreasing rather than increasing.

Two main sources of test data which are used to derive emissions factors are the measurements underlying the HBEFA and VERSIT+ emission factors. TNO has collected data from thousands of vehicle and engine measurements in a large database, which is continuously updated with ongoing vehicle emission measurement programmes. Based on this database, TNO has developed the VERSIT+ emission model for road traffic.

The HBEFA measurement campaign is a joint effort between Sweden (the laboratories of AVL-MTC and TüV-Nord usually run these programs), Germany (testing at TüV-Nord and Dekra), Switzerland (testing at EMPA) and Austria (testing at Technical University Graz: TUG). The data is collected by INFRAS in Switzerland and the emission factors are determined by TUG in Austria, using their emission model PHEM. Nowadays, Norway and France also use HBEFA emission factors.

The Dutch VERSIT+ emission factors are based mainly on measurements undertaken by TNO and tests executed for TNO by the HORIBA laboratory in Germany. LAT in Greece also undertake additional testing, and collects further data, to augment the HBEFA emission factors. The translation from emission measurements to emission factors is explained in Chapter 5. The UK Air Quality Plan modelling utilises factors derived from COPERT which are in turn derived from HBEFA.

The vehicle testing process differs from country to country and from laboratory to laboratory. The testing policy in the Netherlands is to perform as much real world representative testing as possible, to limit the amount of modelling needed to cover the different Dutch traffic situations. This requires a substantial amount of testing per vehicle, in order to get an accurate impression of its emission performance in many different traffic situations.

Apart from vehicle emission measurements for emission factors, there are NGO's and consumer organisations, like ADAC, which also perform vehicle emission testing. They cover mainly new vehicles entering the market. Moreover, the test programs are not always well suited to determine the average real-world emissions, or emission factors. Tests may be limited or somewhat artificial. The precise status of their test programs is not always clear as such parties do not participate in programmes like ERMES, an international collaboration between institutes and ministries with the aim to share emission data and to optimize the testing programmes.

4.2 Limited number of vehicles and tests available

As stated previously the first estimates of emission factors for new vehicles are nearly always based on a very limited number of vehicle tests, because only a few new vehicles are available for testing.

The time taken from a new vehicle model being tested to it starting to have an impact on future air quality predictions, via emission factors, takes a minimum of two years and more often three years. Consequently, the UK Air Quality Plan is based on vehicle test data for Euro 6 vehicles dating back to around 2013.

It is important to note that at that time only a handful of early Euro-6 vehicles were available, which means that the test data could give only a preliminary outlook on the emission performance of these vehicles. The results, at the time, were based specifically on the then available models: Mazda CX5, BMW 330d, BMW730d, BMW 530d, BMW 320d, Mercedes E350, and VW Passat 2.0. Most of these same vehicles were tested by several laboratories, since no other vehicles were available at the time, and in some cases the same engine was tested with different vehicles. It should, however, be noted that in some cases the same vehicle model and engine size had different emission control technologies. Clearly, manufacturers were also investigating the best technology and they shifted focus several times between different emission reduction systems - SCR (Selective Catalytic Reaction)) and LNT (Lean NOx Trap), and combined these with different EGR (Exhaust Gas Recirculation) technologies.

The introduction of Euro-6 vehicles had started earlier. TNO measured the emissions of some very early Euro-6 diesel vehicles in 2009-2010, which were probably intended for the USA market. These vehicles performed better on NO_x emissions than most of the vehicles measured later. The initial emission factors, prior to 2013, for Euro-6 vehicles were partly based on these promising results.

In the Netherlands there was hope that with the introduction of Euro-6 the problems of high NO_x emissions would be over. A tax scheme was set up to ensure the quick influx of Euro-6 vehicles in the Netherlands. Despite a reduction of 1500 Euro on the vehicle sales tax in 2011, 1000 Euro in 2012, and 500 Euro in 2013, only 328, 951, and 4,770 Euro-6 diesel vehicles were registered in the Netherlands in the respective years, prior to the new-models legislative date in 2014. They represent a negligible number on total annual sales of about 100,000 diesel vehicles. In 2013 the first Euro-6 standard high-end vehicle models were sold in large numbers. However, because of the lack of mainstream and compact vehicles prior to 2015 the effect of Euro-6 technology and the consequences for emissions on the wider fleet were still unclear. In 2015 a better understanding around Euro-6 was being gained, before the upheaval from the Volkswagen scandal in September 2015. Based on the Netherlands experience, it can be expected that even with moderate tax advantages, RDE compliant vehicles will not enter the market in large numbers prior to 2019.

It should also be noted that the number of vehicles needed to estimate the emission performance of all vehicles of a certain legislative class should not be exaggerated. For example, with the final update of the TNO emission factors of Euro-5 diesel vehicles in 2012-2013, it was observed that the same engine is used in many different vehicle makes and models. Based on the total sales figures, eleven diesel vehicle engines, as distinguished by the cylinder volume and rated power, are in more than half of all the vehicles sold in a period of a few years.

Depending on the sales volume of Euro-6 diesel vehicles in the respective years, emission performances can vary. The early high-end vehicles seem to perform better than the mid-segment cars. The mix of sales of diesel vehicles in the total fleet may affect the outcome.

4.3 Recent insights into emissions from light commercial vehicles

Light commercial vehicles (LCVs) come in a variety of sizes and under a variety of legislative classes. The main vehicles come in three weight classes. However, some vehicles are tested as incomplete vehicles, such as campers, and others are tested with a heavy-duty engine installed in a light-duty vehicle, with a maximum weight restriction.

In Europe, with the focus on passenger cars, there has been limited testing of these vehicles. However, because of concerns regarding the emission performance of these vehicles, and their contribution, because of their increasing popularity, to total emissions, especially the weight Class III, TNO tested a sample of these vehicles in 2014. The results lead TNO to conclude that these vehicles emit on average much more NO_x than previously assumed.

As a result, from 2015 the Dutch emission factors have been updated to account for these results. Both HBEFA and COPERT will also soon update their emission factors for these vehicles, which will lead to an increase of the expected emissions of Euro-5 vans by about 50% compared to the previously assumed emission factors in COPERT for LCV's, especially in urban conditions. This means that the emission factors used for LCVs in the UK Air Quality predictions are almost certain to have underestimated emissions by some 50%. As for large vans Euro-6 legislation will be compulsory for all new vehicles from 1st September 2016, very few Euro-6 vans are available and measured yet. However, the the recent results for Euro-5 vans should be reflected in higher preliminary estimates of Euro-6 vans emission factors.

4.4 Heavy duty vehicles

Euro-VI legislation for heavy-duty vehicles (HDVs) was introduced in 2014, and made compulsory in 2015. The testing from 2013 of the first generation of Euro-VI vehicles found extremely low emission measurements, as is shown in Figure 4.

These very low emissions were the result of the heavy-duty RDE legislation part of the forthcoming Euro-VI standard. However, it was not expected that emissions from later vehicles would remain as low as the first generation Euro-VI vehicles tested and for this reason it was decided in the Netherlands to use a conservative estimate based on the RDE limit - with values of 0.5-1.0 g/km NO_x emissions – for modelling purposes.

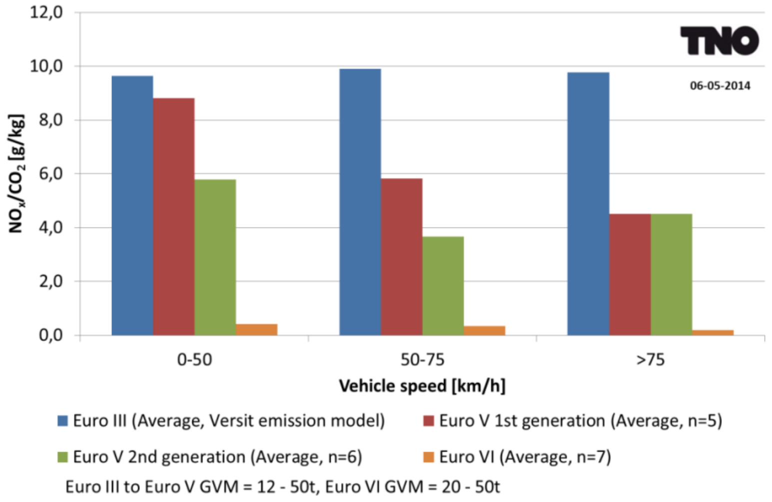

Figure 4 Emission measurements of different legislative classes of heavy-duty vehicles distinguished in the Dutch air quality model.

Recent measurements do now show that the current generation of Euro VI vehicles do have higher emissions than the first generation shown in Figure 4 and the emission values are much closer to the conservative estimates adopted in the Netherlands. Moreover, most testing of Euro-VI heavy-duty vehicles focusses on large long-haulage trucks. The different heavy-duty fleet for urban usage: smaller trucks (for example legislative category N2 in Table 4) and busses (category M3 in Table 4) are underrepresented in the measurement data and may show different emission performances.

COPERT and HBEFA have similar findings in emission testing of heavy-duty vehicles. However, they have not chosen to use conservative estimates for the general Euro-VI emissions. The Euro-VI emission factors of COPERT and HBEFA are substantially lower than the emission factors used in the Netherlands, and are almost certain to be revised upwards for most urban traffic situations in future updates. Based on the recent emission measurements this will be 20%-30% for urban conditions. Given the available margin below the legal limit, it can be up to a 50% increase for future vehicles. The effects are most prominent in urban conditions where it is difficult to achieve low emissions with current emission control technologies.

5 Emission factors

Emission models and emission factors, together with vehicle fleet data and traffic flows provide a major input to emission inventories, calculation of traffic emissions and for local air quality modelling. Apart from traffic related emissions this would also include for example emissions from household heating and industrial plants. This section briefly describes the important European emission models and emission factor data sets. Although the underlying emission data is partly shared, the results of the various models can vary for a number of reasons, which are explained in the following section.

5.1 Average and normalized real world emissions

Emission factors represent the average on-road, or real-world, emissions for the average vehicle of a particular emission class, with the average vehicle usage and the average driving behaviour. Importantly, this means that the emissions testing regimes alone are not sufficient to determine emission factors.

The determination of representative emission factors requires thorough understanding of the vehicle fleet comprised of different technologies, normal vehicle usage and trip length (including passenger and luggage load, air-conditioning usage, etc.). Vehicle age, maintenance state, and deterioration will also affect vehicle emissions, as, very importantly, will particular driving conditions (urban, rural, motorway, free flowing, congested, high speed, low speed, road incline and decline) because these factors affect the load being placed on the engine. Other important influences on emissions are the engine temperature, with higher emissions arising at the start of journeys before the engine warms up. In addition driving styles, including for example gear shifts and braking can vary dramatically from driver to driver, with some effect on fuel consumption but a more dramatic effect on pollutant emissions.

There have been several large research programs to attempt to determine these aspects. The most well-known program was ARTEMIS, from which the CADC (Common Artemis Driving Cycle) was developed around 2005. The CADC is still the most used real-world test cycle to measure emissions in laboratory conditions.

There are various ways of measuring emissions in practice, each of which has advantages and disadvantages, which are summarised below.

5.2 Bag data trip-based results

For the accurate determination of emissions, exhaust gas is collected and diluted in a large bag attached to the engine’s tail pipe. The concentrations of the different pollutants are then analysed, and converted back to emission per kilometre. This process generates total emissions but it does not provide the emissions generated during particular events in the test, such as acceleration and braking.

5.3 Modal-mass based results

Modern emission modelling for emission factors relies on second-by-second data to link incidents of high emissions to specific events during driving, such as acceleration and braking. The quality of this data has not always been good, and in the past this data had to be calibrated with the official bag data results.

Using state-of-the-art measurement equipment in laboratory conditions is challenging enough. These challenges are far greater in the harsh mobile on-road environment. The recent second generation PEMS equipment is more stable, however, and better calibrated than the first generation equipment was.

5.4 Emission models and emission factors

After emission data is collected the measurements of emissions must be matched or normalized to the average traffic situations on the road. The road type is the most coarse distinction, typically urban, rural, and motorway. A slightly better distinction which is used in COPERT is average velocity.

However, the most detailed distinction in traffic situations currently used is a combination of road type, speed limits, and congestion levels. HBEFA makes a distinction of about 90 traffic situations, incorporating special traffic situations from countries like Sweden and Switzerland. The Dutch VERSIT+ emission factors distinguish between eleven Dutch traffic situations. These traffic situations are communicated with the relevant road authorities, who then supply traffic data for the different traffic situations, including the amount and severity of the congestion. The total vehicle distance travelled per traffic situation yields the sum to determine the total emissions.

This type of normalization, from measurement data to average emission per traffic situation, requires an emission model, such as PHEM, VERSIT+, or COPERT. These models are designed to translate emission measurements from arbitrary testing to the average emissions in the different prescribed traffic situations. Each emission model has its own merits and input requirements. The features and the differences are discussed briefly below.

5.4.1 PHEM

The starting point of HBEFA is the PHEM emission model developed by the Technical University of Graz (TUG). This uses a detailed engine model for predicting emissions, which until recently required testing in the laboratory. An engine map is determined and emissions are calculated for the engine speed and power demand. This can be applied to a variety of vehicle weights and vehicle driving resistance, combined with actual velocity profiles for real-world driving.

This model forms the basis of a very large collection of emission factors, used across Europe: the HBEFA emission factors. They are the result of average vehicle characteristics, combined with vehicle usage, and driving behaviour, as established in separate research programs.

5.4.2 HBEFA

The emission factors of HBEFA have been used in Germany, Sweden, Switzerland, and Austria for many years. Traffic situations from the different countries are inputted to the model to ensure the emission factors are determined for relevant traffic situations in these countries. Norway and France have also now started to use the HBEFA emission factors for their emission inventories. The PHEM model is run with representative driving behaviour and generic vehicle properties, to produce a very large collection of emission factors for the traffic situations provided by the experts of the different participating countries.

HBEFA emission factors are updated approximately every three years.

5.4.3 COPERT

COPERT is the most commonly used emission model across Europe and version 4.11 has been used to generate vehicle emissions predictions which are used in the modelling results presented in the UK Air Quality Plan. COPERT is a model which relies on the available data from other sources. The HBEFA emission factors are the main input to the COPERT model. These data are converted into the most comprehensive set of emission factors across Europe.

However, apart from the vehicle categories, the COPERT model distinguishes only average velocity, deterioration and cold start as input. An important limitation is that congestion would be only roughly approximated by using data about average on-road velocity as an input to COPERT. In an urban situation, failing to address periods of heavy congestion will lead to an underestimation of the vehicle emissions in COPERT. This is not a failure of the COPERT model, but mainly of the application of the model to particular situations.

It is not at all clear in what detail the model underlying the UK Air Quality Plan is matched with the COPERT model. This is very important, however, for the calculated levels of vehicle emissions and the resulting local concentrations of NO_2 and other components. Specifically at intermediate velocities between approximately 40 and 80 km/h, the actual road type and congestion level are very relevant for the emission levels. As COPERT only takes into account the average velocity it is not able to distinguish emissions at 50 km/h on congested roads from 50 km/h in free flow conditions.

Generally, the results of COPERT are broadly in line with HBEFA and, to a lesser extent, to VERSIT+. However, there are still significant deviations between the outcomes of different models due to three main factors:

i) the accuracy and detail of the traffic intensity and driving behaviour information;
ii) the underlying emission data, which may, or may not yet include the latest emission measurements/insights;
iii) the forward prediction of emission levels of vehicle legislative classes.

The last two items are discussed extensively in this report.

In the Netherlands average vehicle velocity is used to distinguish degrees of congestion on the different road types, as they can affect the total emissions greatly. In some cases induction loops are used to determine, or calibrate, the traffic data in the air-quality model. This is a good way to yield accurate results. The location of induction loops, e.g. close to junctions or away from them, is shown to affect the emissions generated.

5.4.4 UK Air-Quality Plan COPERT usage

The UK is not an official user of the COPERT model. The PCM implementation is very likely based on the reports provided by the COPERT maintainers, but, as far as these maintainers know, it is not using the COPERT software. The precise implementation in the PCM is unknown. Strictly speaking, it is not COPERT as such, and the COPERT maintainers cannot assure the appropriate implementation and usage of the reported results. Thus it is assumed that only the COPERT documentation v4.11 is underlying the UK Air-Quality Plan and not the model itself. The current Air Quality Plan does not contain sufficient information to check the implementation of COPERT. The only information to go on is the plots in the report. Although these appear to be generally in line with the COPERT results, not much more can be deduced. The previous implementation based on COPERT v4.10 was reported in more and better detail by DEFRA.

5.4.5 VERSIT+

The Netherlands has one of the largest real-world emission test programs in Europe. The data is inputted into the VERSIT+ vehicle emission model. Both the vehicle test program and the emission modelling is carried out by TNO.

The philosophy behind the test program is to perform emission tests as close to the real-world representative situations on the Dutch roads, such that the test results are representative of the average emission performance and little interpretation is required of the modeller to arrive at normalized emission factors, for the traffic situations agreed among the parties involved in the air quality model for the Netherlands.

The model averages the emissions per vehicle for different velocities and accelerations, and applies these results to the different traffic situations, to establish emissions that are representative of the situations on Dutch roads. For example, there are emission factors for urban congestion, with average velocity below 15 km/h – a situation which occurs at a number of locations in the metropolitan area.

It is important to understand that such situations are excluded, or limited, in the oncoming RDE legislation, as the average velocity is too low for the trip to be RDE compliant. These limitations in the RDE test protocol are of some concern. A similar problem is observed for heavy-duty vehicles, where inner-city bus routes are associated with driving behaviour not fully covered in the Euro-VI legislation. Models relying on data which do not cover these realistic traffic situations will not be able to produce realistic emission results for these specific traffic conditions.

5.5 Comparison of VERSIT+ and COPERT emission factors

Emission factors in COPERT have not been updated since 2014. By contrast VERSIT+ emission factors have been updated last in March 2016. The emission factors, calculated with the VERSIT+ model, reflect the latest measurements for Euro 5/V and Euro 6/VI vehicles. These include the emission factors of the main diesel passenger cars which will be most prevalent over the coming 5 to 15 years in Europe.

The Dutch national emission factors for 2016 are presented in Table 5. The current Euro-6 emission factors and the previous emission factors (for 2015) are shown in Figure 2.

Table 5 Emission factors 2016 for the relevant diesel passenger cars for prognoses 2020-2030, the figure comparable to the COPERT emission factors below are highlighted.

emission factors 2016	[g/km]	Euro-6	RDE	Euro-5
urban congestion	NOx	0.679	0.314	1.000
	NO2	0.288	0.129	0.327
urban normal	NOx	**0.571**	**0.244**	0.708
	NO2	0.225	0.100	0.214
urban free flow	NOx	0.454	0.188	0.542
	NO2	0.176	0.077	0.160
rural	NOx	0.397	0.170	0.531
	NO2	0.157	0.070	0.161
motorway average	NOx	0.404	0.171	0.588
	NO2	0.165	0.070	0.181
motorway congestion	NOx	0.594	0.253	0.746
	NO2	0.233	0.104	0.227
motorway strict 80 km/h speed limit	NOx	0.310	0.127	0.405
	NO2	0.122	0.052	0.122
motorway no strict 80 km/h speed limit	NOx	0.312	0.185	0.466
	NO2	0.095	0.046	0.152
motorway strict 100 km/h speed limit	NOx	0.253	0.139	0.501
	NO2	0.111	0.057	0.158
motorway no strict 100 km/h speed limit	NOx	0.294	0.148	0.528
	NO2	0.127	0.061	0.165
motorway 120 km/h speed limit	NOx	0.377	0.166	0.576
	NO2	0.156	0.068	0.178
motorway 130 km/h speed limit	NOx	0.434	0.173	0.589
	NO2	0.174	0.071	0.181

It is relevant to compare these VERSIT+ emission factors with the emission factors from COPERT v4.11 that are used in the UK Air Quality Plan.

Considering the emission factors for Euro-6 and RDE compliant vehicles in urban areas (with an average velocity of 25 km/h) the COPERT v4.11 emission factors are:

- COPERT 4.11 Euro-6 0.254 g/km NO_x
- COPERT 4.11 RDE (Euro 6c) 0.135 g/km NO_x

While this data is provided by COPERT, it is not presented and cannot be deduced from the Air Quality Plan. Comparing these values with the VERSIT+ “urban normal” driving in Table 5, it can be seen that the Dutch values are roughly double the emission factors used from COPERT. This difference is substantial. Moreover, the Euro-6c vehicle category is part of COPERT, but not of the report the PCM is based on. It is possible that the limit values in PCM are taken for the estimate of real-world emissions but this is not stated in the Air Quality Plan. Assumptions on future legislation are therefore unclear.

The Dutch testing for Euro 6 is based on mainly 2013 vehicles, where SCR technology dominated. This Euro 6 technology is known to perform poorly in urban conditions. It is likely, that the eventual emission factor of Euro-6 in urban conditions will settle in a year or more, at a value somewhere in between the COPERT and the VERSIT+ emission factors. However, the current emission factors of COPERT are considered by TNO to be altogether too low to remain tenable. A 50% increase on the current COPERT light duty Euro 6 values for urban conditions is very likely.

The Euro-6c estimates in all emission factors in COPERT, HBEFA, and VERSIT+ were very preliminary, but with the recent developments in Europe such low emission values may be possible. It is no longer the WLTP which will dominate any such change, however, but the RDE legislation. In particular a separate requirement on urban emissions in RDE legislation may indeed bring the value down to below 0.160 g/km after 2020.

Both the HGV and LCV emission factors are lower in COPERT and HBEFA than used in VERSIT+ in 2016. In both cases the Dutch estimates are approximately 30 to 50% higher, mainly for urban conditions. This is for two different reasons. The testing of LCV’s across Europe is limited, and emission factors have been based on estimates rather than measurements. In the Netherlands these estimates are considered no longer tenable. In the autumn of 2014 a group of ten common Euro-5 LCV’s were tested and the emissions were much higher than previously assumed across Europe. In 2015 the Dutch emission factors were updated and the results were shared with HBEFA. Within HBEFA similar data was available, but since the emission factors were updated half a year earlier, these test results are awaiting the next update of HBEFA, which will be probably early 2017. It is expected that COPERT will follow soon after, assuming there is no intermediate update in 2016.

The difference between HGV emission factors of COPERT and HBEFA on one side and the VERSIT+ emission factors on the other side is for a different reason. All parties found from 2013 very low emissions of HGV’s. The Netherlands decided to use conservative estimates based on the available margin to the legal limit, which was double the results from the emission testing. The gap between more recent emissions measurements and the limit has reduced. HBEFA uses a much more optimistic approach, which is also followed by COPERT. The heavy duty emission measurements are currently about 20%-30% higher on average compared on the initial testing on which HBEFA is based, however, variations with vehicle type, payload, velocity and road type are in the same order of magnitude. The differences are most distinct for low velocities in urban conditions.

5.6 Conclusions

Based on the latest TNO emission data, collected by recent measurements (2015) of mainstream Euro-6 vehicles, the VERSIT+ emission model was updated. This resulted in an increase of the new 2016 Euro 6 NO_x emission factors. The previous emission factors were based on older emission data from 2012/2013, when only a few of the first (high end) Euro 6 vehicles were tested.

The COPERT 4.11 Euro 6 emission factors are still based on the older emission data. Until these are updated, the COPERT Euro 6 emission factors are not based on the most recent, best available evidence and very likely underestimate the emission levels of Euro 6 vehicles.

It is likely that in the next update of emission factors for the Euro-6 passenger cars, Euro-5 and Euro-6 LCV’s, and Euro-VI HGV’s, the factors for urban conditions will be increased by about 30%-50%, depending on the vehicle type, compared to those currently used in HBEFA and COPERT. For Euro-5 LCV’s and Euro-6 passenger cars the recent measurement data warrants such an update. The update of Euro-6 LCV’s and Euro-VI HGV’s will in part an expert judgment. In addition it must be noted that this change is not uniform across all road-types and traffic situations. For example, increases linked to congestion, urban driving, and cold start effects are expected to be the largest.

6 Uncertainties and margins for emission factors

The previous section has considered emission factors, but it is important to recognise that emission factors alone do not determine the real-world emissions and their impact on air-quality. Two other aspects are central to the overall effect:

i) the appropriate assignment of the right emission factor to the traffic situations on all the roads, combined with the intensity and distance; and
ii) the average vehicle fleet composition on the different roads.

The former requires a detailed and calibrated traffic model to be combined with the vehicle emission information (the complexity of assigning the right emissions to the traffic situation has already been touched upon in the previous chapter).

In respect of the second aspect, if air quality problems are to be solved in the near future, the dominant cause will be renewal of the vehicle fleet as older cars, which generally pollute more, are replaced with newer vehicles which are expected to be cleaner. It should, however, be noted that the assumption of newer cars being cleaner, does not necessarily hold for the NO_x and NO_2 emissions of diesel cars, where history has shown little overall improvement and in some cases deterioration in real driving conditions as standards have been introduced. This section briefly considers these factors.

6.1 Fleet and fleet renewal

If vehicles are not imported or exported they live out their natural life in one country. Historically, older vehicles were scrapped earlier in their life cycles, normally after about 14 years. However, vehicle reliability has improved. A modern vehicle’s life span now covers on average about 17 years in most European countries, including the UK. This means it takes longer for the fleet to renew and it also takes longer to see the effect of the influx of newer and cleaner vehicles on air quality. In one year typically only 6% of the vehicles are replaced with new vehicles. If the average vehicle on the road has double the emissions of a new vehicle, one year will bring an improvement of 3% (the 6% new vehicles with half the emissions). Therefore, halving emissions will take at least ten years, after the first introduction of clean vehicles. Since a number of old vehicles with high emissions remain in the fleet, the improvements from the influx of clean vehicles is somewhat limited. It takes more than half the fleet replaced for half the effect on the emissions.

For example, in 2016 we are now seeing the major out flux of Euro-2 vehicles, sold from 1996 to 2000 (i.e. 16-20 years later), and a diminishing but still significant number of Euro 3 and 4 vehicles. These are currently being replaced by a growing number of Euro 6 vehicles. The number of poorly performing Euro-5 vehicles, which entered the market from 2009, will start to diminish more significantly from 2018, comprising roughly a third of diesel cars in 2018 and a fifth in 2022.

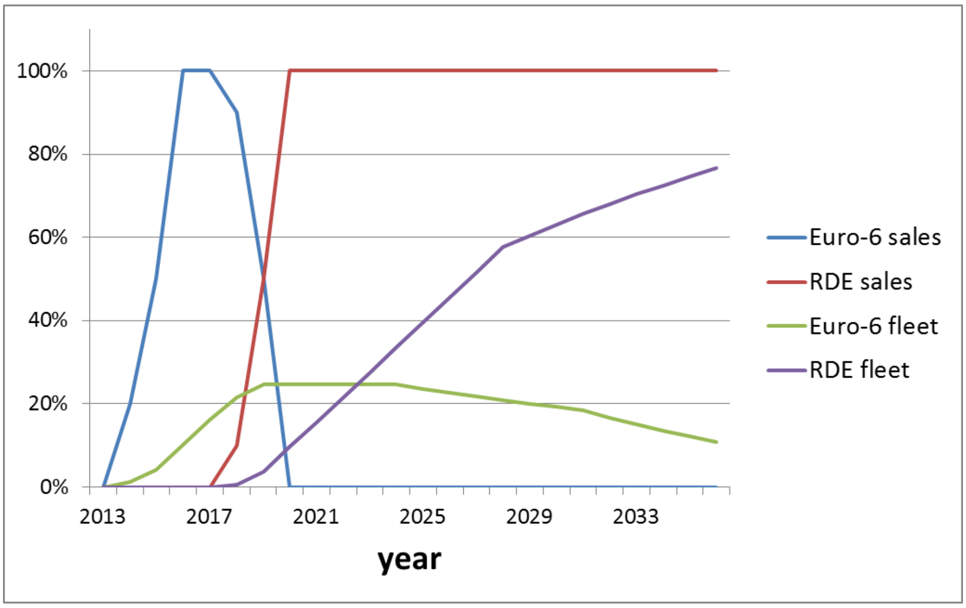

Figure 5 A simple representation of the influx of new vehicles and the effect on their fraction in the total fleet in a given year. This is based on a 6% replacement of the fleet per year, corresponding to an average lifetime of 17 years.

The older vehicles tend to make larger contributions to the total emission than younger ones, so only at the tipping point of half the fleet of a certain build year being depleted, does the effect of the out flux start to offer benefits. It follows that if Euro-6 had been very effective in reducing the diesel NO_x emission right from the start in 2015, the tipping point, with half the fleet complying with Euro-6 would be around 2025. However, the RDE legislation is compulsory for all vehicles from September 2019. It is very probable that manufacturers will wait till the latest possible date for complying with the complex and difficult demands of RDE. Consequently, only after about nine years will half the fleet be replaced with RDE legislation compliant vehicles, which is 2028. Therefore, it is expected that the major benefits of clean vehicles, say halving the emissions from the diesel car fleet, will occur in the window 2028 to 2035, depending on the effectiveness of vehicle legislation to reduce the real-world urban emissions of new vehicles. Combined with the vehicle replacement scenario above, a bandwidth is given in Figure 6. In the case of highly effective legislation a substantial reduction is already assumed with Euro-6, within the bandwidth of current measurements.

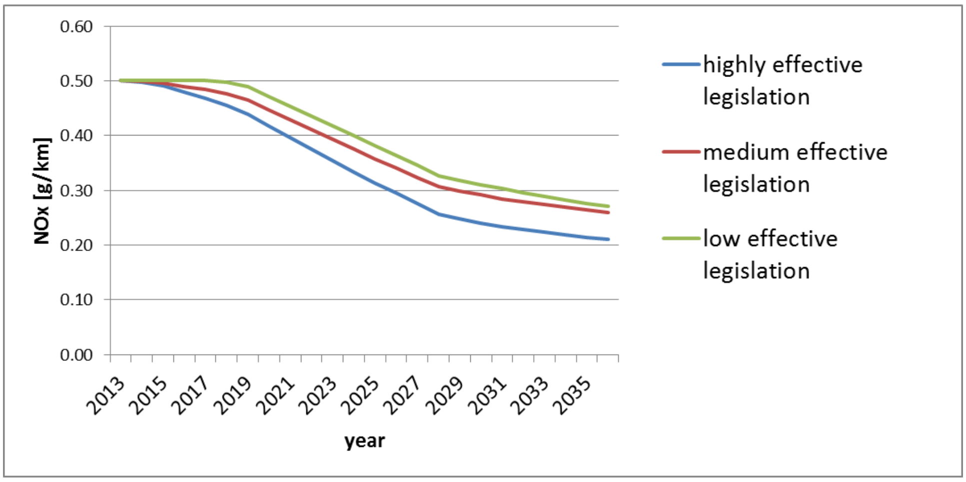

Figure 6 Different scenarios of reducing NO_x emissions over time, based on the vehicle replacement scenario presented in the previous figure and different assumption for the emission of Euro-6 and RDE compliant vehicles.

Combined with the evidence that the Euro-6 standard has not yet brought about the reductions expected, hope is now being placed that the RDE legislation will do so. This means the tipping point for improvement in emissions will be delayed by approximately 5 years (introduction of Euro 6 RDE), which brings the tipping point, where the majority of the fleet is clean and air quality improvements are fully realised back to post 2030.

In the Netherlands older diesel vehicles are exported, due to increased road taxes being applied as vehicles age. This policy has had the effect of reducing the average lifespan of vehicles to about 8 years, thereby accelerating the fleet turnover and bringing forward improvements in air quality. As shown in Figure 5 the road tax system facilitates the rapid out flux of diesel vehicles through export, and this has particularly occurred in the last few years, since 2009.

Therefore, the effects of diesel fleet renewal on air quality are observed much earlier in the Netherlands than in most other European countries, where the lifespan of vehicles has increased by about a year in the period 2005-2012 to 17 years.

There is nothing in the UK Air Quality Plan which seeks to accelerate the fleet turnover of older more polluting diesel cars. On the contrary, the sale of diesel vehicles in the UK has increased, creating a fleet of long-lived new diesel cars, many of which will remain on the road beyond 2025.

Hence, even though higher mileages are often driven in younger cars and the contribution of new cars to the total mileage is greater, the effect of vehicles sold ten years or longer ago on emissions remains a significant factor influencing air quality.

Fleet renewal is therefore a key part in the air quality assessment and a lag of ten years or more is not unusual.

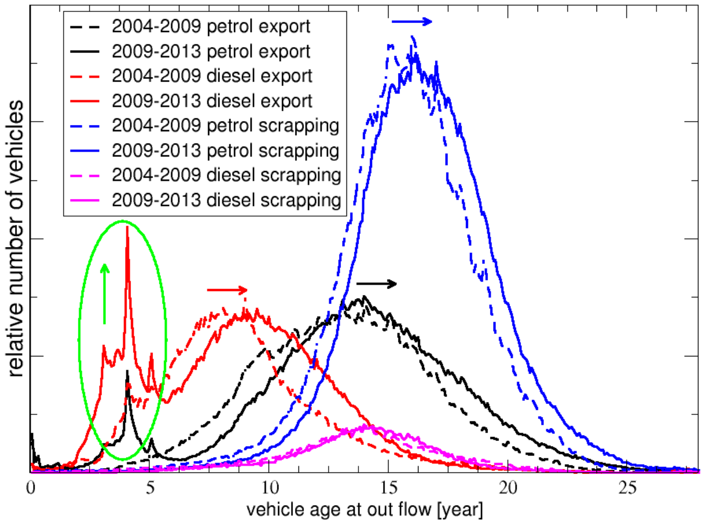

Figure 7 The out flow of vehicles in the Netherlands. The road tax system ensures the rapid out flux of diesel vehicles through early export (green circle), especially since 2009. Therefore, the effects of diesel fleet renewal on air quality are observed much earlier in the Netherlands than in most other European countries. The lifespan of vehicles has increased by about a year in the period 2005-2012 to 17 years.

6.2 Driving behaviour, speed limits, and congestion

Another set of important influences on emissions is driver behaviour, speed limits, and congestion.

Low velocities are associated with high emissions for three reasons:

i) the large residence time on a road segment compared to a vehicle driving faster;
ii) more braking and acceleration associated with this low average velocity, which is wasted energy and results in high fuel consumption and more emissions;
iii) the low exhaust gas temperatures at low velocities makes it difficult for catalytic emission reduction technology to function at its optimum. Evidence shows that with velocities dropping below 50 km/h the emissions increase rapidly, to more than three times the value at 50 km/h in heavy congestion. For Euro-6 cars emissions of 8 times the type approval limit have been recorded, with wide variability by make and model.

Whilst average vehicle speed on road segments has been taken into account, there is no indication that the particular driving conditions within road segments has been taken into account in the case of the modelling predictions the UK Air Quality Plan.

6.3 Vehicle usage and vehicle state

Modern vehicles, with tailpipe exhaust gas emission levels far below the level of pollutants created in the engine, have complex after treatment technologies to achieve emission reductions of 80% and higher. These technologies fail from time to time, causing significantly higher emissions.

A one in ten failure rate may result in a substantial increase in the average emissions. This is especially the case for the particulates filter, but to a lesser extent also for NO_x emissions. For Euro-5 vehicles with particulates filter, a substantial number of failures are found. The 1 in 20 to 1 in 10 failure rate doubles the total emissions of the total vehicle category. For NO_x reducing technology such evidence does not exist yet, so no evidence of failures can be gathered.

So far, this factor has been of little relevance because NO_x emissions are almost always high compared to the type-approval limits. However, with the introduction of RDE compliant vehicles in the RDE test, subsequent increasing emissions from failures, engine adjustments, deterioration, inferior replacement parts, etc. are a major concern and risk.

If a periodic check-up, combined with legal enforcement was to be introduced, meaning that the proper state of emission control technology would be frequently tested, this risk would be much less. However, there are no such proposals at this time for in service maintenance of vehicles, meaning that this responsibility is likely to lie with vehicle owners and will not be enforced.

7 Air quality across Europe and in the Netherlands

Air quality problems are not unique to the UK. All across Europe urban NO_2 concentrations are high. Despite policy and legislative measures improvements have been limited in the last years There is an overall trend assumed, which varies somewhat from country to country. The UK Air Quality Plan can be compared against the assumptions other countries make for the future reduction of emissions. This will put the UK Air Quality Plan baseline scenario and the subsequent improvements into perspective.

7.1 Small diesel fraction in the Netherlands

The Netherlands has a lower fraction of diesel cars than the UK. Moreover, a comprehensive plan was put in place in 2008 to achieve compliance with limit values by 2015. Even so in 2015, a number of air quality problems still remained.

These problems are mainly the result of succession of setbacks on the performance of new vehicle emission standards:

- Starting with Euro-4 in 2009, this first significant setback in NO_x emission reduction was reported.
- Euro-V emission factors had to be increased three-fold in 2010.
- In 2013, the Euro-5 emission factors were upped by a substantial amount.
- This was followed by the preliminary emission factors for Euro-6 in 2014 being increased.
- In 2015 the emission factors for LCV’s were increased again;
- and in 2016 emission factors for Euro-6 based on test data alone were increased overall compared to the previous 2014 estimate.

Only the Euro-VI emission factors of 2014 were lower than previously estimated, The effect of the introduction of RDE legislation is expected also to lead to emission reduction.

The Dutch air quality model is calibrated with air quality measurements. These measurements contain both background and street level results. The emission factors are matched with air quality predictions. This ensures that future predictions start from the proper baseline, based on the currently observed air quality situation. The Dutch emission factors provide a prediction close to the observed results.
For the past years TNO had to increase the expected emission factors for 2015 and beyond, mainly because the promised positive effects of Euro 6 and legislation has not been achieved. In consequence, the measures, by local and national governments to achieve air quality standards have become more drastic over the years.

For example, heavy-duty low emission zones have now existed for many years. Light-duty vehicle low emission zones are heavily debated, but have currently been introduced only in a number of large cities. The expected positive effect of a light-duty low emission zone on NO_2 concentrations is limited, as the newer diesel vehicles are only slightly cleaner than the older ones.

7.2 Dutch emission factors update 2016

The emission factors for air quality models are updated and published annually in the Netherlands. The 2016 updated values are shown in Table 6 below. With the rather small share of diesel passenger cars in the Netherlands, it is expected that the emission factors for light-duty vehicles (passenger cars and LCV’s) in the UK would be about 60% higher than the Dutch average emission factors for light duty vehicles.

In the Netherlands, substantial reductions of NO_x and NO_2 emissions due to RDE legislation are not expected until close to 2030. The emission factors of TNO are combined with the fleet development prognoses of the *Planbureau voor the Leefomgeving*[12]; a government institute which assesses the effects of national policies. In the Netherlands the emission factors in the table below are used for emission inventory and calculation of local air quality. The factors represent typical NO_x emissions per vehicle class, per road and traffic type and for current and future years.

Table 6 The emission factors for 2016 for the use in Dutch air-quality models. With the share of slightly less than 30% of diesel passenger cars in the Netherlands, a simular set of emission factors will be higher for other European countries including the UK (60%).

emission factors [g/km]	year	2015	2015	2020	2020	2030	2030
		NOx	NO2	NOx	NO2	NOx	NO2
road and traffic type	vehicle category						
urban congested	Light duty [<3.5 ton]	0.565	0.139	0.41	0.119	0.191	0.053
	Busses	7.053	0.83	2.649	0.419	1.097	0.378
	medium heavy [3.5-20 ton]	11.493	0.653	5.719	0.444	1.755	0.318
	heavy [> 20 ton]	14.753	0.77	5.583	0.629	2.083	0.595
urban normal	Light duty [<3.5 ton]	0.381	0.093	0.297	0.086	0.142	0.04
	Busses	4.408	0.519	1.656	0.262	0.686	0.236
	medium heavy [3.5-20 ton]	7.029	0.391	3.519	0.271	1.087	0.197
	heavy [> 20 ton]	9.006	0.465	3.44	0.389	1.296	0.372
urban free flow	Light duty [<3.5 ton]	0.369	0.086	0.266	0.073	0.124	0.032
	Busses	3.161	0.372	1.184	0.187	0.487	0.168
	medium heavy [3.5-20 ton]	4.868	0.264	2.455	0.188	0.764	0.139
	heavy [> 20 ton]	6.222	0.317	2.403	0.274	0.916	0.264
rural	Light duty [<3.5 ton]	0.3	0.088	0.25	0.081	0.113	0.036
	Busses	2.588	0.3	1.022	0.163	0.441	0.145
	medium heavy [3.5-20 ton]	4.492	0.253	2.258	0.192	0.88	0.145
	heavy [> 20 ton]	4.994	0.291	1.992	0.252	0.804	0.238
motorway average	Light duty [<3.5 ton]	0.402	0.124	0.315	0.108	0.129	0.043
	medium heavy [3.5-20 ton]	3.158	0.28	1.455	0.169	0.506	0.12
	heavy [> 20 ton]	3.326	0.272	1.187	0.209	0.568	0.186
motorway congested	Light duty [<3.5 ton]	0.491	0.151	0.403	0.137	0.167	0.055
	medium heavy [3.5-20 ton]	6.465	0.448	2.977	0.265	0.817	0.188
	heavy [> 20 ton]	7.882	0.419	2.8	0.377	1.147	0.373
motorway 80 km/h strict speed limit	Light duty [<3.5 ton]	0.268	0.077	0.222	0.073	0.095	0.03
	medium heavy [3.5-20 ton]	3.088	0.277	1.423	0.167	0.499	0.119
	heavy [> 20 ton]	3.239	0.269	1.156	0.205	0.557	0.182
motorway 80 km/h no strict speed limit	Light duty [<3.5 ton]	0.283	0.083	0.213	0.061	0.114	0.026
	medium heavy [3.5-20 ton]	3.088	0.277	1.423	0.167	0.499	0.119
	heavy [> 20 ton]	3.239	0.269	1.156	0.205	0.557	0.182
motorway 100 km/h strict speed limit	Light duty [<3.5 ton]	0.301	0.092	0.231	0.079	0.103	0.034
	medium heavy [3.5-20 ton]	3.088	0.277	1.423	0.167	0.499	0.119
	heavy [> 20 ton]	3.239	0.269	1.156	0.205	0.557	0.182
motorway 100 km/h no strict speed limit	Light duty [<3.5 ton]	0.333	0.102	0.256	0.088	0.111	0.037
	medium heavy [3.5-20 ton]	3.088	0.277	1.423	0.167	0.499	0.119
	heavy [> 20 ton]	3.239	0.269	1.156	0.205	0.557	0.182
motorway 120 km/h speed limit	Light duty [<3.5 ton]	0.417	0.129	0.312	0.107	0.127	0.042
	medium heavy [3.5-20 ton]	3.088	0.277	1.423	0.167	0.499	0.119
	heavy [> 20 ton]	3.239	0.269	1.156	0.205	0.557	0.182
motorway 80 km/h speed limit	Light duty [<3.5 ton]	0.466	0.146	0.344	0.118	0.135	0.045
	medium heavy [3.5-20 ton]	3.088	0.277	1.423	0.167	0.499	0.119
	heavy [> 20 ton]	3.239	0.269	1.156	0.205	0.557	0.182

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[1] www.pbl.nl

On the other hand, it must be observed that the improvements of emissions of heavy-duty vehicles, trucks and buses are expected to be substantial from 2020 onwards. These emission factors in The Netherlands are based on conservative estimates. Both COPERT and HBEFA use lower values than these estimates based on the emission testing up to 2013 of the first Euro-VI vehicles. This discrepancy is based on expert judgment whether the emissions of Euro-VI heavy-duty vehicles remain at the initial level.

The scenarios for 2020 and 2030 above in Table 6 can be compared with the vehicle renewal scenario shown in Figure 6. The trend is faster than the medium effective legislation scenario. This is due to two effects in the Netherlands, which are not common to the UK or most other European countries. First, diesel passenger cars are exported early, and second, there is a further reduction of the diesel share expected in the fleet for 2025 and beyond.

For the UK Air Quality Plan it would be more appropriate to compare to other scenarios, where the optimistic emission factors for Euro-6 and Euro-VI are factored in. The maintainer of HBEFA is the Swiss institute INFRAS, who also provides the prognoses of emission reductions for Switzerland. Their data provide a good comparison for the UK Air Quality plan for 2025 and 2030.

7.3 Future emission reductions in Switzerland based on HBEFA

The INFRAS institute published the emission prognoses based on HBEFA on-line (see www.hbefa.net, HBEFA 3.2, Update of Emission Factors for EURO 5 and Euro 6 vehicles for the HBEFA Version 3.2, 17.7.2014). They show a substantial reduction of emissions in the years to come (See Table 7).

Table 7 The prognoses for diesel fleet average emissions for Switzerland based on HBEFA.

NOx [g/km]	2010	2015	2020	2025	2030
passenger cars	0.608	0.596	0.418	0.272	0.182
LCVs	1.182	1.03	0.775	0.497	0.327
Trucks	4.887	2.994	1.507	0.789	0.532

The air quality improvements in the UK Air Quality plan are more or less in line with these figures, although they appear to suggest a more dramatic reduction earlier, which would not be explained by these figures. With such reductions in traffic emissions between 2015 and 2030 the NO_2 concentrations are likely to be reduced significantly. However the impending update of HBEFA shows that the emission factors for 2020 are likely to be approximately 50% higher for LCV's and can be approximately 30 to 50% higher for trucks. Therefore, with the exception of trucks, where a one third reduction would still be forecast between 2015 and 2020, little or no improvement is expected by 2020.

This impending change in 2020 is not an isolated change. Changes will also affect the result in the years 2025 and 2030. Assuming a vehicle renewal rate of 6% per year, more than 60% of the fleet responsible for the traffic emissions in 2020 will still be on the road in 2025 and 30% in 2030.

8 Conclusions

Emission legislation provides the starting point for calculating the emissions of future vehicle fleets. However, proposed emission limits should no longer be taken at face value, although the reduction in emission limits from one standard to the next is sometimes used as a first estimate for emission factors for future vehicle categories. A factor of 3 to 5 has generally been assumed between the official limit and the real-world performance. This conservative estimate no longer seems tenable based on the evidence for Euro-5 vehicles, particularly in urban conditions. With Euro-6 the evidence is also gathering that actual emissions are significantly higher than these conservative estimates. RDE legislation may bring much needed improvement in real-world emission performance but this legislation is still being negotiated, so the final outcome is unclear.

There are a number of institutes in Europe who provide emission factors, which incorporate the effects of the changing vehicle fleet on emissions. The emission measurements are translated using emission models into normalized and standardized emission factors which can be used in national air quality models and national emission inventories. Both are part of the international obligations to monitor and improve the environment.

There is always a delay from emission measurements to their visibility in air quality prognoses. As new Euro-6 vehicles enter the market the emission factors are expected to be updated. The emission factors of COPERT, used in the UK, are not updated yet and they are based on favorable results from testing the very first Euro-6 vehicles. In the Netherlands, the emission factors have subsequently been updated and the new results are about 50% higher in the urban environment and more in heavy congestion. It is likely the same changes will show in the update of the emission factors in HBEFA and COPERT. Even following this update it is unlikely that the emission factors for Euro-6 will be finalized, as some uncertainty still remains. Euro-6 emissions factors are dominant for the air quality predictions for 2020-2025. Between 2025-2030 and beyond the effectiveness of the new RDE legislation will be of paramount importance for NO_2 air quality improvement.

There is always a great deal of optimism of the effectiveness of new legislation. For petrol cars and trucks, the promise of the legislation was fulfilled. However, for diesel passenger cars the last 25 years of legislation has brought little reduction in real-world NO_x emissions. With RDE legislation, optimism has returned, bringing real hope that on-road testing will lead to reduced emissions. Two drawbacks are the late introduction date for this type of testing to be compulsory and the possible limitation of the applicability of the manufacturer’s type-approval RDE test for real-world performance of on-road vehicles Even in an optimistic case, little benefit can be expected for air quality prior to 2025.

The UK Air Quality plan is based on COPERT. However, the actual COPERT software is not used and little information is presented in the Plan about how COPERT is implemented in the latest air quality modelling. Apart from the vehicle fleet changing over time, traffic flows and congestion resulting in lower average velocity must be properly represented in the model to achieve a realistic result. Countries like the Netherlands, Norway, Sweden, France, Germany, Switzerland,

and Austria opt for a more detailed model, where driving behavior is matched with the road type and established degree of congestion. The accuracy of the prediction of the emissions in each traffic situation is thereby improved.

The UK does not use such detailed information as it is not part of COPERT. Moreover, it is uncertain if the UK implementation of COPERT makes the most of the accuracy which can be achieved by having an accurate local vehicle velocity, instead of using average speed data. For the same average velocity the predictions can vary easily up to 40% with the road type. These types of uncertainty are hidden in the large and complex implementation in the PCM, for which very little detail is available.

With traffic congestion the emissions are substantially higher per vehicle. Assigning the proper emission factors to the level of congestion and determining the different levels of congestion on the road network is therefore essential to predict the emissions accurately. It is unclear to what extent the UK Air Quality Model does incorporate the effect of congestion.

It is very likely, based on the positive initial estimates of the emission factors for light-duty Euro-6, heavy-duty Euro-VI and RDE compliant vehicles in COPERT that the ambient NO_2 concentration estimated is too low, especially for the period 2020-2030.

Given the current emission measurement data available, actual emissions of Euro-6/VI are likely to be 50% higher for light duty (including cars and vans) and 30 to 50% higher for heavy duty vehicles in metropolitan areas like greater London than COPERT’s current estimates. In heavily congested conditions, emissions from Euro-6 cars can be 8 times the type approval limit, with very wide variability between makes and models. RDE compliant vehicles may enter the market only very late, from 2019-2020, which will delay their main positive effect on air quality to well beyond 2025.

9 Literature and further information

Since emission inventories (Pollutant Release and Transfer Registers) and air quality modelling are part of the international obligations: the Kyoto Protocol, the EU Water Framework Directive, the European Pollution Release and Transfer Register (E-PRTR) and various other UN and EU obligations, many of the emission factors and the methodologies are reported and the information is available on-line.

9.1 COPERT emission factors

COPERT emission factors are provided by EMISIA on www.emisia.com.
The latest version v4.11 is reported in:

- Methodology for the calculation of exhaust emissions, Ntziachristos, L., & Samaras, Z..

9.2 HBEFA emission factors

HBEFA emission factors are provided by INFRAS on www.hbefa.net.
The latest update (3.2) is reported in:

- Update emission factors EURO-5 and Euro-6 vehicles for HBEFA version 3.2, Rexeis, M., Hausberger, S., Kühlwein, J., Luz, R. (Contributions by Ligterink, N.E. & Kadijk, G.A. , TNO)

9.3 VERSIT+ emission factors

VERSIT+ emission factors are provided by TNO on www.tno.nl and on www.emissieregistratie.nl.

The latest update of the emission factors is reported in :

- 2016 Emission factors for diesel Euro-6 passenger cars, light commercial vehicles and Euro-VI trucks, report number TNO 2016 R 10304, 7 March 2016

Further information can be found in:

- On-road NO_x and CO_2 investigations of Euro 5 Light Commercial Vehicles, report number TNO 2015 R 10192.
- Emissions of nitrogen oxides and particulates of diesel vehicles, report number TNO R 2015 10838.
- Determination of Dutch NO_x emission factors for Euro-5 diesel passenger cars, report number TNO 2012 R11099.
- Investigations and real world emissions performance of Euro 6 light-duty vehicles, TNO 2013 R 11891.
- Detailed investigations and real-world emission performance of Euro 6 diesel passenger cars, report number TNO 2015 R10702.
- Emission performance of a diesel plug-in hybrid vehicle, TNO 2015 R 10858.
- NO_x emissions of Euro 5 and Euro 6 diesel passenger cars – test results in the lab and on the road, report number TNO 2016 R10083.

- The Netherlands in-service testing programme for heavy-duty vehicle emissions TNO 2012 R 10753.
- The Netherlands In-service emissions testing programme for heavy-duty 2011-TNO 2013 R 10641.
- HD Euro-V Truck PM10 and EC emission factors, TNO 2015, R 11041.
- In-use compliance and deterioration of vehicle emissions, TNO 2015, R 11043.

An overview of TNO emission measurements with vehicle make and model information was recently made available under the Freedom of Information Act in a report:

- NOx emissions on road and in the lab, TNO 2016 R 10083.

9.4 ERMES

Further information can be found at the ERMES website www.ermes-group.eu. The European collaboration of institutes ERMES perform real-world emissions of mobile sources and determine emission factors. The ERMES group is chaired by JRC, the research institute of the European Commission.

In particular, the joint statement from October 2015 provides an overview of the current status of NO_x emissions of diesel vehicles in the light of recent events:

- Information Paper - Diesel light duty vehicle NOx emission factors, ERMES, October 2015.

10 Signature

Delft, 14 April 2016 TNO

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