HBEFA

HBEFA Version 3.3

Background documentation
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Mario Keller (MK Consulting GmbH)
Stefan Hausberger, Claus Matzer (IVT / TU Graz)
Philipp Wüthrich, Benedikt Notter (INFRAS)

MKC Consulting GmbH, Distelweg 5, CH-3012 Bern/Switzerland
IVT Institute for internal combustion engines and thermodynamics, TU Graz, Inffeldgasse 19, A-8010 Graz/Austria
INFRAS, Sennweg 2, CH-3012 Bern/Switzerland

Content

Summary

HBEFA 3.3 is a "quick update" of HBEFA 3.2 and is focusing on the NOx-emission of newer diesel passenger cars. All other parts of HBEFA 3.2 remain unchanged. A fully reviewed version of HBEFA is planned for 2018. In version 3.3 the following elements were adapted:

- The "hot" NOx emission factors (EF) of diesel passenger cars of the concepts Euro-4, Euro-5 and Euro-6 are updated taking into account new measurements from different sources (laboratory and real world measurements [PEMS measurements on the road] as well as Remote Sensing data).
- As a new element the influence of ambient temperature on the hot NOx EF of diesel cars (Euro-4, Euro-5 and Euro-6) is introduced. This influence is taken into account by correction factors. They are applied to the "base EF" provided by the PHEM model of the TU Graz as in previous HBEFA versions and take into consideration that most emission tests are performed at temperatures between 20°C and 30°C in the labs while the real world ambient temperatures are on average clearly lower. The correction factors are derived mainly from remote sensing data (in Sweden and Switzerland). The empirical basis of the temperature influence so far is limited, hence the correction factors are considered as indicative and require further investigation.
- With version HBEFA 3.2 (2014) a new stage 'Euro-6c' was introduced (in addition to Euro-6). With the new version HBEFA 3.3 this concept is replaced by two stages 'Euro-6d1' (=stage 1) and 'Euro-6d2' (=stage 2) assuming a stepwise increased effectiveness of additional type approval procedures, particularly RDE (real-driving emissions with on board emission testing) and hence lower emissions. These concepts will be introduced at later points in time than previously assumed. As a consequence the fleet compositions of diesel passenger cars had to be adapted. The fleet compositions of all other vehicle categories and technologies (e.g. petrol cars) remain unchanged.
- The "base EF" of Euro-4 (PC diesel) were updated in 2010. New emission measurements advised an adaptation (particularly for motorway-driving). The "base EF" of Euro-5 were updated in 2014 (HBEFA 3.2) and remain unchanged. The "base EF" of Euro-6 are updated again; however, they still rely on a limited amount of measurements and hence are of indicative character. Since the available measurements were taken from a sample of comparatively new vehicles a slight deterioration (with age and mileage respectively) is assumed. The concepts Euro-6d1 and Euro-6d2 are not yet on the roads hence their EF rely on expectations about the effect of the corresponding regulations (particularly RDE).
- Cold start excess emissions: the new measurements referring to NOx emissions of cold start of diesel cars confirmed the values and trends assumed in the previous HBEFA version 3.2 to a large extent. Hence the values remain unchanged in version 3.3.

- **Results**

The following two figures show the resulting emission factors: the 'hot' EF particularly of Euro-5 and Euro-6 are notably higher than expected in the previous version, mainly as influence of the newly

introduced correction for ambient temperature. The newer RDE-concepts Euro-6d1 and Euro-6d2 though are assumed to remain at a similar level as in HBEFA 3.2 (figure S1). Figure S2 shows the impact on the overall specific emission (in g NOx/km) of the entire passenger car fleet (including petrol cars): the overall emission factor in 2015 is 25% higher than assumed in the previous version, the difference raises up to 47% in 2020 and then continuously drops down again so that the values in 2030 are almost at the same level as expected in version 3.2.

Figure S1: NOx emission factors of the diesel cars Euro-4/-5/-6 – in HBEFA 3.2 and HBEFA 3.3

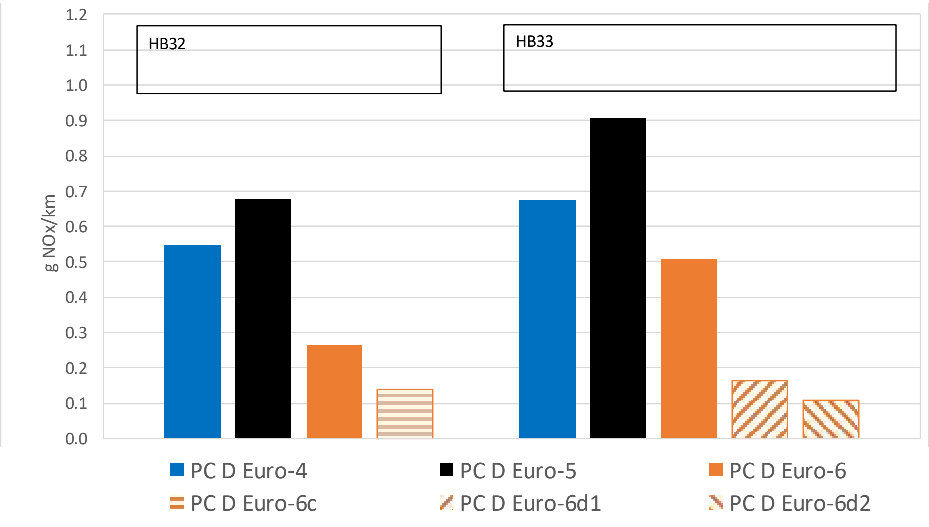
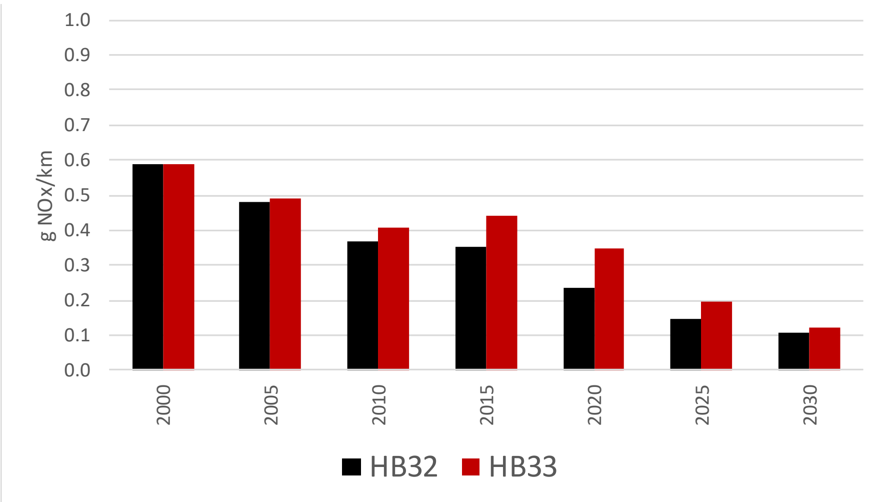


Figure S2: Weighted NOx emission factors for the German total passenger car fleet in HBEFA 3.3 vs. 3.2



1. Context and objective

Context

The Handbook Emission Factors for Road Transport (HBEFA) provides emission factors for all current vehicle categories (PC, LCV, HGV, urban buses, coaches and motor cycles), each divided into different categories, for a wide variety of traffic situations. Emission factors for all regulated and the most important non-regulated pollutants as well as fuel consumption and CO2 are included. The first version of HBEFA (HBEFA 1.1) was published in December 1995. Since then every 4 to 5 years HBEFA-updates were developed taking into account the newest technological developments in emission behavior of the vehicles, new or adapted regulations, new methodologies in emission measurement and modelling, changes in the fleet compositions and driving behavior etc. The last version (HBEFA 3.2) was published in 2014. At the end of 2016 the work for a new version was launched by the Environmental Agencies of the six countries which continuously support the development of HBEFA (Austria, France, Germany, Norway, Sweden and Switzerland). The working title for the new version is "HBEFA 4.1" with the intention to publish it in 2018. The news about emission control failures of diesel cars and the discussion about cycle recognition and defeat devices have raised concerns on the representativeness of diesel light duty vehicles emission factors, hence this issue is one of the main topics to be addressed in a new update. In addition, fuel consumption and the rising importance of the CO2-emissions of the vehicles is another main topic since the difference between test results and real world fuel consumption resp. CO2-emissions seems to get bigger continuously. Other elements shall be looked at as well, as e.g. the foreseeable technological changes in the fleets (electromobility) and hence adjusted fleet compositions in the near future.

Objective

Due to urgent short-term needs the German Umweltbundesamt commissioned the HBEFA consortium to produce a "quick update" focusing particularly (and only) on the NOx emission factors of the recent diesel passenger cars. Therefore, it was decided to produce an interim version "HBEFA 3.3" with the objective to adapt the NOx emission factors of the diesel cars. All other elements remain unchanged compared to "HBEFA 3.2".

Work process

Originally the focus was set on the newest concept Euro-6. Work was started under the assumption that the emission factors up to Euro-5 would not need to be adapted, since the emission factors of the HBEFA were always based on real world emission measurements over non-regulatory driving cycles which reflect a realistic driving behavior. As a result, Euro 5 diesel car emission factors already have been significantly higher than the emission limit value (0.18 g/km). The values in the current version of HBEFA (3.2) – weighted over all traffic situations for example for Germany – are close to 0.7 g/km, i.e. ca. 4 times higher than the limit value. However, after the emission control failures of diesel cars became public several investigations and measurement programs in different countries were performed (BMVI/KBA 2016, MEEM 2016, CTA 2016, DfT 2016). The results indicate that also other factors influence the emission behavior of the vehicles, one of them is the ambient temperature. As a consequence, this influence is now taken into account not only for Euro-6, but also for earlier concepts.

The emission factors of earlier HBEFA versions had to rely almost exclusively on emission measurements performed on chassis dynamometers in manufacturer-independent laboratories (as ADAC, EMPA, JRC, LAT, TNO, TRL, TUG etc.). In general, standardized real world driving cycles were used to get comparable data from different laboratories. These emission measurements (measured second-per-second) are a crucial input to build the engine maps out of which the PHEM (Passenger car and Heavy duty Emission Model) of the TU Graz eventually calculates the emission factor (in g pollutant/km) for the different traffic situations and vehicle concepts which are then integrated in HBEFA. This approach is also used for version HBEFA 3.3. However, it does not (yet) integrate the influence of ambient temperature. Therefore, additional data sources were analyzed.

The HBEFA activities and related measurement programs always tried to capture the real world behavior of the vehicles. The special investigations mentioned above focused also on whether control failures were a generally followed approach and whether this was manufacturer-specific and whether the official test cycle (NEDC) could be recognized by the vehicles. Their measurement programs therefore varied the NEDC cycle, but also added on-road tests using new measurement techniques, in particular PEMS (portable emission measurement systems). The HBEFA group collected and integrated these emission measurement results in the so called “ERMES LDV bag database”. This database has its origin in the ARTEMIS project of the 4th EU Framework program (ARTEMIS 2007, André JM 2005) and has since regularly been updated by the HBEFA group to get a robust and comprehensive empirical basis for a continuous HBEFA development. These extended datasets are here used for validating the modelled emission factors, and they also give indications on influencing factors as e.g. ambient temperature.

On-road measurements will become more prominent in the future particularly due to the Real-Driving Emissions (RDE) regulation which is expected to improve the effectiveness of emissions control in the real world. PEMS measurement campaigns were also started by independent third parties to monitor emission behavior of the vehicles. Collecting and analyzing such data will continue also for future HBEFA versions.

An additional measurement technique in monitoring air quality is remote sensing (RS). This method monitors the on-road emissions by determining the concentration of certain pollutants in the exhaust plumes of vehicles passing at particular locations and assigns the emission levels out of the concentrations to individual vehicles[1]. While tests on chassis dynamometers as well as on road tests with PEMS provide emission data for individual vehicles, remote sensing delivers information on a much wider set of vehicles resp. a whole fleet passing by at singular locations, hence giving indications about fleet emissions overall. Therefore, RS can be seen as complementary approach to

[1] For information about RS data see e.g. AWEL 2015, Borken-Kleefeld 2013, Chen et. al. 2016

the classical measurement techniques. It is particularly valuable for identifying the influence of factors which are difficult to be captured by measuring individual vehicles, as e.g. deterioration with increasing mileage or age or the influence of ambient temperature.

As the term "quick update" indicates the work for HBEFA 3.3 had to be done in a limited amount of time. Therefore, the results are considered as indicative. Additional measurements will have to be collected and analyzed to confirm the results for the follow up version 4.1. which is planned for 2018.

Structure of this document

This report explains the empirical basis of the adapted emission factors and illustrates their impact by comparing the NOx emission factors of HBEFA version 3.3 vs. 3.2. It is structured as follows:

Chapter 2 describes the work about the "base emission factors" including the impacts on the fleet composition. Chapter 3 discusses the influence of ambient temperature, and chapter 4 presents the resulting emission factors of HBEFA version 3.3 and compares them with those of version 3.2. Chapter 5 makes some additional comments on cold start excess emissions and some other adjustments (based on national inputs).

2. "Base emission factors"

2.1. Approach: the PHEM model

The "base emission factors" (i.e. the g pollutant / km, differentiated by traffic situation and vehicle type) are provided by the PHEM (Passenger car and Heavy duty Emission Model, developed by the TU Graz). The term "*base* emission factors" means that some other influencing factors (as e.g. age-dependent deterioration or ambient temperature) are not yet taken into account.

Details about this approach are described in a separate TU Graz report (TUG 2017). In short: PHEM calculates the fuel consumption and emissions of vehicles based on the vehicle longitudinal dynamics and on engine emission maps. For each second PHEM computes for each vehicle the actual engine power to overcome the driving resistances and the losses in the drive train. A driver model simulates the corresponding gear shift behavior to calculate the actual engine speed. With engine speed and engine power the emissions are taken from engine maps. A transient correction module adapts the emission levels from the engine maps to the actual driving cycle. Additional modules take into account the behavior of specific technologies. The model results are 1 Hz courses of engine power, engine speed, fuel consumption and emissions of different pollutants – for each cycle and differentiated vehicle types, i.e. for each subsegment and driving pattern according to the HBEFA definitions. These values then can be aggregated for the full cycle which results in the familiar emission factors (in g/km).

2.2. Emission factors of diesel cars Euro 6

Measurements and emission factors in HBEFA

At the time when HBEFA 3.2 was developed (2013/14) modal measurements of only 5 EURO 6 cars were available (TUG 2013, chapter 3.1.3) as basis for the PHEM model. Additional uncertainties were due to the fact that these vehicles were premium class vehicles, hence not representative for the fleet. Further uncertainties were due to the unknown shares of NOx control technologies. Additional measurements of another 12 vehicles as “bag values” (i.e. not on a second-by-second basis) were available for calibrating the emission level. Details of the common driving cycles used in the context of HBEFA are available in Annex A.

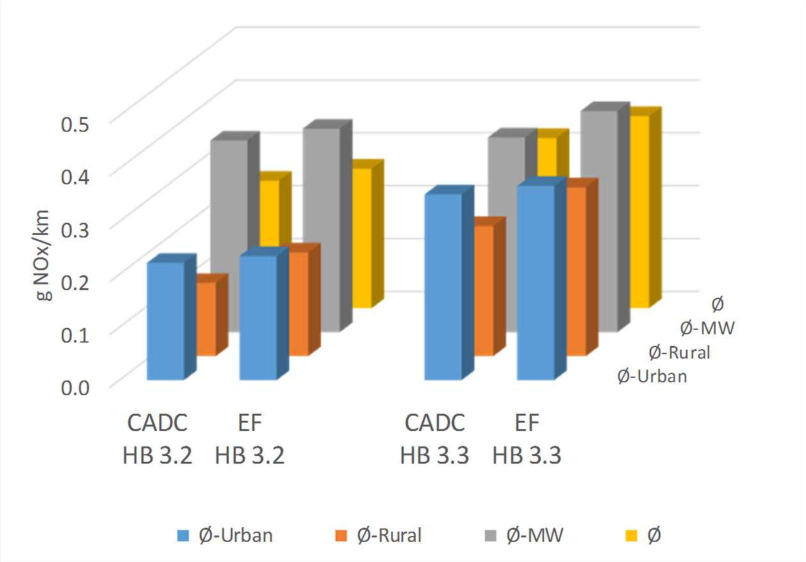
For HBEFA 3.3 the number of available Euro-6 vehicles resp. measurements with comparable real world cycles, particularly in the CADC cycle[2], could be increased and is now 25. This is still a limited sample size but nevertheless contributes to decrease the uncertainty.

Figure 1 shows on one side the NOx emissions as empirical basis from chassis tests (CADC) in typical driving patterns (urban, rural and motorway and an overall average[3]) which were available for HBEFA 3.2 and now for 3.3, and on the other side the emission factors derived by the PHEM model for comparable average driving patterns as HBEFA provides them for Germany, i.e. weighted sets of urban, rural and motorway traffic situations. One should take note that the two data sets shown in Figure 1 (CADC and EF) are not directly comparable since the underlying driving behavior is not the same. But the figure should illustrate that the available empirical basis eventually determines the emission factors of HBEFA: The new measurements (CADC) indicate that the previous sample (basis for HBEFA 3.2) was indeed not representative and underestimated the average emission level of the Euro-6 diesel cars significantly particularly in the urban and rural driving (e.g. ca. 0.2 instead 0.35 g NOx/km in urban driving as indicates the new sample). This underestimation hence was transferred to the HBEFA emission factors. The new value of 0.35 g NOx/km is approximately the result for the overall average emission factors according to HBEFA 3.3. This means that the new “base emission factor” of Euro-6 diesel cars is about 4-5 times higher than the limit value for Euro-6 (0.08 g/km).

[2] CADC: Common Artemis Driving Cycle (André M, 2004). This well-established cycle was developed in the ARTEMIS project and is used since more than 10 years by most labs in Europe to produce comparable emission data (see also Annex A).

[3] The overall average shown here corresponds to an equally weighted mix of urban, rural and MW driving.

Figure 1: Comparison between the NOx emissions for Euro-6 vehicles according to the available measurements (CADC cycle) and the NOx emission factors modelled by PHEM in the context of the HBEFA versions 3.2 resp. 3.3



The emission factors HBEFA 3.3 which are shown in this diagram are the «base emission factors» according to PHEM and do not yet take into account further corrections for e.g. ambient temperature as explained in chapter 3.

Different stages of Euro-6

The previous version HBEFA 3.2 distinguished between a first generation of Euro-6 vehicles (referring to stage Euro-6b, labelled as 'Euro-6') and vehicles which were expected to enter the market based on a more stringent emission regulation in 2017/18 (labelled as 'Euro-6c'). The new HBEFA version 3.3 adjusts the segmentation of the Euro-6 vehicles to the adapted regulation which will require on road emission testing with PEMS equipment (RDE tests)[4]. This will be introduced in two stages differentiating as usual between new type approvals (TA) and new registrations. In addition, the conformity factors[5] will be tightened for NOx from 2.1 (in stage 1) to 1.5 (in stage 2), and the relevant temperature range will be lowered to 3°C (in stage 1) and to 0°C (in stage 2). The introduction of two stages will be as follows:

	For new type approval	For all new registrations
Stage d1 (or 'EU6d-Temp/RDE')	Sept. 2017	Sept. 2019
Stage d2 (or 'EU6d/RDE')	Jan. 2020	Jan. 2021

[4] Road tests have to comply with certain conditions to be accounted for as a RDE test, as e.g. a certain split between urban, rural and motorway driving joint with speed boundaries, stop times, overall length, altitude meters etc.

[5] Conformity factors basically mean higher limit values since the official standard (0.08 g NOx/km for Euro-6) is multiplied by these factors. Translated into real terms this means limit values for on-road tests of 0.168 g/km in stage 1 and 0.12 g/km in stage 2.

Due to this new RDE regulatory framework the previous concept of Euro-6 in HBEFA 3.2 which distinguished between Euro-6 and Euro-6c will be replaced in HBEFA 3.3 by Euro-6, Euro-6d1 and Euro-6d2. Since the vehicles approved according to Euro-6d1 and Euro-6d2 are not yet available on the market the new standards (limit values including conformity factors) are taken as guides for assuming the new emission levels. Since some of the vehicles tested do in fact already reach these low emission levels one can assume that in future these values should be attainable.

The re-definition of the Euro-6-generations has implications on the PC fleet composition which is explained in chapter 2.4.

Deterioration effects

The emission values underlying the new emission factors for Euro-6 are deferred from comparatively new vehicles. A certain deterioration over the lifetime resp. the mileage of the vehicles may occur. Empirical information on such effects however is difficult to obtain since the same vehicle would have to be measured regularly over a considerably long period (e.g. every 30'000 km). Remote sensing data have the potential to isolate this effect since the emission levels monitored resp. the underlying fleet can be split up by registration years, hence providing information about a potential deterioration. Figure 2 shows the emission levels (in g NOx per kg fuel) monitored in a remote sensing campaign in Zurich/Gockhausen in 2016 (AWEL 2015[6]) as a function of their age (as a proxy for mileage). The figure shows for the Euro-6 vehicles not a deterioration with age but rather an improvement. This is in line with the measurements presented in Figure 1 where the early Euro-6 vehicles show a very low level of emissions since they were premium class vehicles while the present new registrations on average show higher emissions. For Euro-5 a similar "sample effect" can be excluded. The "base emission factor" of the Euro-5 vehicles was not derived from new Euro-5 vehicles but from a vehicle sample which is well distributed with respect to age. Therefore, deterioration is already included and should not be taken into account additionally. The situation is different for the Euro-6 vehicles: also the new "base emission factors" are derived from a sample of comparatively new vehicles. Hence a deterioration may well occur. We assume that a correction similar to the observed effect for Euro-5 vehicles (according to Figure 2) can be attributed to the Euro-6 vehicles. The effect is moderate and corresponds to a linear increase of the base emission factor up to 20% at a cumulative mileage of 150'000 km (assuming a yearly mileage of 15'000 km/a over 10 years). For the concepts Euro-6d1 and Euro 6d2 there are no empirical data available, hence it is assumed that these correction factors will be slightly reduced (by 25% compared to Euro-6) which results in an increase of 15% after a cumulative mileage of 150'000 km.

There are indications that some deteriorations are also an issue for previous concepts (≤ Euro-4) [Chen et. al. 2016]. But for the time being (i.e. HBEFA version 3.3) no deterioration effects will be taken into account for the earlier concepts.

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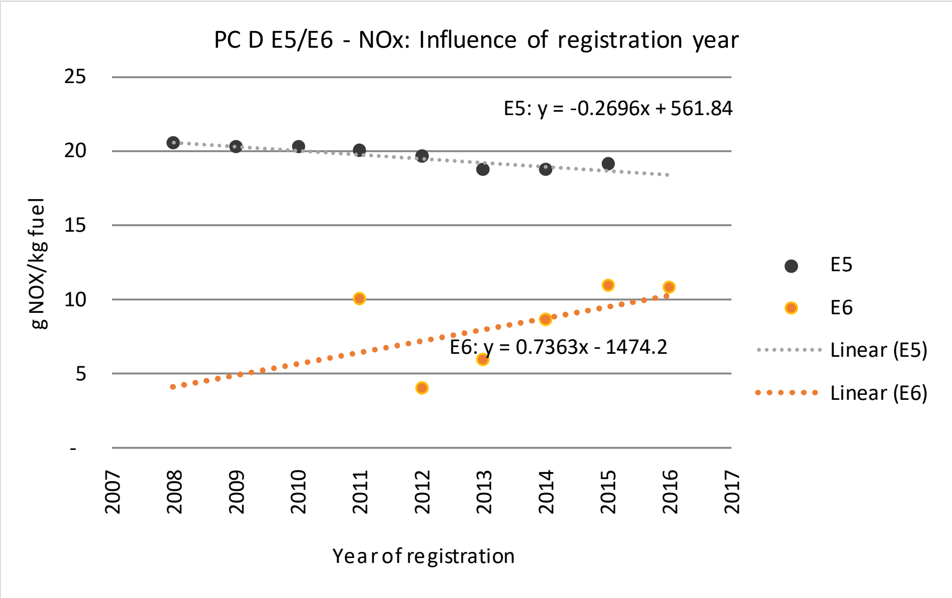
[6] This document (AWEL 2015) refers to the campaign of the year 2015. The data shown in Figure 2 though refer to the data gathered in 2016 with a higher share of Euro-6 vehicles. The report about the 2016 campaign is presently not yet available.

Figure 2: NOx emission levels of Euro-5 and Euro 6 diesel cars, measured 2016 in Zurich, as a function of their age



2.3. Emission factors of diesel cars Euro-4 and Euro-5

The empirical basis for determining the base emission factors of the concept Euro-4 and Euro-5 has not changed significantly even if the number of measurements has increased. The average emission values in the CADC cycle remain more or less at the same level. Hence the emission factors of Euro-5 in HBEFA 3.3 are the same as in HBEFA 3.2. Also for Euro-4 the empirical basis is basically the same. However, the emission factors of Euro-4 were developed for HBEFA 3.1 (2009/2010) and remained unchanged since then. The calculation model PHEM has been adapted in the meantime. For consistency reason the NOx emission factors Euro-4 were adapted as well (TUG 2017). However, the impact is not very significant: only the motorway emission factors are higher while urban and rural traffic situations remain at roughly the same level.

2.4. Impacts on the fleet composition

Due to the re-definition of the stages in HBEFA (Euro-6/6d1/6d2 replacing Euro-6/6c) and a new schedule for the introduction of stages d1 and d2 the fleet composition had to be adjusted. Table 1 illustrates the new assumptions about the shares of new registrations compared to the assumptions of HBEFA 3.2. Changes are assumed to take place not before 2017. But the basic implication is a delay in the introduction of vehicles complying with the RDE regulation.

Table 1:Introduction of the different Euro-6 stages into the market as assumed for HBEFA version 3.3 vs. 3.2

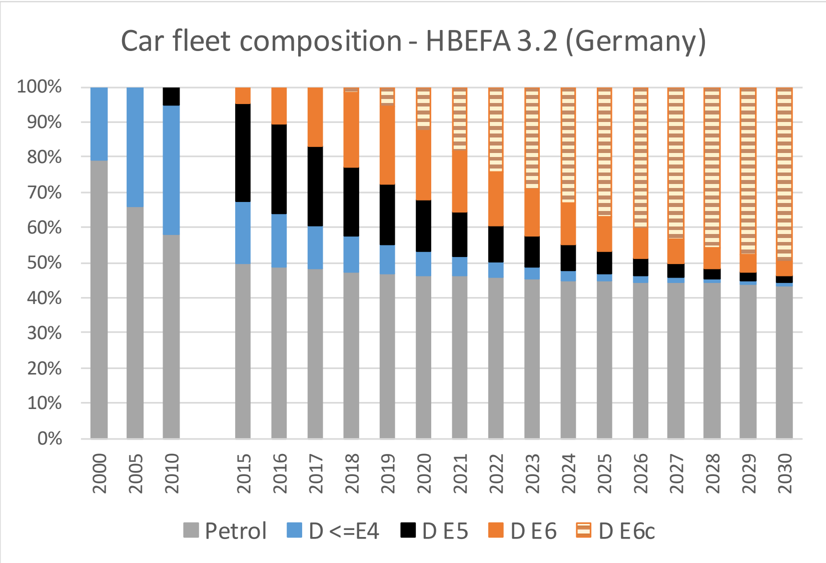
HB32

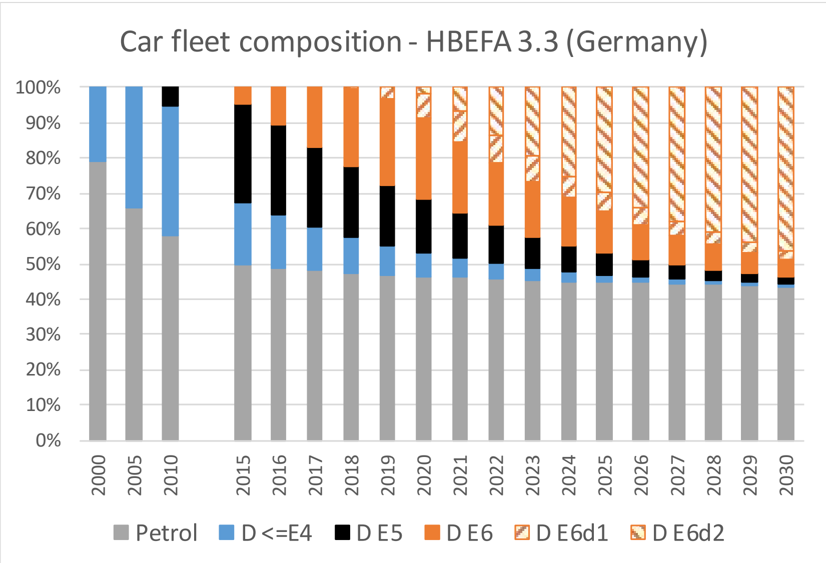
	EURO-5	EURO-6	EURO-6c
2013	95%	5%	
2014	75%	25%	
2015	25%	75%	
2016		100%	
2017		90%	10%
2018		75%	25%
2019			100%
2020			100%
2021ff			100%

HB33

	EURO-5	EURO-6	EURO-6 d1	EURO-6 d2
2013	95%	5%		
2014	75%	25%		
2015	25%	75%		
2016		100%		
2017		100%		
2018		95%	5%	
2019		25%	75%	
2020			50%	50%
2021ff				100%

Figure 3: Car fleet compositions in HBEFA version 3.2 vs. 3.3 – Example Germany





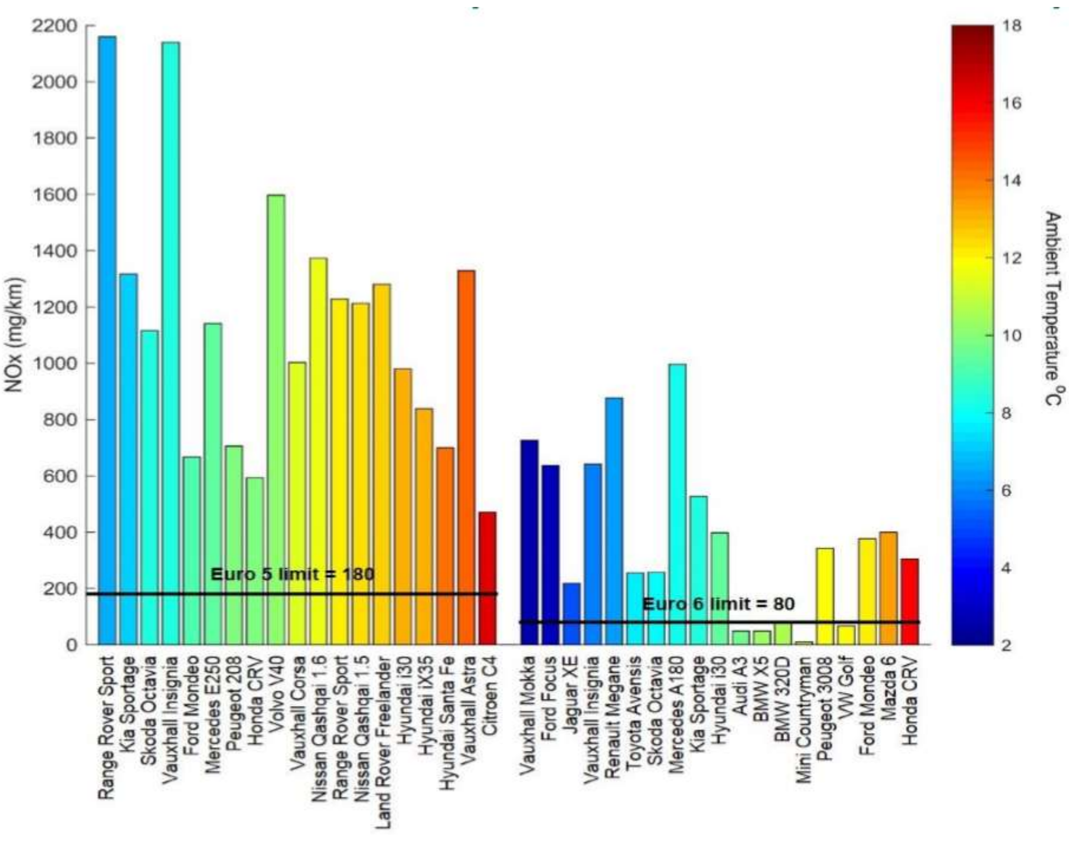
These vehkm-weighted fleet compositions include also all petrol cars as well as the diesel cars previous to Euro-4.

3. Influence of ambient temperature

3.1. Ambient temperature and NOx emissions

Ambient temperature appears to be a significant factor influencing the emissions as the results of several measurement campaigns indicate. Figure 4 shows the track test NOx emission results of the UK investigation plotted in order of temperature (DfT 2016): vehicles that were tested at lower ambient temperatures tended to produce higher NOx emissions than those which were tested at higher ambient temperatures. However, it is difficult to draw a direct conclusion from these results on a quantitative effect of ambient temperature since a potential temperature effect may be blurred by a genuine vehicle effect. In addition in on-board emission tests the driving style and the traffic condition are likely to have a higher influence than expected from temperature.

Figure 4: Track test results plotted in ambient temperature order

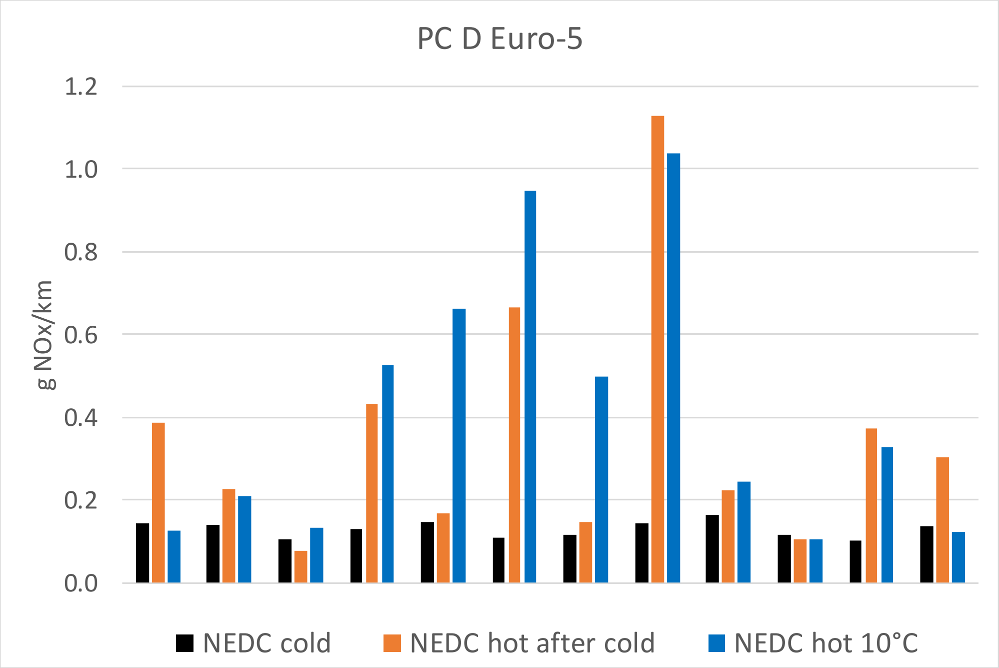


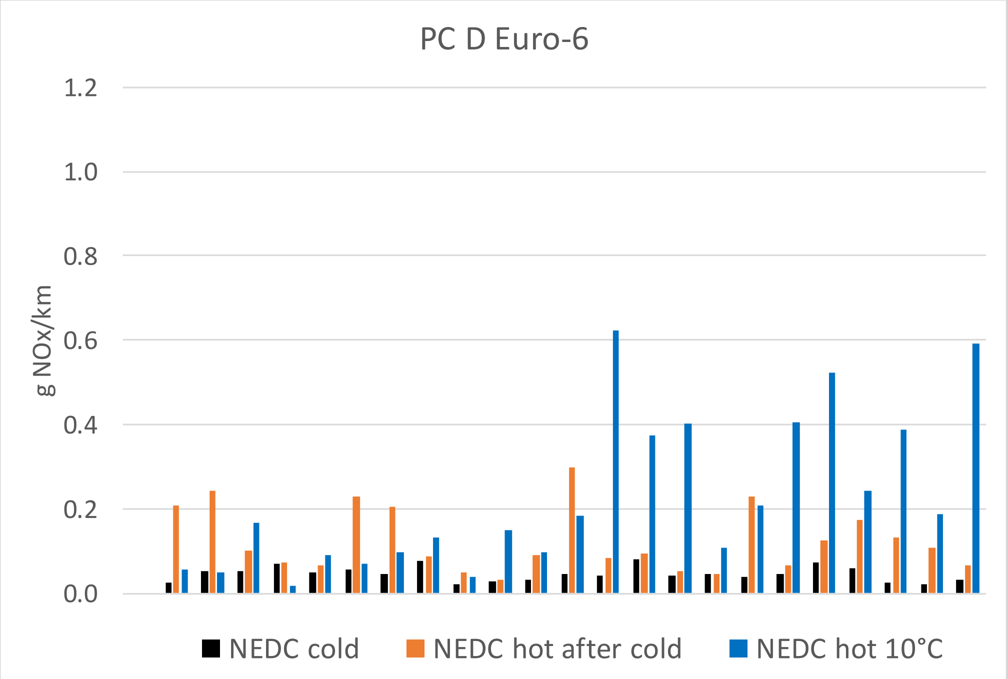
Source: UK investigation (DfT 2016)

In the German investigation project (BMVI/KBA 2016) several vehicles were measured at 10°C in addition to the normal test temperature of ca. 20 – 25°C. Also these measurements indicate a significant influence of the ambient temperature. However, the diagram shows a substantial heterogeneity, in the sense that some vehicles show hardly any difference while others show a substantial increase. On the average, the increase for these samples are roughly 15-20% for the Euro-5 vehicles and ca. 80% for the Euro-6 vehicles (comparing the 'NEDC hot at 10°C' to the 'NEDC hot after cold').

These values obviously depend very much on the samples which are not necessarily representative for the fleets, and the NEDC cycle is not representative for real world driving either.

Figure 5: Results of varying NEDC tests at different ambient temperatures

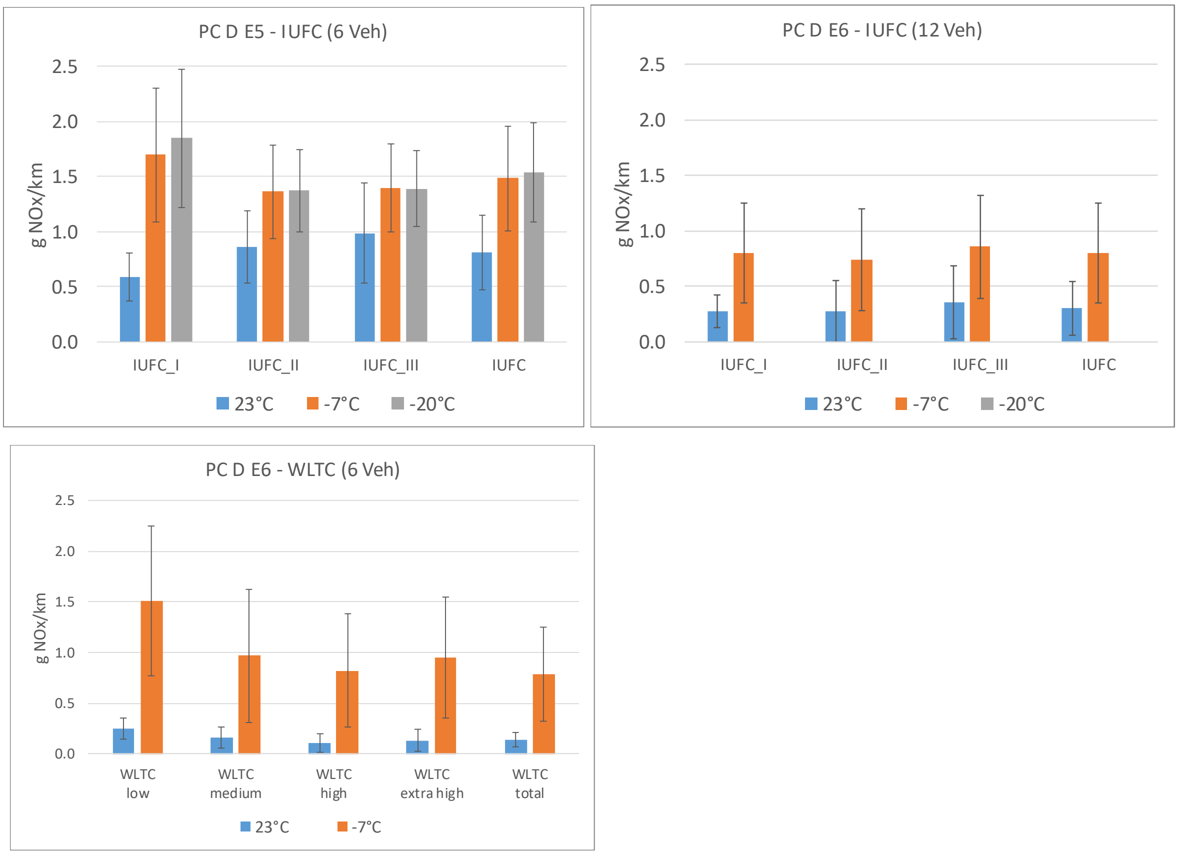




The diagram shows the emission results of 12 Euro-5 resp. 24 Euro-6 diesel cars measured in 3 NEDC cycles (1. standard NEDC with cold start, 2. 'Hot NEDC' driven after the NEDC with a cold start, and 3. Hot NEDC at 10°C).
Source: BMVI/KBA 2016

In the regular Swiss measurement programs for the updates of HBEFA which are commissioned by the Swiss Federal Office of Environment, EMPA measured several diesel cars in different cycles (IUFC and WLTC) and at different temperatures. Figure 6 shows for the Euro-5 vehicles an increase of a factor close to 2 if ambient temperature drops from the normal test temperature of ca. 23°C down to -7°C (from ca. 0.8 g NOx/km up to 1.5 g/km). The relative increase of the Euro-6 vehicles is even higher leading to an increase form ca. 0.3 g/km up to 0.75 g/km. Noticeable is the fact that a further temperature reduction below the -7°C level (Euro-5 vehicles) does not increase the emission level further.

Figure 6: Results of IUFC and WLTC tests at different ambient temperatures



Source: EMPA measurement programs:
6 Euro-5 vehicles were measured in the IUFC cycle (see Annex A) at 3 temperatures (23°C, -7°C and -20°C), and 12 Euro-6 vehicles in the same IUFC cycle at 2 temperatures. Six of the 12 Euro-6 vehicles were also measured in the WLTC cycle at 2 temperatures (23°C, -7°C).

These measurements indicate a significant influence of the ambient temperature on the NOx emissions. This has a technical background (see e.g. BMVI/KBA 2016, DfT 2016). A widely used technology for control of NOx emissions generated during combustion is exhaust gas recirculation (EGR). This technique reduces peak combustion temperatures and in turn reduces formation of NOx. The amount of EGR which can be used is dependent on ambient temperature. At low temperatures moisture condensation may lead to a build-up of deposits and in turn can lead to preventing the

EGR from operating correctly and – according to manufacturers – possibly influence proper operation of the vehicles. State of the art technology for NOx control on Euro 5 diesel vehicles is a combination of EGR with control of the fuel injection timing to influence the combustion process. For Euro 6 vehicles additional exhaust aftertreatment is used, either a lean NOx trap (LNT) or selective catalytic reduction (SCR). Ambient temperature influences the temperature of the aftertreatment systems and thus can also impact the efficiency with which LNT and SCR exhaust NOx after treatment control can work. Both technologies have optimum temperature windows for effective operation and do not convert NOx below approx. 200°C.

3.2. Correction factors

For HBEFA the question is how to capture this influence of ambient temperature. Since singular measurements do not provide an ideal basis for building an appropriate average we again refer to the remote sensing monitoring method. Recent measurement campaigns in Sweden (Göteborg, Sjödin et.al. 2017) and Switzerland (Zurich/Gockhausen) performed in 2016 register data about concentrations and individual vehicle types as well as the ambient temperature. Even if the measurements cover a limited temperature window between 10 and 20°C they allow to derive a quantitative dependency. Figure 7 shows the results of the analysis: the emission levels at temperatures below 20° were set in relation to the average of the emission level measured at the RS station above 20°C which corresponds to the normal temperatures of laboratory tests from which the base emission factors are derived. These functions are transformed into the format visualized in Figure 8 where ratios below 100% from Figure 7 were limited to 100% since it is unlikely that between approx. 18° and 20°C lower emissions occur than above 20°C. These functions are applied in HBEFA version 3.3 as temperature correction factors. For e.g. 0°C this means an increase of 41% in NOx emissions for Euro-4 cars, of 78% for Euro-5 and 92% for Euro-6 vehicles. Below 0°C no further reduction is assumed – in line with the measurements presented in Figure 6.

Figure 7: Influence of ambient temperature on NOx emissions compared to levels at ≥20°C

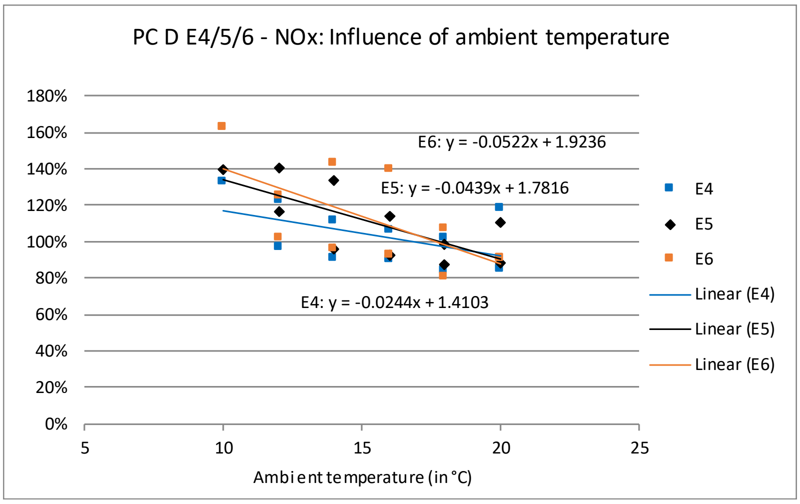
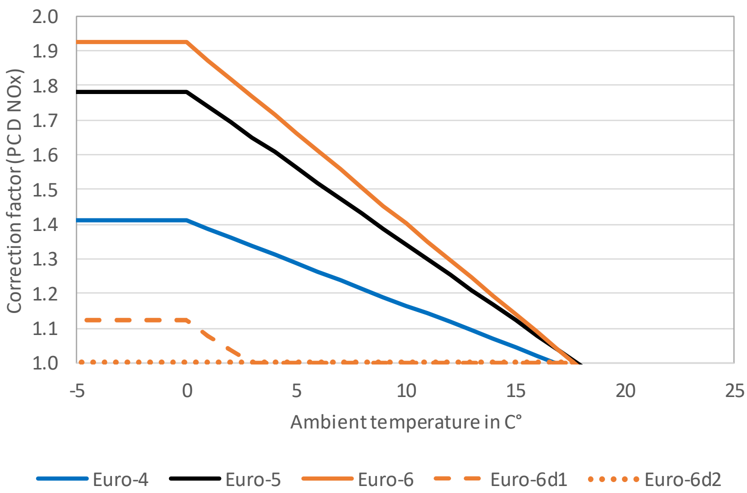


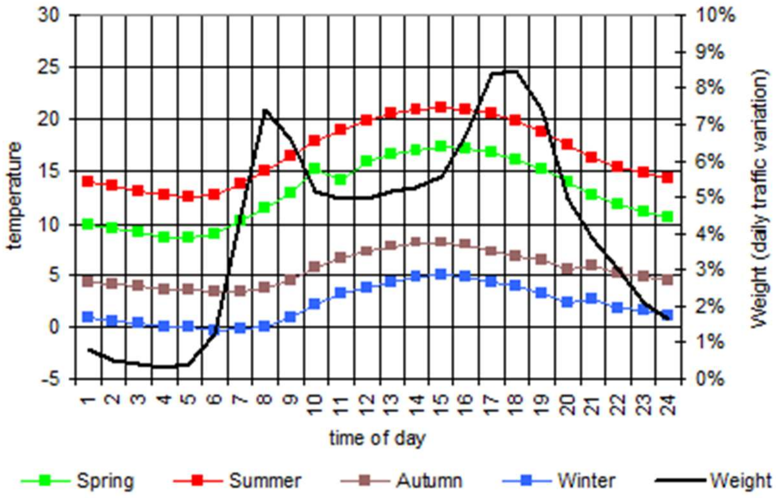
Figure 8: Correction functions for ambient temperature <20°C for hot NOx emission factors of diesel cars in HBEFA version 3.3



3.3. Ambient temperatures and their impact

Taking into account the ambient temperature as influencing factor is new for the hot emissions – but not new for the cold start and evaporation emissions. Therefore, HBEFA contains already country-specific distributions of ambient temperatures. For example, for Germany HBEFA assumes temperatures as shown Figure 9 which shows temperature distributions for four typical seasonal days; the black line corresponds to an average daily traffic variation which is used as weighted factor. Based on these assumptions the weighted temperature distributions can be calculated, as illustrated as cumulative distributions in Figure 10. Weighting the temperatures with the correction factors of Figure 8 the average correction factors can be derived as shown in Figure 11 for all HBEFA countries. The corrections for the concepts Euro-6d1 and Euro-6d2 are minimal or zero assuming that the RDE regulations are effective also with respect to ambient temperature.

Figure 9: Temperature distributions for 4 typical seasonal days and a typical daily traffic variation: Example Germany



The black line (daily traffic variation) is used for weighting the frequencies of the different temperatures.

Figure 10: Cumulative temperature distributions as assumed in HBEFA for the different countries

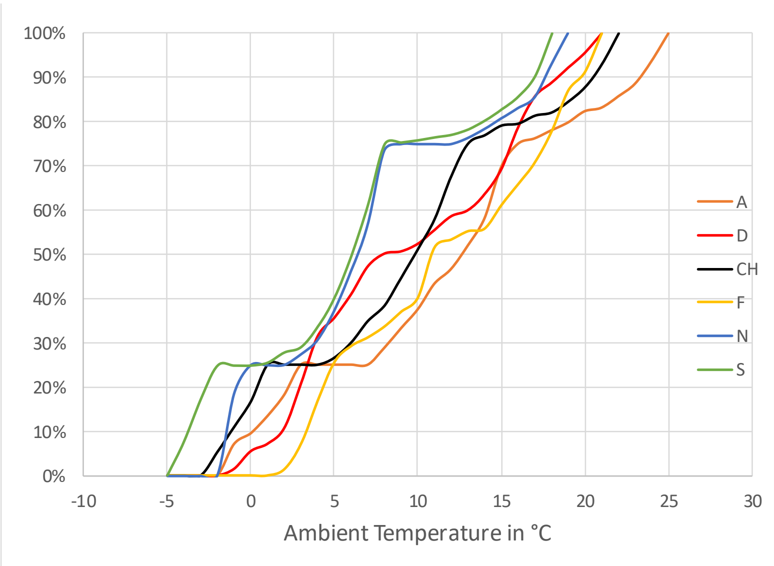
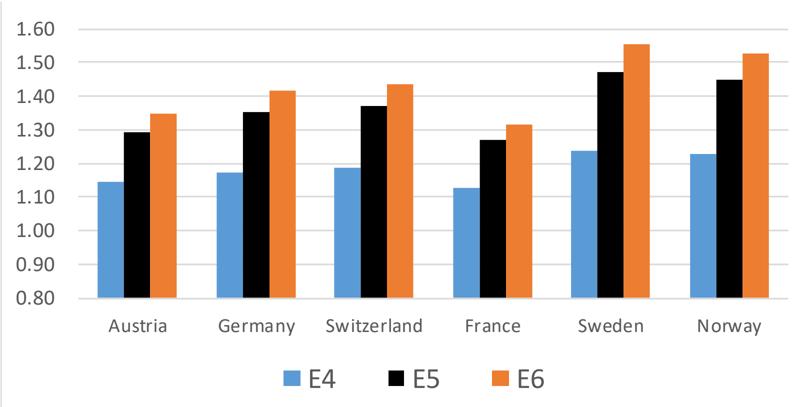


Figure 11: Average ambient temperature correction factors for NOx of diesel cars in the different countries

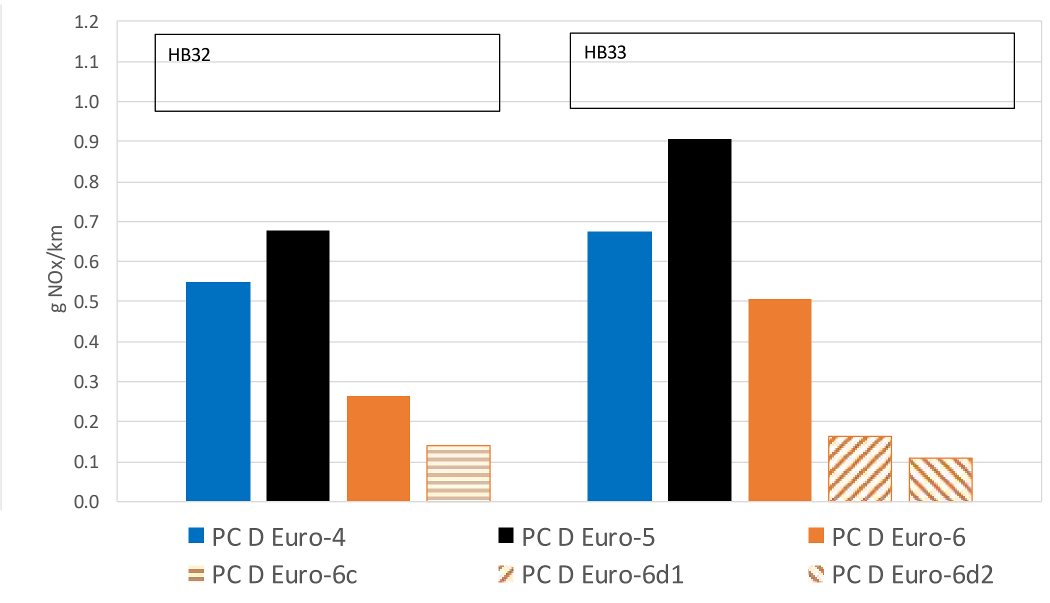


4. Results

4.1. The new emission factors and comparison with HBEFA 3.2

Figure 12 displays the new average NOx emission factors for diesel cars of the different concepts and compares them with the previous values of HBEFA version 3.2. All values refer to average driving over all road categories (weighting for Germany). Since HBEFA 3.3 includes a slight deterioration over mileage the values are shown for vehicle with a cumulative mileage of 50’000 km. As the figures indicate the new values result in an increase by 24% for Euro-4, by 34% for Euro-5 and by 92% for Euro-6. The newer concepts corresponding to the future RDE regulation Euro-6d1 and 6d2 are assumed to remain at a similar levels as already expected in HBEFA 3.2, i.e. close to the limit values (including RDE conformity factors). Figure 13 gives more differentiated values by road categories and shows also the impact of the new corrections for ambient temperature for the different concepts.

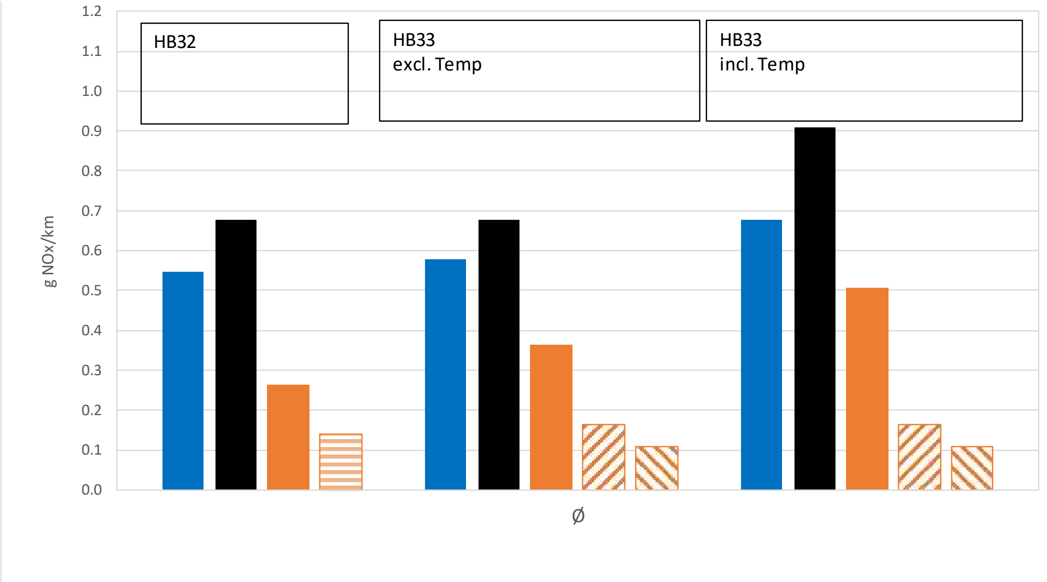
Figure 12: NOx emission factors of the diesel cars Euro-4/-5/-6 – in HBEFA 3.2 and HBEFA 3.3



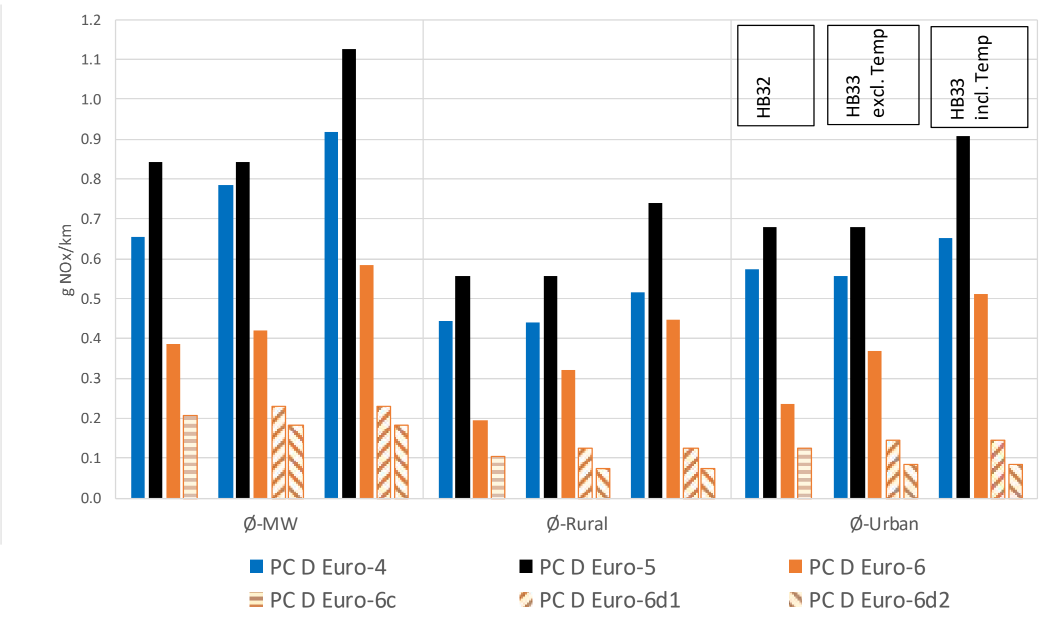
Details are given in Annex B.

Figure 13: NOx emission factors of the diesel cars Euro-4/-5/-6: in HBEFA 3.2 vs. HBEFA 3.3 excluding resp. including the effect of ambient temperate

- Ø all road categories:



- differentiated by three driving patterns (Øurban, Ørural, Ømotorway)

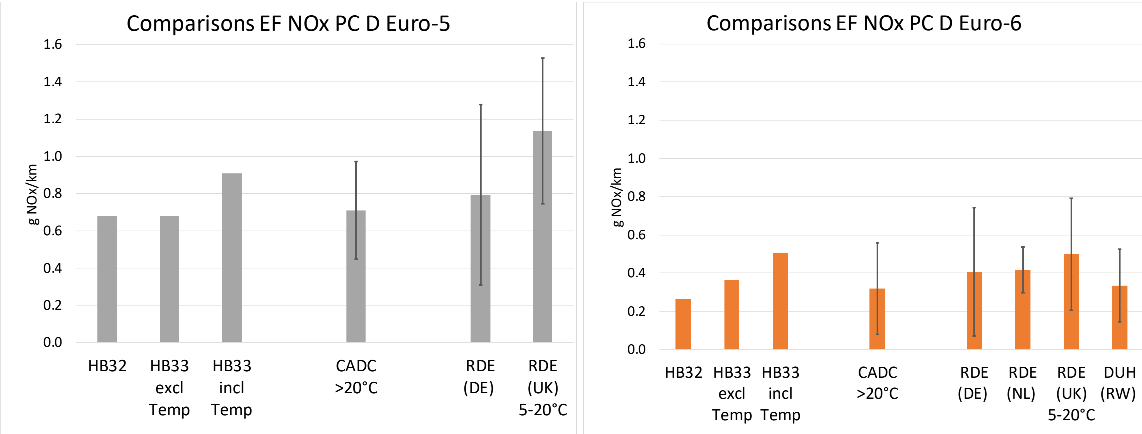


Details are given in Annex B.

4.2. Comparison with on-road measurements

As a validation the old and new emission factors can be compared to on road measurements (RDE-values which are taken from different sources: BMVI/KBA 2016, DfT 2016, DUH/EKI 2016). Some of the data did not disclose the ambient temperature when the measurements were taken; some tests were driven during the summer months hence do not necessarily capture the representative temperature distribution. The variation of the measurement results between vehicles within the same campaigns is remarkably high, leaving a considerably uncertainty range. Overall one can conclude that the new emission factors fit better to the real world measurements than the previous ones.

Figure 14: Comparison of HBEFA emission factors (diesel cars, Euro-5 and Euro-6) with real world measurements



Average values +/- standard deviations (per measurement campaign).

4.3. Impact on the emission factor development 2000-2030 (Germany)

Finally, the following two figures show the fleet weighted emission factors for the years 2000 up to 2030 in Germany once for the diesel car fleet (Figure 15) and once for the overall car fleet (Figure 16). The figures show the average values for all road categories. The overall emission factor in 2015 is 25% higher than assumed in the previous version, the difference raises up to 47% in 2020 and then continuously drops down again so that the values in 2030 are almost at the same level as expected in version 3.2. The emission factors for urban roads are very similar to the overall averages. Yearly figures can be found in Annex B.

Figure 15: Weighted NOx emission factors for the German diesel car fleet in HBEFA 3.3 vs. 3.2

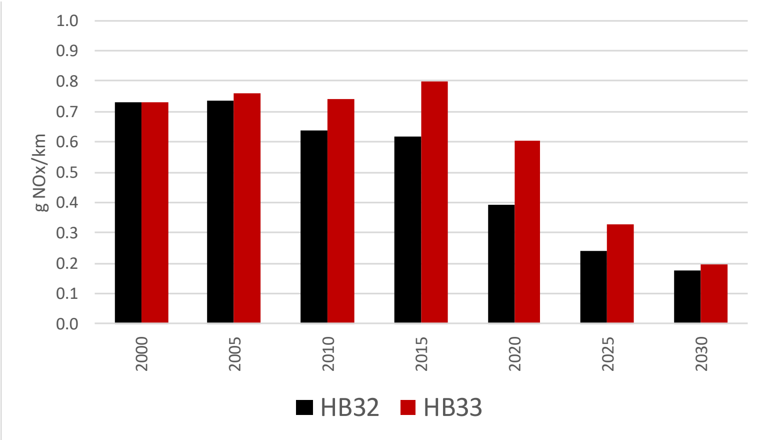
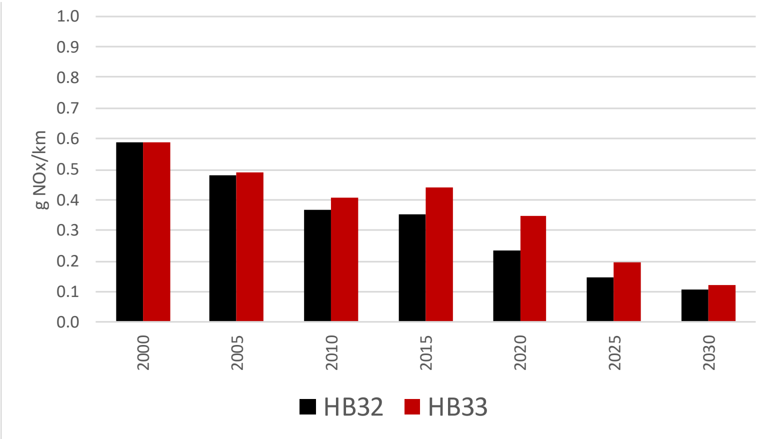


Figure 16: Weighted NOx emission factors for the German total car fleet in HBEFA 3.3 vs. 3.2



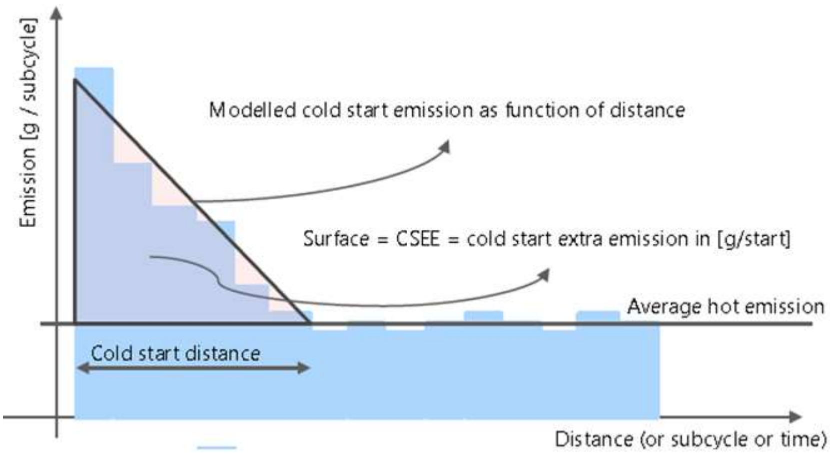
Yearly figures can be found in Annex B.

5. Additional Comments

5.1. A note on cold start excess emissions

HBEFA provides cold start emissions as cold start *excess* emissions in g/start, i.e. in relation to hot emissions. Figure 17 shows the principle. In general, engines starting at ambient temperatures of 20°C to 25°C (as it is usually the case during lab testing) emit higher emissions than fully warmed up engines since engine resp. catalyst temperature influences the effectiveness of the engine's operation.

Figure 17: Cold start emissions are modelled in HBEFA as 'excess' emissions in g/start, i.e. in addition to the 'hot' emission factors.



NOx emissions however are generated by high peak temperatures and pressures during the engine's combustion process. An engine which has started with a 'cold' engine might therefore be expected to generate less NOx emissions than a fully warm resp. hot engine (the terms 'hot' and 'cold' refer here to the engine's temperature and not to the ambient temperature). Therefore – as HBEFA users may have noticed – the NOx cold start emission factors of diesel cars in general are negative – which is not an error in the program! The values decrease from Euro-3 (-0.2 g/start) to Euro-5 (-1.3 g/start) and then go back again to -0.5 g/start for Euro-6 cars. At very cold ambient temperatures however, the amount of NOx may be higher at starting the engine than when the engine is fully warm, hence the cold start excess emissions become positive. These trends as well as the absolute values assumed in the previous HBEFA version are confirmed by the new measurements to a large extent. Hence we did not see the necessity to change those values.

One should also note that the relevance of cold start excess emissions of NOx e.g. compared to other pollutants is much smaller.

5.2. Updates of national data

The "quick update" was taken as occasion to update some national input data which turned out to be erroneous or not up-to-date. This was particular the case for France where the following elements were adjusted:

- **Fuel consumption of cars and light commercial vehicles**: HBEFA 3.2 did not assume any improvement of the efficiency. In HBEFA 3.3. this has been adjusted now taking into account trends as captured by the CO2-monitoring of new registrations. In parallel, the fleet compositions were updated. The resulting emission factors (EF) are representative for the fleet WITHOUT taking into account e-mobility. Therefore, the EF refer to the fleet with internal combustion engines which is considered as 100%. Expected shares of e-mobility should be considered separately[7]. This comment is equally valid for all countries.
- **Traffic situations**: A new set of 'aggregate traffic situations' was defined for France, i.e. weighted aggregates of individual traffic situations.

[7] The next version of HBEFA (planned to be published in 2018) will take electric vehicles into account.

Annex

Annex A: Common driving cycles used in the context of the HBEFA development

Cycle	Type	Subcycle	Comment	Duration		Distance	Ø Speed	Start cond.
	L: legislative RW: RealWorld			t (sec)	t (min)	dist (km)	v (km/h)	(default)
NEDC	L	ECE		781	13	4.058	18.7	cold
		EUDC		401	7	6.955	62.4	hot
		NEDC		1'181	20	11.013	33.6	cold
FTP	L	FTP1		506	8	5.779	41.1	cold
		FTP2		871	15	6.211	25.7	hot
		FTP3		506	8	5.779	41.1	hot
		FTP (total)		1'376	23	17.769	31.4	cold
WLTC	L	WLTC Low		589	10	3.095	18.9	cold
		WLTC Medium		433	7	4.756	39.5	hot
		WLTC High		455	8	7.158	56.6	hot
		WLTC Extra high		323	5	8.254	92.0	hot
		WLTC (total)		1'800	30	23.263	46.5	cold
CADC	RW	CADC urban		922	15	4.472	17.5	hot
		CADC rural		863	14	14.724	61.4	hot
		CADC MW130	v max 130 km/h	737	12	23.822	116.4	hot
		CADC MW150	v max 150 km/h	737	12	24.632	120.3	hot
		CADC URM130 (total)		3'144	52	50.878	58.3	hot
		CADC URM150 (total)		3'144	52	51.687	59.2	hot
ERMES	RW	ERMES urban		418	7	3.674	32.6	hot
		ERMES rural		305	5	6.764	79.3	hot
		ERMES MW		384	6	11.530	107.8	hot
		ERMES (total)		1'107	18	21.969	72.0	hot
IUFC	RW	IUFC_I	Inrets urbain fluide court	945	16	4.997	18.9	cold
		IUFC_II		945	16	4.997	18.9	intermediate
		IUFC_III		945	16	4.997	18.9	hot
		IUFC (total)		2'835	47	14.991	18.9	cold
BAB	RW	-	Bundesautobahn (DE)	1'001	17	32.646	117.4	hot

Annex B: NOx-emission factors of diesel cars in HBEFA 3.3 vs. 3.2

NOx emission factors of diesel cars Euro-4,-5,-6 in HBEFA 3.3 vs. 3.2 for Germany

	Subsegment	Ø-MW	Ø-Rural	Ø-Urban	Ø
	PC D Euro-4 (HB32)	0.654	0.445	0.573	0.546
	PC D Euro-5 (HB32)	0.843	0.555	0.679	0.679
	PC D Euro-6 (HB32)	0.385	0.196	0.235	0.264
	PC D Euro-6c (HB32)	0.206	0.105	0.125	0.141
Temp:					
T+20°C	PC D Euro-4 (HB33) excl. Temp correction	0.784	0.440	0.556	0.577
T+20°C	PC D Euro-5 (HB33) excl. Temp correction	0.842	0.554	0.677	0.677
T+20°C	PC D Euro-6 (HB33) excl. Temp correction	0.418	0.319	0.366	0.363
T+20°C	PC D Euro-6d1 (HB33) excl. Temp correction	0.230	0.124	0.144	0.162
T+20°C	PC D Euro-6d2 (HB33) excl. Temp correction	0.182	0.073	0.082	0.108
Temp:					
ØGermany	PC D Euro-4 (HB33) incl. Temp correction	0.916	0.513	0.649	0.674
ØGermany	PC D Euro-5 (HB33) incl. Temp correction	1.127	0.741	0.905	0.906
ØGermany	PC D Euro-6 (HB33) incl. Temp correction	0.584	0.445	0.511	0.507
ØGermany	PC D Euro-6d1 (HB33) incl. Temp correction	0.232	0.125	0.146	0.163
ØGermany	PC D Euro-6d2 (HB33) incl. Temp correction	0.182	0.073	0.082	0.108

Aggregate NOx emission factors 2000-2030 for Germany acc. to HBEFA 3.3 vs. 3.2

	HBEFA 3.2: Average EF NOx (g NOx/km)				HBEFA 3.3: Average EF NOx (g NOx/km)			
Fleet:	PC total	diesel cars	PC total	diesel cars	PC total	diesel cars	PC total	diesel cars
Traffic Sit.:	Ø	Ø	Ø-Urban	Ø-Urban	Ø	Ø	Ø-Urban	Ø-Urban
2000	0.59	0.73	0.50	0.68	0.59	0.73	0.50	0.68
2001	0.58	0.75	0.50	0.69	0.58	0.75	0.50	0.69
2002	0.55	0.75	0.48	0.70	0.55	0.76	0.48	0.70
2003	0.52	0.76	0.47	0.70	0.52	0.76	0.47	0.71
2004	0.50	0.75	0.46	0.70	0.51	0.76	0.46	0.71
2005	0.48	0.73	0.44	0.69	0.49	0.76	0.45	0.71
2006	0.46	0.71	0.43	0.67	0.47	0.75	0.44	0.70
2007	0.43	0.68	0.41	0.66	0.45	0.74	0.42	0.69
2008	0.40	0.66	0.38	0.64	0.42	0.73	0.40	0.69
2009	0.38	0.65	0.37	0.63	0.41	0.73	0.39	0.69
2010	0.37	0.64	0.36	0.63	0.41	0.74	0.39	0.70
2011	0.36	0.64	0.36	0.64	0.42	0.76	0.40	0.73
2012	0.36	0.65	0.36	0.64	0.43	0.79	0.41	0.76
2013	0.37	0.65	0.36	0.65	0.44	0.80	0.42	0.78
2014	0.36	0.64	0.36	0.64	0.45	0.81	0.43	0.79
2015	0.35	0.62	0.35	0.61	0.44	0.80	0.43	0.78
2016	0.33	0.58	0.33	0.57	0.43	0.77	0.42	0.76
2017	0.31	0.53	0.30	0.52	0.41	0.73	0.40	0.72
2018	0.28	0.48	0.28	0.48	0.40	0.70	0.39	0.70
2019	0.26	0.44	0.25	0.43	0.38	0.66	0.37	0.66
2020	0.24	0.39	0.23	0.39	0.35	0.60	0.34	0.60
2021	0.21	0.35	0.21	0.35	0.31	0.54	0.31	0.53
2022	0.19	0.32	0.19	0.31	0.28	0.47	0.27	0.47
2023	0.18	0.29	0.17	0.28	0.24	0.41	0.24	0.41
2024	0.16	0.26	0.16	0.25	0.22	0.37	0.22	0.36
2025	0.15	0.24	0.14	0.23	0.19	0.33	0.19	0.32
2026	0.14	0.22	0.13	0.21	0.17	0.29	0.17	0.28
2027	0.13	0.21	0.12	0.20	0.16	0.26	0.15	0.25
2028	0.12	0.19	0.11	0.18	0.14	0.23	0.14	0.22
2029	0.11	0.18	0.11	0.17	0.13	0.21	0.12	0.20
2030	0.11	0.18	0.10	0.16	0.12	0.20	0.11	0.18

Abbreviations

ADAC:	Allgemeiner Deutscher Automobil-Club (Germany)
ARTEMIS:	Assessment and Reliability of Transport Emission Models and Inventory Systems (EU project, 4th Framework program)
AWEL:	Amt für Abfall, Wasser, Energie und Luft (Zurich)
BAB:	German motorway driving cycle (Bundesautobahn)
BAFU:	Swiss Federal Office for the Environment (FOEN), Bundesamt für Um welt
BMVI:	Bundesministerium für Verkehr und digitale Infrastruktur (Germany)
CADC:	Common ARTEMIS driving cycle
CH:	Switzerland
CO2:	Carbon dioxide
CTA:	Centre de Technologie Avancée (Wallonie)
D:	Diesel
DfT:	Department for Transport (UK)
DP:	Driving pattern
DPF:	Diesel Particle Filter
ECE:	Economic Commission for Europe
EFA, E-Factor:	Emissions factor
EGR:	Exhaust Gas recirculation
EMPA:	Federal Materials Testing and Research Institute, Dübendorf/Zurich
ERMES:	European Research for Mobile Emission Sources (Group)
EURO-1, -2, -3 etc:	European exhaust emissions regulations for passenger cars and light vehicles
EURO-I, -II, -III etc:	European exhaust emissions regulations for heavy vehicles
FRG:	Federal Republic of Germany
HB / HBEFA:	Handbook Emission Factors for Road Transport
HGV:	Heavy Goods Vehicles
IUFC:	Inrets Urbain Fluide Courte driving cycle
JRC:	Joint Research Center of the EU
KBA:	Kraftfahrt-Bundesamt (Germany)
LAT:	Laboratory of Applied Thermodynamics, Aristotle University of Thessaloniki
LCV:	Light commercial vehicle <3,5t (small buses, trucks, camper vans, other motor vehicles)

LDV:	Light duty vehicle, general term for passenger cars and light commercial vehicles
LNT:	Lean NOx trap
MEEM:	Ministère de l'Environnement, de l'Énergie et de la Mer (France)
NEDC:	New European Driving Cycle
NOx :	Nitrogen oxide
PC:	Passenger car
PEMS:	Portable Emission Measurement System
PHEM :	Passenger car and Heavy duty Emission Model (of the TU Graz)
RDE:	Real-Driving Emissions
RPA:	Relative positive acceleration
RS:	Remote Sensing
RWC:	Real world driving cycle
SCR:	Selective catalytic reduction (for NOx-reduction)
TA:	Type Approval
TNO:	Netherlands Organisation for applied scientific research
TRL:	Transport Research Laboratory (UK)
TS:	Traffic situation
TÜV (RL):	Technical inspection agencies (DE)
TUG:	Technical University, Graz
UBA:	Umweltbundesamt (Germany, Austria), Federal Environment Agency
v:	Speed, velocity (in km/h)
VDA:	Verband der Automobilindustrie e.V.
WLTC:	World-wide Harmonized Light duty Test Cycle

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