TEXTE
46/2026

HBEFA 5.1 – Correction factors, non-regulated pollutants and Euro 7

Elements for the development of the Handbook of Emission Factors for Road Transport (HBEFA), Version 5.1

by:

Konstantin Weller, Martin Opetnik, Stefan Hausberger
Graz University of Technology - Institute of Thermodynamics and Sustainable Propulsion Systems, Graz

Jens Borken-Kleefeld, Pinky Kumawat, Likhitha Potturu
Dresden University of Technology – Chair of Transportation Ecology, Dresden

Benedikt Notter
INFRAS, Bern

Christoph Heidt

Institute for Energy and Environmental Research (ifeu), Heidelberg

publisher:
German Environment Agency

Umwelt
Bundesamt

TEXTE 46/2026

Project No. 181031
FB002054/ENG

HBEFA 5.1 – Correction factors, non-regulated pollutants and Euro 7

Elements for the development of the Handbook of
Emission Factors for Road Transport (HBEFA), Version 5.1

by

Konstantin Weller, Martin Opetnik, Stefan Hausberger
Graz University of Technology - Institute of Thermodynamics
and Sustainable Propulsion Systems, Graz

Jens Borken-Kleefeld, Pinky Kumawat, Likhitha Potturu
Dresden University of Technology – Chair of Transportation
Ecology, Dresden

Benedikt Notter
INFRAS, Bern

Christoph Heidt
Institute for Energy and Environmental Research (ifeu),
Heidelberg

On behalf of the German Environment Agency

Imprint

Publisher
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
buergerservice@uba.de
Internet: www.umweltbundesamt.de

Report performed by:
Institut für Energie und Umweltforschung Heidelberg gGmbH
Wilckensstr. 3
69120 Heidelberg
Germany

Report completed in:
August 2025

Edited by:
Section I 2.2
Dr. Christiane Vitzthum von Eckstädt

DOI:
https://doi.org/10.60810/openumwelt-8340

ISSN 1862-4804

Dessau-Roßlau, April 2026

Abstract: HBEFA 5.1 – Correction factors, non-regulated pollutants and Euro 7

This report describes the work done for three of the main work packages for the Handbook of Emission Factors for Road Transport (HBEFA) version 5.1.

The first part explains the deterioration functions related to increasing vehicle mileage for passenger cars, light-duty and heavy-duty vehicles. The add-on emissions due to deterioration can reach significant levels until end of vehicle life. They can be even higher than the emission limits themselves in some specific cases.

The next section illustrates the elaboration of the Euro 7 emission models. Since Euro 7 vehicles are not yet on the road, the emission models are derived from the latest Euro 6/VI models in order to meet the Euro 7 development targets defined by TU Graz (50 % of the limit) in worst-case test situations. The emission reductions from Euro 6/VI to Euro 7 can be up to 90 percent, but for some components also an emission increase is possible.

The last part describes the integration of additional relevant non-regulated pollutants into HBEFA, which are Formaldehyde, Acetaldehyd, Isocyanic acid and Nitrous acid. For Euro 6/VI vehicles test data were available and could be used for setting up emission maps. For the emission factors for former emission standards correction factors were derived based on test data and literature research.

Kurzbeschreibung: HBEFA 5.1 - Alterungsfunktionen, nicht regulierte Schadstoffe und Euro 7

Dieser Bericht beschreibt die Arbeiten, die für drei der wichtigsten Arbeitspakete für das Handbuch der Emissionsfaktoren für den Straßenverkehr (HBEFA) Version 5.1 durchgeführt wurden.

Der erste Teil erläutert die Alterungsfunktionen im Zusammenhang mit steigenden Fahrleistungen für Personenkraftwagen, leichte Nutzfahrzeuge und schwere Nutzfahrzeuge. Die zusätzlichen Emissionen aufgrund von Alterung können bis zum Ende der Lebensdauer eines Fahrzeugs ein erhebliches Ausmaß erreichen. In bestimmten Fällen können sie sogar höher sein als die Emissionsgrenzwerte selbst.

Der nächste Abschnitt veranschaulicht die Ausarbeitung der Euro 7 Emissionsmodelle. Da Euro 7 Fahrzeuge noch nicht auf den Straßen unterwegs sind, wurden die Emissionsmodelle aus den neuesten Euro-6/VI-Emissionsmodellen abgeleitet. Dazu wurde die Euro-6/VI-Modelle modifiziert, um die von der TU Graz definierten Euro-7-Entwicklungsziele (50 % des Grenzwerts) in Worst-Case-Testsituationen zu erreichen. Die Emissionsreduktion von Euro 6/VI zu Euro 7 kann bis zu 90 Prozent betragen, bei manchen Komponenten können sich die Emissionen aber auch erhöhen.

Der letzte Teil beschreibt die Integration zusätzlicher relevanter, nicht regulierter Schadstoffe in HBEFA, nämlich Formaldehyd, Acetaldehyd, Isocyansäure und Salpetersäure. Für Euro 6/VI-Fahrzeuge lagen Testdaten vor, die für die Erstellung von Emissionskennfeldern verwendet werden konnten. Die Emissionsfaktoren für frühere Emissionsnormen wurden auf der Grundlage von Testdaten und Literaturrecherchen abgeleitet.

Table of content

List of figures

List of tables

List of abbreviations

Abbreviation	Explanation
A	Cross sectional area
AT	Articulated truck
Cd	Drag coefficient
CF	Correction factor
CH_3CHO	Acetaldehyde
CI	Compression ignition
CO	Carbon monoxide
CO_2	Carbon dioxide
d	Correction parameter 2
DBEFA	Database for HBEFA
DF	Dilution Factor
EF	Emission Factor
EGR	Exhaust Gas Recirculation
Ermes	European Research Group on Mobile Emission Sources
FR0	Rolling resistance coefficient
FTIR	Fourier Transformed Infrared Spectroscopy
HBEFA	Handbook on Emission Factors
HNCO	Isocyanic acid
IUFC	Inrets Urbain Fluide Courte
g	Gramm
GUI	Graphical User Interface
GVW	Gross vehicle weight
h	Hour
HC	Hydrocarbons
HCHO	Formaldehyde
HDV	Heavy-Duty Vehicle
HGV	Heavy Goods Vehicle
HNO_2	Nitrous acid
ISC	In-service conformity
k	Correction parameter 1
km	Kilometre

Abbreviation	Explanation
kWh	Kilo Watt Hour
LDV	Light-Duty Vehicle
m	Mileage
MAW	Moving Average Window
MIL	Motor Investigation Light
n.a.	Not available (means usually, that the exhaust component is not available for a specific vehicle layer)
NH_3	Ammonia
NMOG	Non-Methane Organic Gas
N_2O	Nitrous oxide (laughing gas)
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
NEDC	New European Driving Cycle
OEM	Original equipment manufacturer (here vehicle manufacturer)
OBD	On-Board Diagnosis
PC	Passenger Car
PEMS	Portable Emission Measurement System
PHEM	Passenger Car and Heavy-Duty Emission Model
RDE	Real Driving Emissions
SCR	Selective Catalytic Reduction
SI	Spark ignition
TT	Tractor trailer
v	Vehicle speed
VSP	Vehicle Specific Power
We+	Positive engine work
WHSC	World Harmonized Stationary Cycle
WHTC	World Harmonized Transient Cycle
WHVC	World Harmonized Vehicle Cycle
WLTC	Worldwide Harmonized Light-Duty Vehicles Test Cycle
WLTP	Worldwide Harmonized Light-Duty Vehicles Test Procedure

Summary

This report describes the work done for three of the main work packages for the Handbook of Emission Factors for Road Transport (HBEFA) version 5.1, which are the correction functions for deterioration and ambient temperatures, the Euro 7 emission models and the integration of non-regulated pollutants into HBEFA.

Work package correction Factors for the Deterioration of Exhaust Gas Aftertreatment Systems and Temperature Effects

This chapter summarises the development and results of the correction factors for deterioration of exhaust aftertreatment systems and temperature effects in passenger cars (PC), light-duty (LDV) and heavy-duty vehicles (HDV).

Vehicle emissions increase over lifetime due to the ageing of components such as catalysts, sensors, and EGR systems. Thermal and chemical deterioration mainly raises emissions of CO, HC, and NO_X, while reducing NO_2 and NH_3. Additionally, ambient temperature affects EGR and SCR operation: at low or high temperatures, EGR and reagent dosing are reduced to protect the engine, which increases NO_X. These effects are captured in HBEFA by deterioration and temperature correction functions.

Deterioration Functions – PC and LDV

For HBEFA 5.1, deterioration factors were updated using two data sources:

- Pan-European CARES Remote Sensing data (950,000 records, 2017–2023),
- Vehicle pair testing (low vs. high mileage).

The RS data were carefully filtered and stratified by temperature and vehicle specific power to isolate mileage effects. For Euro 6abc diesel cars, NO_X deterioration follows a linear trend, increasing with load, while gasoline cars show no significant deterioration.

For Euro 6ab, a comprehensive RS dataset (120,000 vehicles, up to 160,000 km) enabled improved NO_X factors. CO and HC were taken from previous models due to measurement limitations. For Euro 6d-TEMP and 6d, targeted chassis-dyno and PEMS tests on vehicle pairs (7 diesel, 6 gasoline) provided reliable deterioration trends, showing no difference between PC and LDV behaviour. Euro 7 factors were estimated, and earlier Euro classes mainly adopt HBEFA 4.1 values.

Deterioration is now calculated additively instead of multiplicatively due to the very low base emissions of modern vehicles:

$EF(x\ km) = EF(50{,}000\ km) + DF(mileage)$

Deterioration Functions – HDV

Modern Euro VI and Euro 7 heavy-duty vehicle catalyst systems achieve conversion efficiencies above 99% under optimal conditions, but chemical, thermal and mechanical ageing reduce performance over time. For HBEFA 5.1, the database was significantly expanded with additional chassis-dyno and PEMS data, including Euro VI D vehicles with mileages above one million kilometres and FTIR data for NO_X, NH_3, N_2O, CO, HC, CH_4 and formaldehyde.

The analyses show higher deterioration for rigid trucks than for long-haul trucks, due to more frequent cold starts and regeneration events.

The additive approach replaces the former multiplicative method to better reflect low base emission levels also for HDVs.

Remote sensing data confirmed the plausibility of the derived functions.

Work package Temperature Correction Functions

Temperature corrections, first introduced in HBEFA 4.1, were re-evaluated with pan-European RS data. For Euro 5 and 6abc diesel cars, NO_X emissions rise by 80–100 % as ambient temperature drops from 20 °C to 0 °C, particularly under low-medium load. Euro 6d-TEMP and newer cars maintain stable NO_X across 0–30 °C, confirming the effectiveness of RDE-compliant designs.

Existing linearised correction functions remain valid for HBEFA 5.1.

Implementation and Validation

All factors were validated in the HBEFA application by comparing emission outputs with and without corrections, confirming their plausibility and consistency with empirical data.

Emission Factors for Euro 7 Vehicles

The Euro 7 regulation will be introduced in 2026/2027 for passenger cars and light-duty vehicles, and in 2028/2029 for heavy-duty vehicles. As no Euro 7 vehicles are currently on the road, test data are unavailable. The Euro 7 fleet is therefore represented in HBEFA using the PHEM simulation model, based on extrapolations from Euro 6/VI vehicles and the new Euro 7 emission limits.

PC and LDVs

For passenger cars, Euro 7 vehicle properties were derived from Euro 6d-TEMP and Euro 6d statistics. Engine power, empty weight, and rated speed were extrapolated, while driving resistance parameters were adjusted based on WLTC data and real-world corrections (rolling resistance, crosswind, ambient temperature, roof/trailer usage). Transmission ratios, auxiliary power demand, and start-stop shares were adopted from the HBEFA 4.2 Euro 7 model.

Euro 7 CO_2 emissions were estimated with a 2% improvement over Euro 6d maps. Pollutant emissions were derived using Euro 6d emission maps, cold start effects, and deterioration functions. The WLTC development target was set 25% below the Euro 6d limit, while RDE targets were 40% below the not-to-exceed limits. Reduction measures for NO_X, CO, HC, and particle number were applied differently for hot and cold start conditions. For diesel, NO_X reductions were evenly split between warm and cold starts; for petrol, approximately 70% of reductions were in hot operation and 30% in cold start.

HDVs

For heavy-duty vehicles, Euro 7 uses the same WHSC and WHTC cycles as Euro VI, with operational conformity verified through ISC tests up to 300,000 km for vehicles under 16 t and 700,000 km for heavier vehicles. Euro 7 limits reduce NO_X by up to 62%, CO by 70%, and introduce limits for N2O and PN10.

The emission factors show a reduction of real-world emissions by 50–90% for NO_X, by up to 70% for NH_3 and 30% for N_2O, while CO increases moderately but remains below limit values. PN_{10}, NMHC/NMOG, and CH_4 remain largely unchanged.

Vehicle-level improvements include reduced empty weight, air resistance, rolling resistance, and increased engine and auxiliary efficiency, reducing fuel consumption by about 10% for a standard tractor-trailer combination.

The PHEM model is also applied to buses, producing similar reduction rates.

Integration

Integration in HBEFA involved defining 147 new subsegments, importing PHEM Euro 7 emission factors, and checking plausibility against older subsegments. Euro 7 generally shows improved emissions compared to Euro 6/VI.

Work package Integration of Non-regulated Pollutants

Recent analyses of non-regulated exhaust gas components from passenger cars and heavy-duty vehicles identified four substances of environmental and health relevance for inclusion in HBEFA 5.1 in addition to the already included ones: Formaldehyde, Acetaldehyde, Isocyanic acid and Nitrous acid. These compounds were measurable with FTIR analysers and are now integrated into the HBEFA pollutant set.

Emission Factors for Euro 6/VI Vehicles

Because FTIR measurements exist mainly for recent campaigns, emission data were available only for Euro 6/VI vehicles. These data were processed using the PHEM model following the standard HBEFA procedure: real-world measurements in 1 Hz resolution were converted into engine emission maps per vehicle, aggregated to category averages using EU sales-weighted data, and simulated across all HBEFA driving situations to derive distance-specific emission factors (g/km).

Emission Factors for Older Vehicles

For pre-Euro 6 vehicles, emission factors were estimated using “Euro-standard-correction factors,” derived from limited Euro 4 and 5 tests and literature. Although based on small and partly uncertain datasets, this approach ensures completeness of the pollutant database across all Euro classes, enabling fleet-average calculations. The correction factors scale the Euro 6d-TEMP or Euro VI D reference values according to technology and fuel type. While uncertainty increases for earlier vehicle generations, the method is considered robust for contemporary and future fleet modelling.

Integration and Plausibility Checks

The new pollutant emission factors were implemented in HBEFA analogously to existing components. For Euro 6/VI, PHEM-derived data were integrated at subsegment, cycle, and load level. For older vehicles, the correction factors were applied directly.

The integrated datasets were verified by querying and visualizing results in HBEFA for various vehicle types. Results show plausible trends: HNCO and HNO_2 emissions are negligible for petrol vehicles, while diesel engines emit measurable values. Representative examples for petrol cars, diesel cars, and 40-tonne truck-trailer combinations confirm consistent implementation and realistic magnitude of emission factors.

Zusammenfassung

Dieser Bericht beschreibt die Arbeiten, die für drei der wichtigsten Arbeitspakete für das Handbuch der Emissionsfaktoren für den Straßenverkehr (HBEFA) Version 5.1 durchgeführt wurden. Dabei handelt es sich um die Korrekturfunktionen für Alterung und Umgebungstemperaturen, die Euro 7 Emissionsmodelle und die Integration nicht regulierter Schadstoffe in das HBEFA.

Arbeitspaket Korrekturfaktoren für die Verschlechterung von Abgasnachbehandlungssystemen und Temperatureinflüsse

Dieses Kapitel fasst die Entwicklung und die Ergebnisse der Korrekturfaktoren für die Alterung von Abgasnachbehandlungssystemen und Temperatureinflüsse in Personenkraftwagen (PC), leichten Nutzfahrzeugen (LDV) und schweren Nutzfahrzeugen (HDV) zusammen.

Die Fahrzeugemissionen steigen im Laufe der Lebensdauer aufgrund der Alterung von Komponenten wie Katalysatoren, Sensoren und AGR-Systemen. Die thermische und chemische Verschlechterung erhöht hauptsächlich die Emissionen von CO, HC und NO_X, während NO_2 und NH_3 reduziert werden. Darüber hinaus beeinflusst die Umgebungstemperatur den Betrieb von EGR und SCR: Bei niedrigen oder hohen Temperaturen werden EGR und Reagenzdosierung zum Schutz des Motors reduziert, was zu einem Anstieg von NO_X führt. Diese Effekte werden in HBEFA durch Alterungs- und Temperaturkorrekturfunktionen erfasst.

Alterungsfunktionen – PC und LDV

Für HBEFA 5.1 wurden die Alterungsfaktoren anhand von zwei Datenquellen aktualisiert:

- paneuropäische CARES Remote Sensing Daten (950.000 Datensätze, 2017–2023),
- Fahrzeugpaar-Tests (niedrige vs. hohe Laufleistung)

Die RS-Daten wurden sorgfältig gefiltert und nach Temperatur und fahrzeugspezifischer Leistung geschichtet, um die Auswirkungen der Kilometerleistung zu isolieren. Bei Euro 6abc-Dieselfahrzeugen folgt die NO_X-Alterung einem linearen Trend und nimmt mit der Last zu, während Benzinfahrzeuge keine signifikante Verschlechterung aufweisen.

Für Euro 6ab ermöglichte ein umfassender RS-Datensatz (120.000 Fahrzeuge, bis zu 160.000 km) ein Update der NO_X-Faktoren. CO und HC wurden aufgrund von Messbeschränkungen aus früheren Modellen übernommen. Für Euro 6d-TEMP und 6d lieferten gezielte Rollenprüfstands- und PEMS-Tests an Fahrzeugpaaren (7 Diesel, 6 Benziner) zuverlässige Alterungstrends, die keinen Unterschied zwischen PC- und LDV-Verhalten zeigten. Die Euro 7 Faktoren wurden von Euro 6d abgeleitet, und frühere Euro-Klassen übernehmen hauptsächlich HBEFA-4.1-Werte.

Die Alterung wird nun aufgrund der sehr geringen Basisemissionsniveaus von modernen Fahrzeugen additiv statt multiplikativ berechnet:

EF(x km) = EF(50.000 km) + DF(Kilometerstand)

Alterungsfunktionen – HDV

Moderne Euro VI- und Euro 7-Katalysatorsysteme für Schwere Nutzfahrzeuge erreichen unter optimalen Bedingungen Konvertierungen von über 99 %, aber chemische, thermische und mechanische Alterung verringern die Leistung im Laufe der Zeit. Für HBEFA 5.1 wurde die Datenbank erheblich erweitert, unter anderem um zusätzliche Rollenprüfstands- und PEMS-Daten, darunter Euro VI D-Fahrzeuge mit einer Laufleistung von über einer Million Kilometern und FTIR-Daten für NO_X, NH_3, N_2O, CO, HC, CH_4 und Formaldehyd.

Die Analysen zeigen bei Verteiler-Lkws eine höhere Alterung als bei Fernverkehrsfahrzeugen, was auf häufigere Kaltstarts und Regenerationsvorgänge zurückzuführen ist.

Der additive Ansatz ersetzt die bisherige multiplikative Methode, um auch für schwere Nutzfahrzeuge den niedrigen Basisemissionswerte gerecht zu werden.

RS-Daten bestätigten die Plausibilität der abgeleiteten Funktionen.

Temperaturkorrekturfunktionen

Die erstmals in HBEFA 4.1 eingeführten Temperaturkorrekturen wurden mit paneuropäischen RS-Daten neu bewertet. Bei Euro 5- und 6abc-Dieselfahrzeugen steigen die NO_X-Emissionen um 80–100 %, wenn die Umgebungstemperatur von 20 °C auf 0 °C sinkt, insbesondere bei niedriger bis mittlerer Last. Euro 6d-TEMP- und neuere Fahrzeuge weisen über einen Temperaturbereich von 0–30 °C stabile NO_X-Werte auf, was die Wirksamkeit der RDE-konformen Auslegungen bestätigt.

Die bestehenden linearisierten Korrekturfunktionen bleiben für HBEFA 5.1 gültig.

Implementierung und Validierung

Alle Faktoren wurden in der HBEFA-Anwendung durch einen Vergleich der Emissionswerte mit und ohne Korrekturen validiert, wodurch ihre Plausibilität und Übereinstimmung mit empirischen Daten bestätigt wurde.

Emissionsfaktoren für Euro 7 Fahrzeuge

Die Euro 7 Verordnung wird 2026/2027 für Personenkraftwagen und leichte Nutzfahrzeuge und 2028/2029 für schwere Nutzfahrzeuge eingeführt. Da derzeit noch keine Euro 7 Fahrzeuge auf den Straßen unterwegs sind, liegen keine Testdaten vor. Die Euro 7 Flotte wird daher in HBEFA unter Verwendung des PHEM-Simulationsmodells dargestellt, das auf Extrapolationen von Euro-6/VI-Fahrzeugen in Kombination mit den neuen Euro 7 Emissionsgrenzwerten basiert.

PKW und LDV

Für Personenkraftwagen wurden die Eigenschaften von Euro 7 Fahrzeugen aus Euro-6d-TEMP- und Euro-6d-Statistiken abgeleitet. Motorleistung, Leergewicht und Nenndrehzahl wurden extrapoliert, während die Fahrwiderstandsparameter auf der Grundlage von WLTC-Daten und Korrekturen für reale Bedingungen (Rollwiderstand, Seitenwind, Umgebungstemperatur, Dach-/Anhängernutzung) angepasst wurden. Die Übersetzungsverhältnisse, der Hilfsenergiebedarf und die Start-Stopp-Anteile wurden aus HBEFA 4.2 Euro 7 Modell übernommen.

Die CO_2-Emissionen nach Euro 7 wurden mit einer Verbesserung von 2 % gegenüber den Euro 6d-Karten geschätzt. Die Schadstoffemissionen wurden anhand der Euro 6d-Emissionskennfeldern, der Kaltstarteffekte und der Alterungsfunktionen abgeleitet. Das WLTC-Entwicklungsziel wurde 25 % unter dem Euro 6d-Grenzwert festgelegt, während die RDE-Ziele 40 % unter den Grenzwerten lagen. Die Maßnahmen zur Reduzierung von NO_X, CO, HC und Partikelanzahl wurden für Warm- und Kaltstartbedingungen unterschiedlich angewendet. Bei Dieselmotoren wurden die NO_X-Reduzierungen gleichmäßig auf Warm- und Kaltstarts aufgeteilt; bei Benzinmotoren entfielen etwa 70 % der Reduzierungen auf den Warmbetrieb und 30 % auf den Kaltstart.

HDVs

Für schwere Nutzfahrzeuge verwendet Euro 7 die gleichen WHSC- und WHTC-Zyklen wie Euro VI, wobei die Betriebskonformität durch ISC-Tests bis zu 300.000 km für Fahrzeuge unter 16 t und 700.000 km für schwerere Fahrzeuge überprüft wird. Die Euro 7 Grenzwerte reduzieren NO_X um bis zu 62 %, CO um 70 % und führen Grenzwerte für N_2O und PN_{10} ein.

Die Emissionsfaktoren zeigen eine Verringerung der realen Emissionen um 50–90 % für NO_X, um bis zu 70 % für NH_3 und um 30 % für N_2O, während CO moderat ansteigt, aber unter den Grenzwerten bleibt. PN_{10}, NMHC/NMOG und CH_4 bleiben weitgehend unverändert.

Zu den Verbesserungen auf Fahrzeugebene gehören ein geringeres Leergewicht, ein geringerer Luftwiderstand, ein geringerer Rollwiderstand und eine höhere Motor- und Hilfsaggregatseffizienz, wodurch der Kraftstoffverbrauch einer Standard-Sattelzugkombination um etwa 10 % gesenkt wird.

Das PHEM-Modell wird auch auf Busse angewendet und erzielt ähnliche Reduktionsraten.

Integration

Die Integration in HBEFA umfasste die Definition von 147 neuen Untersegmenten, den Import von PHEM-Euro 7 Emissionsfaktoren und die Überprüfung der Plausibilität gegenüber älteren Untersegmenten. Euro 7 weist im Vergleich zu Euro 6/VI generell verbesserte Emissionen auf.

Arbeitspaket Integration nicht regulierter Schadstoffe

Jüngste Analysen nicht regulierter Abgaskomponenten von Personenkraftwagen und schweren Nutzfzeugen identifizierten vier umwelt- und gesundheitsrelevante Stoffe, die zusätzlich zu den bereits enthaltenen in HBEFA 5.1 aufgenommen werden sollten: Formaldehyd, Acetaldehyd, Isocyansäure und Salpetersäure. Diese Verbindungen waren mit FTIR-Analysatoren messbar und sind nun in den HBEFA-Datensatz integriert.

Emissionsfaktoren für Euro 6/VI-Fahrzeuge

Da FTIR-Messungen hauptsächlich für aktuelle Messkampagnen vorliegen, waren Emissionsdaten nur für Euro 6/VI-Fahrzeuge verfügbar. Diese Daten wurden unter Verwendung des PHEM-Modells gemäß dem Standardverfahren von HBEFA verarbeitet: Realmessungen mit einer Auflösung von 1 Hz wurden in Motor-Emissionskennfelder pro Fahrzeug umgewandelt, unter Verwendung EU-verkaufsgewichteter Daten zu Kategoriedurchschnitten aggregiert und über alle HBEFA-Fahrsituationen simuliert, um Emissionsfaktoren (g/km) abzuleiten.

Emissionsfaktoren für ältere Fahrzeuge

Für Fahrzeuge älter als Euro 6 wurden die Emissionsfaktoren anhand von „Euro-Norm-Korrekturfaktoren" geschätzt, die aus begrenzten Euro 4- und 5-Tests und der Literatur abgeleitet wurden. Obwohl dieser Ansatz auf kleinen und teilweise unsicheren Datensätzen basiert, gewährleistet er die Vollständigkeit der Schadstoffdatenbank für alle Euro-Klassen und ermöglicht so die Berechnung von Flottendurchschnittswerten. Die Korrekturfaktoren skalieren die Euro 6d-TEMP- oder Euro VI D-Referenzwerte entsprechend der Technologie und dem Kraftstofftyp. Während die Unsicherheit für frühere Fahrzeuggenerationen zunimmt, gilt die Methode als robust für die Modellierung aktueller und zukünftiger Flotten.

Integration und Plausibilitätsprüfungen

Die neuen Schadstoffemissionsfaktoren wurden analog zu bestehenden Komponenten in HBEFA implementiert. Für Euro 6/VI wurden die aus PHEM abgeleiteten Daten auf Subsegment-, Zyklus- und Lastniveau integriert. Für ältere Fahrzeuge wurden die Korrekturfaktoren direkt angewendet.

Die integrierten Datensätze wurden durch Abfrage und Visualisierung der Ergebnisse in HBEFA für verschiedene Fahrzeugtypen verifiziert. Die Ergebnisse zeigen plausible Trends: Die HNCO- und HNO_2-Emissionen sind bei Benzinfahrzeugen vernachlässigbar, während Dieselmotoren messbare Werte ausstoßen. Repräsentative Beispiele für Benzinfahrzeuge, Dieselfahrzeuge und

40-Tonnen-Lkw-Anhänger-Kombinationen bestätigen die konsistente Umsetzung und die realistische Größenordnung der Emissionsfaktoren.

1 Introduction

The Handbook Emission Factors for Road Transport (HBEFA) contains emission factors for the European on-road traffic. It covers all vehicle categories from motorcycles up to heavy good vehicles over all emission standards including all relevant developments in regulations and their effect on real-world emissions. HBEFA gives emission factors in gram (or number in case particle number) per driven vehicle kilometre. These factors can be used for analysis of possible measures in terms of emission reduction or can be used as input for air quality or other related models, i.e. Germany uses HBEFA to feed its model for emission reporting to the EU.

To implement newest scientific knowledge and data of ongoing measurements HBEFA is updated every couple of years. For the latest update – HBEFA 5.1 (22nd October 2025) the German Environment Agency - Umweltbundesamt - assigned ifeu, infras and TU Graz in order to elaborate specific topics, which are:

- Correction factors: the project team sets up correction factors for the deterioration of engines and exhaust aftertreatment systems and the influence of ambient temperatures on the emission behaviour of vehicles based on vehicle test data
- Non-regulated pollutants: FTIR exhaust gas analysers have been in use for the last years. These measurement systems provide data for up to 30 different emission components. In this project a literature study was performed to analyse all components, which are not covered in the former HBEFA versions, to their significant impact on air quality and health effects. The relevant ones are included in the emission models for HBEFA 5.1.
- Euro 7: The Euro 7 regulation will come into force in the next years. The project team set up a real-world emission model based on the proposed limits and assumed development targets for OEMs in terms of safety margins compared to the limits.

All other topics included in HBEFA 5.1 are elaborated in other projects financed by other partners. The content of all updated aspects in HBEFA 5.1 is summarised in (Notter et al., 2025).

2 Correction factors for the deterioration of exhaust gas aftertreatment systems and temperature effects

This chapter illustrates the work and results for the correction factors for the deterioration of exhaust gas aftertreatment systems and temperature effects for passenger cars, light duty vehicles and heavy-duty vehicles.

Background deterioration: the components of the engine, such as injection systems, EGR valves, lambda- and NO_X-sensors etc. as well as catalytic converters undergo deterioration effects over the vehicle life time with effects on the exhaust emission levels. Main effect for modern vehicles is the thermal and chemical deterioration of the catalysts, which usually lead to increasing emissions of those exhaust gas components converted by the catalysts (CO, HCs, NO_X) but decreasing emission levels of components formed during the catalytic processes (such as NO_2, NH_3). This effect is considered in HBEFA via the deterioration functions.

Background ambient temperature: EGR rates need to be reduced at very low and high temperatures to avoid damages on the engine, e.g., due to condensing hydrocarbons and corresponding formation of deposits. Before the introduction of RDE tests with emission limits with Euro 6d-TEMP, several manufacturers of diesel cars reduced EGR rather early and also the dosing of the reagent into the SCR systems was partly reduced outside of the chassis dyno type approval ranges. This leads to increasing NO_X emissions with decreasing temperatures from ca. 20°C on. The temperature correction functions consider this effect in HBEFA.

2.1 Deterioration functions for PCs and LDVs

Already in HBEFA 4.1, the deterioration factors for NO_X and CO were revised in order to take better account of the findings on the influence of vehicle mileage on emissions (Matzer et al, 2019). For HC emissions, on the other hand, no new data could be taken into account for HBEFA 4.1, which is why the corresponding factors were adopted from HBEFA 3.3 (Hausberger and Matzer, 2017). The basis for the update was exclusively remote sensing data, as no suitable vehicle measurements were available in which vehicles in new condition and with sufficiently high mileage could be directly compared.

For the version 5.1 update, two different data sources and analytical approaches were used:

- Remote Sensing data from the pan-European CARES database and
- Individual vehicle pairs with low and high mileages.

Analysis of Remote Sensing data

Remote sensing data provide information about the emission behaviour of groups of vehicles as they are passing different measurement locations (Borken-Kleefeld and Dallmann 2018). Here we analyse records from Euro 5 and Euro 6 gasoline and diesel cars as remotely measured in Belgium, the Czech Republic, Germany, Italy, Poland, Sweden and Switzerland between years 2017 and 2023. Full details will be given in the report “Tracking NO_X Emissions Decay in Euro 5 and 6 Passenger Cars: Remote Sensing Insights across Europe” by Kumawat and Borken-Kleefeld which was in the preprint phase at the time of this report; here we summarize the essential steps.

For each emission record the vehicle age is known, which in turn is converted to an average cumulative mileage using HBEFA’s lifetime mileage functions. Then emission records are clustered into mileage bins with a minimum of at least 100 records each. Finally, the average emission is calculated as function of mileage for each vehicle layer. The increment of the regression lines, normalised to a base emission factor at 50,000 km, is then the fleet averaged increase with vehicle mileage as determined by remote sensing.

Before all processing, utmost care has been given to eliminate artefacts: Data were extensively quality controlled removing outliers, sites with high shares of cold-started vehicles, inconsistent data, wrong labels and misclassifications. Furthermore, several known confounding effects have been accounted for, most importantly (Davison et al. 2022)[1]:

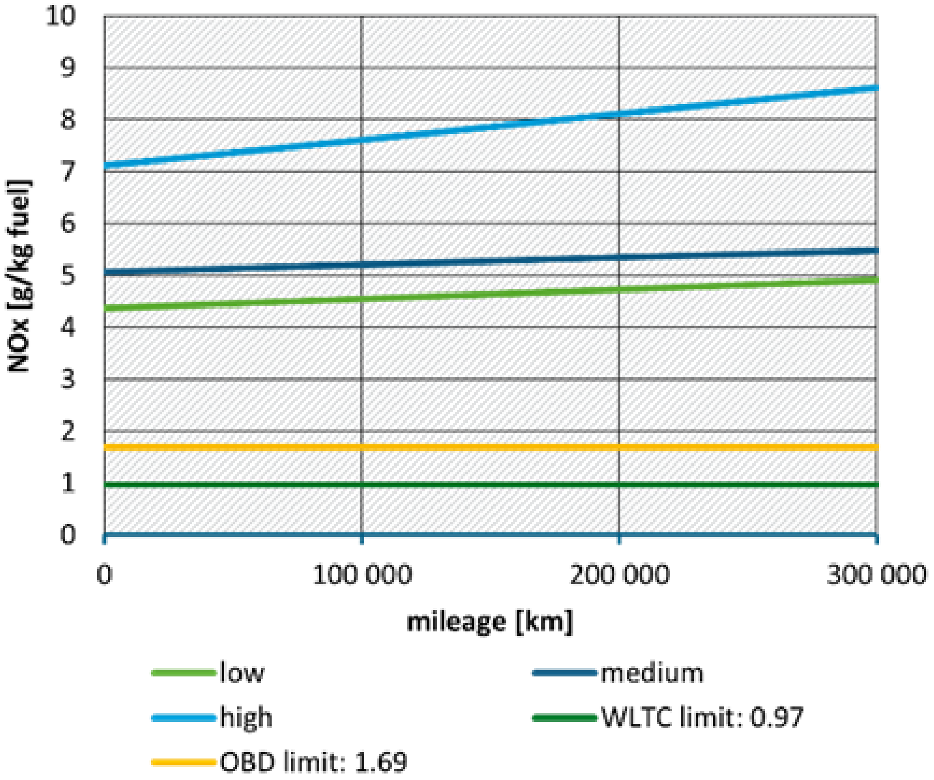
- The influence of temperature notably on NO_X emissions from diesel cars is controlled by stratifying the data first into temperature bins. The deterioration calculated here is given for an ambient temperature bin of 18°C to 25°C. Thus, the effect of ageing/mileage is separated from an influence of temperature; the temperature effect is represented by a correction function of its own.
- The influence of engine load, again most notable for NO_X emissions from diesel cars, is controlled by grouping records into three, roughly homogenous bins characterised by their vehicle specific power. For each power bin, the development over age/mileage is analysed separately. The influence of engine load is in itself accounted for by the PHEM modelling.

In previous deterioration analyses, e.g., Borken-Kleefeld & Chen (2014), there were not enough records for this separation into three main factors of age/mileage, temperature and engine load. This careful data treatment was possible now thanks to in total 950,000 remote sensing records available. After all filtering 120,000 fully valid and suitable records remained. Full results are given in (Kumawat and Borken-Kleefeld 2025). Here we highlight the results for diesel cars with Euro 6abc emission standard (Figure 1). Their deterioration of NO_X emissions can be approximated by a linear line. Both, the absolute emission level as well as the slope, i.e., the deterioration, differ by engine load as indicated by the different VSP classes. That is, however, not the case for modern gasoline cars.

---

[1] Additional details will be given in the report "Impact of Engine Loads and Ambient Temperatures on Passenger Car NO_X Emissions across Europe by Potturu and Borken-Kleefeld, which was not yet published at the time of this report

Figure 1: **NO_X emissions of diesel Euro 6abc cars over vehicle mileage, differentiated by engine load**



Source: (Kumawat and Borken-Kleefeld 2025)

Deterioration functions for Euro 6ab

The NO_X, CO and HC deterioration factors for Euro 6ab vehicles were updated here, as more comprehensive remote sensing data set are now available, which also include vehicles with significantly higher mileages (sufficient data up to 160,000 km) and thus enable a more realistic representation of the ageing effect. The data used originates from measurement campaigns carried out during several remote sensing campaigns in Europe. In total, more than 120,000 vehicles were measured and used for these deterioration functions. Since remote sensing data could not provide clear information about deterioration effects for CO, and HC cannot be measured with RS, the deterioration factors for these components of Euro 6ab vehicles were calculated considering the data from HBEFA 4.1 and Euro 6d-TEMP deterioration functions.

Deterioration functions for Euro 6d-TEMP and 6d

For vehicles of the Euro 6d-TEMP and Euro 6d emission standards, the available remote sensing data currently only provide information up to a mileage of around 80,000 kilometres. However, these data were not sufficient to derive a reliable and stable deterioration behaviour of the emissions over the entire service life of the vehicles. Thus, RS data are not used for the elaboration of the deterioration functions for Euro 6d-TEMP and 6d. In order to nevertheless be able to make reliable statements, targeted measurements on the chassis dyno and on-road with PEMS were carried out in which vehicle with identical engine models with both low and high mileage were examined. These vehicles are also stored in the DBEFA. Based on these direct comparative measurements, specific deterioration factors for Euro 6d-TEMP and Euro 6d vehicles could be determined.

A total of 7 pairs of diesel vehicles and 6 pairs of petrol vehicles were used for this evaluation. It was important to ensure that measurements of identical cycles on the chassis dynamometer were used. The measurements of the vehicle pairs include the WLTC, the high-load Ermes cycle, and the urban IUFC. The list of vehicle pairings and the measured cycles used is shown in the Appendix A in Table 12 and Table 13. Since the chassis dynamometer measurements do not show any trend toward different deterioration behaviour with changing driving dynamics, the same deterioration was applied to passenger cars and LDVs for all driving situations.

Deterioration functions for Euro 7

The deterioration factors for Euro 7 were estimated, this is documented in chapter 3.1.2.2.

Deterioration functions for other Euro classes

For NO_X and CO from diesel and gasoline vehicles, the deterioration functions up to Euro 5 were adopted from HBEFA 4.1. Since there was no deterioration function for HC from diesel vehicles in HBEFA 4.1, the deterioration effects from Euro 6d-TEMP were adopted. For gasoline vehicles, the HBEFA 4.1 data were adopted up to Euro 2. Since the deterioration modelled in HBEFA 4.1 was too low from Euro 3 onwards, the newly calculated value for Euro 6d-TEMP was adopted from Euro 3 onwards. However, the effect of the deterioration on the total HC emissions is minor compared to other effects like cold start.

The deterioration function for Euro 6c was interpolated between Euro 6ab and Euro 6d-TEMP.

Deterioration factors were multiplicative in HBEFA 4.1, but were changed to an additive influence in HBEFA 5.1. The reason for this is that due to the very low emission level of Euro 6d-TEMP and 6d with increased mileage, multiplicative factors of up to 10 would be necessary in some cases to accurately represent the deterioration effects. However, this would lead to a high absolute increase in emissions in certain driving situations in which the average map shows only slightly higher emission behaviour. For this reason, the calculation was changed to an additive method. The following equation shows the calculation of the emission factors as a function of the mileage.

$$EF_{x\ km} = EF_{50kkm} + DF_{mileage}$$

$EF_{x\ km}$ … emission factor at x km mileage [g/km]

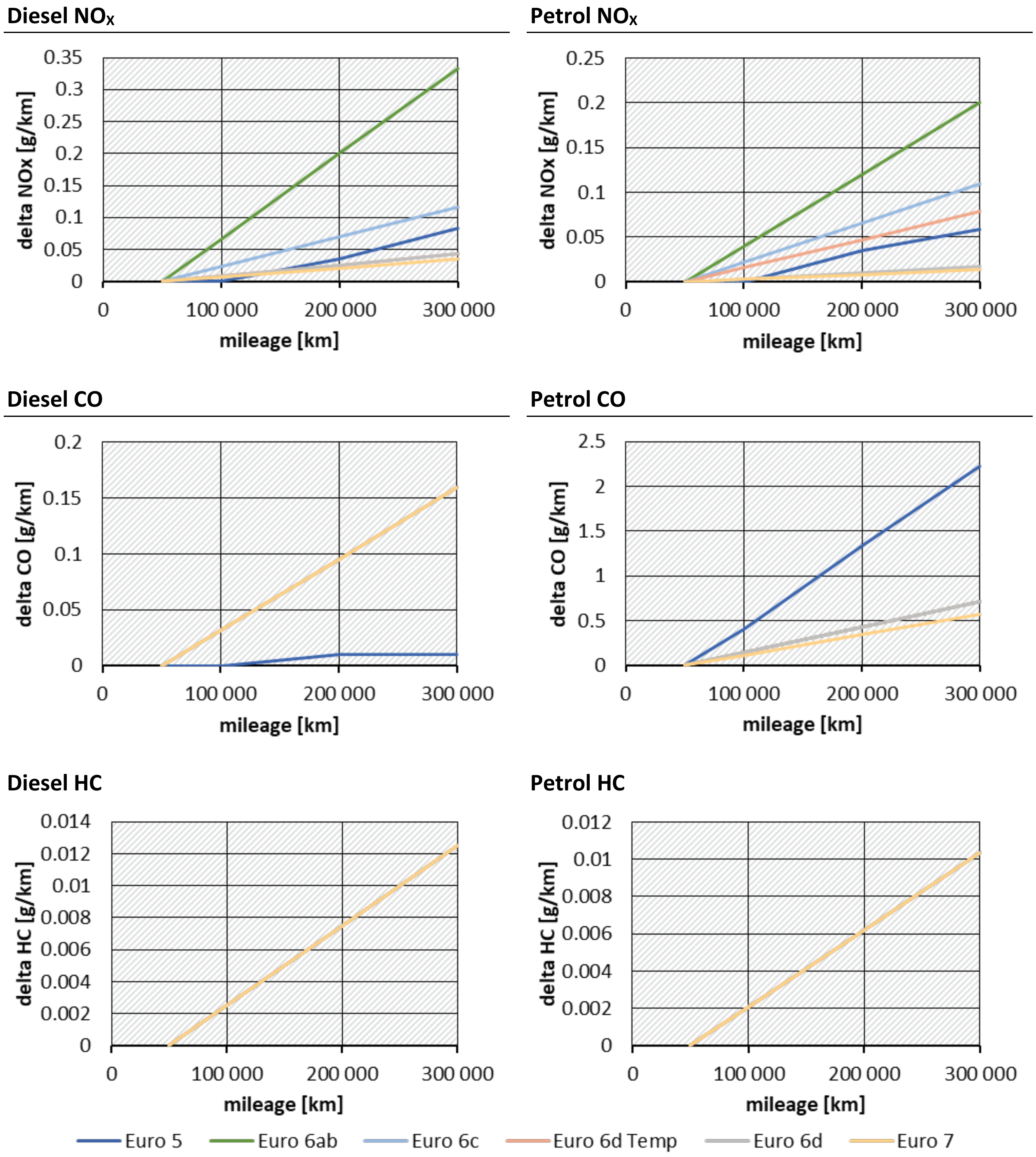
EF_{50kkm} … base emission factor at 50,000 km mileage [g/km]

$DF_{mileage}$ … deterioration factor depending on mileage [g/km]

The following figure shows the deterioration factors that were determined in the course of this work. The deterioration factors from Euro 0 to Euro 4 are not shown here, as otherwise the effect of the current Euro classes would not be recognizable.

For diesel CO deterioration, only Euro 5 and Euro 7 are visible in the graph, as the deterioration function is identical for Euro 6ab to Euro 7. The same applies to petrol CO Euro 6ab to Euro 6d and to all HC deterioration functions.

Figure 2: deterioration functions for NO_X, CO and HC for petrol and diesel vehicles



Source: own illustration

2.2 Deterioration functions for HDVs

Modern heavy-duty vehicles use exhaust aftertreatment systems in order to reduce engine out emissions to meet the tailpipe limits. The systems can reach conversion rates of more than 99 % in best operating conditions, especially the latest Euro VI and upcoming Euro 7 technology. However, chemical, thermal and mechanical ageing effects can reduce the performance over the lifetime. Measurement data prove these effects and the upcoming Euro 7 technology considers this also in the limit values. (Weller, 2025)

For that reason, deterioration functions for heavy-duty vehicles were first included in HBEFA 4.1. These functions were only set up for NO_X for Euro VI ABC vehicles based on chassis dyno and PEMS test data (Matzer et al., 2019). The method was revised for HBEFA 4.2 due to a broader data base including remote sensing data in addition to chassis dyno and PEMS data. These ageing functions comprised also CO and NO_2 in addition to NO_X and included a vehicle speed dependency in order to include the effects of different driving situations on the deterioration. At that point, data were available for Euro V and Euro VI ABC vehicles (Notter et al., 2022).

For HBEFA 5.1 the database was extended with additional chassis dyno and PEMS test data:

- First Euro VI D vehicles with high mileage were on the road and consequently tested.
- The Euro VI ABC dataset could be enlarged by additional vehicles, for example with mileages up to 1,000,000 km or vehicle categories not covered so far.
- The broad availability of FTIR test data allowed the elaboration of deterioration functions for all relevant gaseous emission components
- The test data allowed a differentiation in rigid trucks and long-haul vehicles. The various mission profiles lead to different deterioration behaviours of the vehicle categories.
- Test data for urban busses with high mileage were also available for the first time for this HBEFA version, but finally not used due to the low number of test vehicles and low fleet coverage (only two brands).

Table 1 illustrates the available data set for HBEFA 5.1 for chassis dyno and PEMS HDV test data for deterioration functions.

Table 1: Number of test vehicles[2] for HDV deterioration functions

Emission standard [-]	number of test vehicles - total [-]	number of test vehicles - rigid trucks [-]	number of test vehicles - long-haul trucks [-]
Euro V	*	*	*
Euro VI ABC	21	11	10
Euro VI DE	16	6	10

* Euro V was not updated and is still based on remote sensing test data as in HBEFA 4.2

In addition, further remote sensing test data were available. These data contain mainly Euro VI ABC and Euro V vehicles and covers only CO and NO_X emissions. Due to this limited coverage of Euro-classes and exhaust components, remote sensing test data were used for validation of the functions. The functions have been produced on basis of the available chassis dyno and PEMS test data.

The following part describes the method for the elaboration of deterioration functions based on the chassis dyno and PEMS data:

---

[2] These numbers include all single vehicles used for the elaboration of the functions, thus vehicles with low and with high mileage.

- The test vehicles for the chassis dyno and PEMS tests were selected in order to gather vehicle pairs. That means each vehicle with high mileage was selected based on the reference vehicles available with low mileage. In the best case, the vehicle with high mileage is exactly the reference vehicle, but this is not feasible in most cases as hundreds and thousands of kilometres of driving are needed between the measurements. Thus, the vehicles with high mileage were selected as the same make and model as one of the reference vehicles with low mileage. In addition, the aim of the vehicle selection is to be fleet representative, covering different brands and vehicle categories.
- The next step is the elaboration of the deterioration functions according to following specifications:
  - Test cycle: the increase of the emissions over mileage was elaborated based on a hot started WHVC[3] test[4, 5], which includes urban, rural and motorway driving. This test allows to distinguish the effects of different driving situations on the ageing behaviour. This effect is illustrated in Figure 3 for the NO_X emissions of a tractor trailer combination with emission standard Euro VI DE. The deterioration for NO_X is higher in urban driving compared to rural and especially motorway driving. High-speed and thus high-power driving as in motorway situations leads to perfect operating conditions for the exhaust after treatment system. In these situations, the deterioration effects are obviously less distinctive as in low load urban driving. Low load driving challenges the catalyst system in terms of operating temperature, which is at the lower border of the operating window.

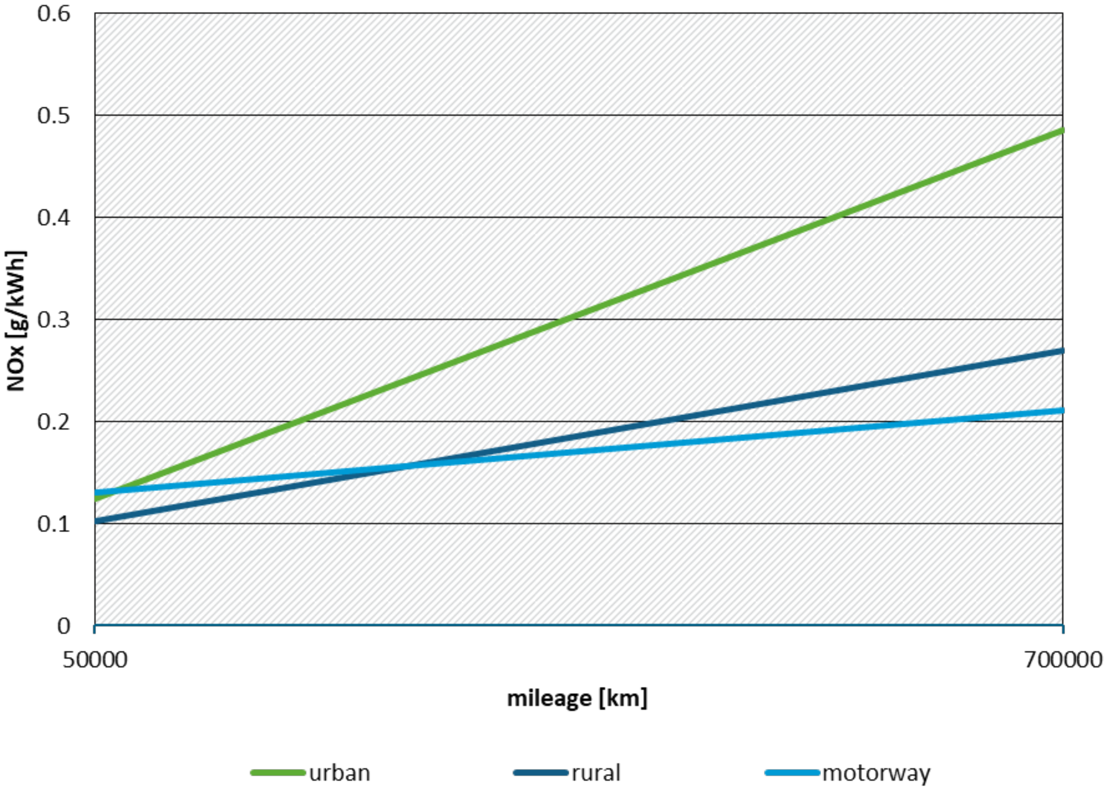
---

[3] The deterioration functions in HBEFA represent hot driving conditions. Latest research shows that deterioration effects are different for cold start and low load driving. This will be a topic for HBEFA 5.2.

[4] The WHVC represents the WHTC, the HDV Euro VI engine test bed, on the chassis dyno.

[5] If no WHVC test was available, ISC test data were used.

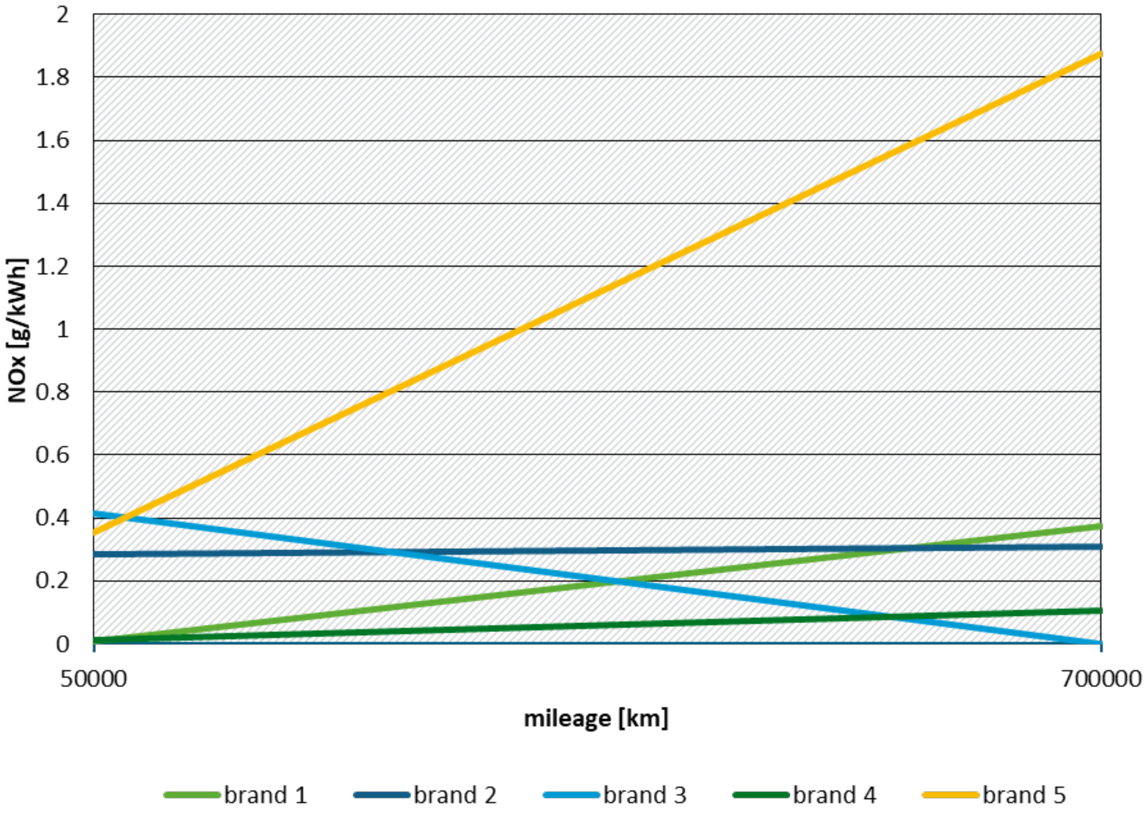
Figure 3: Deterioration functions per road category, NO_X, Euro VI DE, long-haul trucks



Source: own illustration

- Brand: the deterioration functions are set up for vehicle pairs of each brand. These functions are illustrated in Figure 4 for the absolute NO_X emissions of Euro VI DE long-haul trucks. The sample shows the big spread between the different vehicles in the fleet. In a next step these brand specific functions are combined to fleet representative deterioration functions according to the fleet share of each brand in the EU.

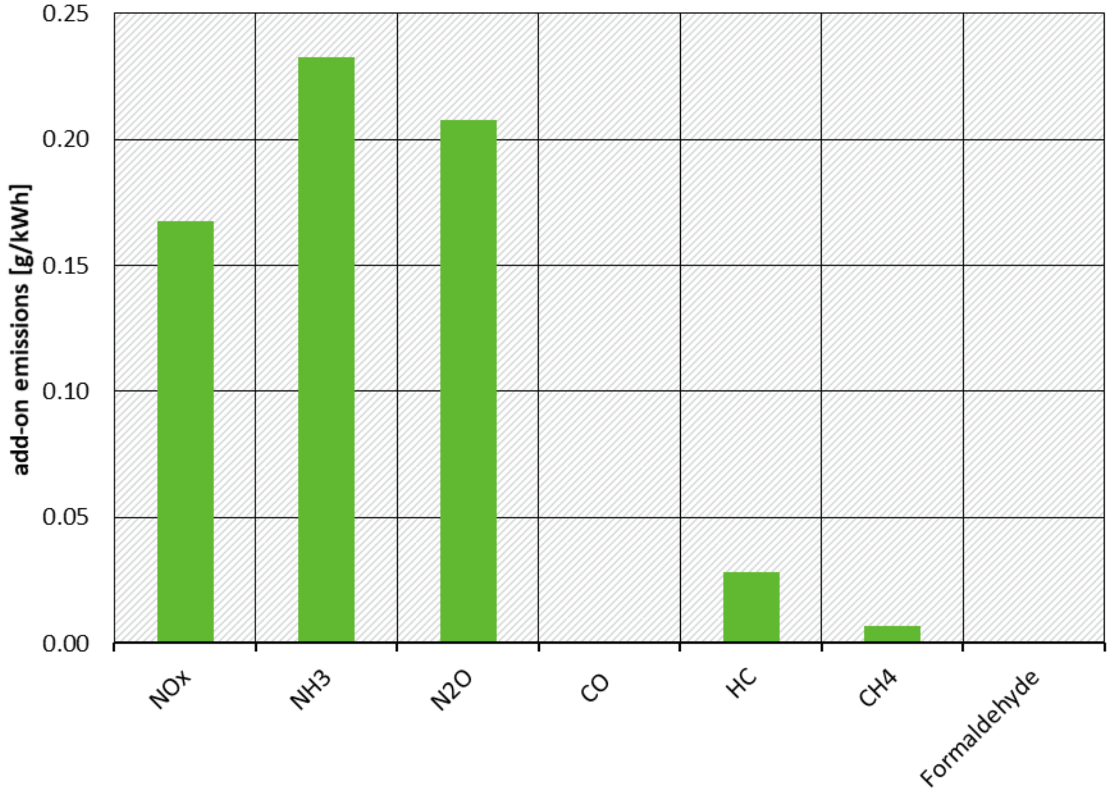
Figure 4: Absolute NO_X emissions over mileage per manufacturer, Euro VI DE, long-haul trucks



Source: own illustration

- Emission components: The combination of particle and FTIR measurement system covers up to 30 different emission components. Not all of them show deterioration effects by mileage and some are on an emission level below the limit of detection of the analysers. Thus, the HBEFA deterioration functions are finally set up for NO_X, NH_3, N_2O, CO, HC, CH_4 and Formaldehydes. In addition, a deterioration function for the NO_2 to NO_X ratio was elaborated. The add-on emissions are shown in Figure 5 for a long-haul truck in a typical rural driving situation. NO_X, N_2O and NH_3 increase most over mileage.

Figure 5: Add-on emissions from 50,000 km to 700,000 km for an average German traffic situation, long haul trucks, Euro VI DE[6]



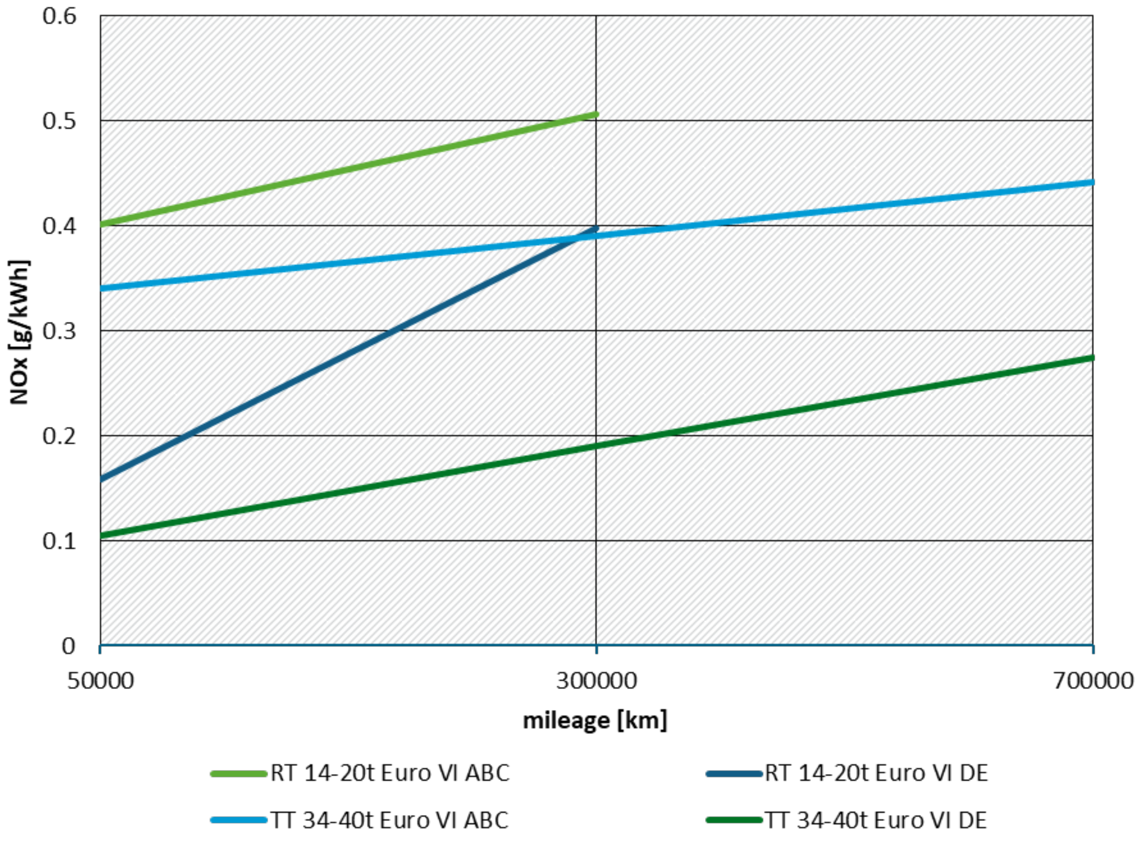
Source: own illustration

---

[6] CO and Formaldehyde increases also by mileage due to deterioration in principle, but only in urban driving conditions. This is included in HBEFA by the speed dependent deterioration function.

- Vehicle category: the data set enables a split in rigid and long-haul trucks. Figure 6 shows the different fleet representative NO_X deterioration functions for Euro VI ABC and DE split in a rigid truck and a long-haul truck for the average German traffic mix. The upper mileage represents the specific maximum mileages, for which emission limits have to be met at in-service conformity (ISC) tests, which is 300,000 km for N2 and N3 < 16 tons gross vehicle weight (GVW) and 700,000 km for all N3 > 16 tons GVW. The base emission factors at a mileage of 50,000 km are higher for rigid trucks compared to long-haul vehicles, but more relevant for this chapter is the higher deterioration for rigid trucks compared to long-haul vehicles. This can be explained with the different emission profiles, which are obviously more challenging for rigid trucks due to a higher frequency of cool down and heat up cycles. In addition, the frequency of DPF-regenerations, which lead to a high thermal stress of the catalyst system and thus to an increased aging of all catalysts, is higher for rigid trucks due to the lower share of motorway driving including the possibility for passive filter regeneration.

Figure 6: **Fleet representative absolute NO_X emissions over mileage for a rigid truck and a tractor trailer, Euro VI ABC and Euro VI DE, average German traffic mix**



Source: own illustration

- Emission standard: According to the categories in HBEFA the Euro VI data were split in Euro VI ABC and DE vehicles. For Euro V no additional test data were available since the last HBEFA, thus the function is not updated. The difference of Euro VI ABC and DE is illustrated in Figure 6.

The emission increase by mileage of all components remains at a constant level when reaching the on-board diagnosis (OBD) threshold. Such a threshold does only exist for NO_X looking at Euro V and Euro VI. Reaching this threshold leads to an activation of the motor investigation light (MIL) and consequently to a repair of the entire after-treatment system. Thus, this repair affects all emission components and not only NO_X.

These deterioration functions were validated by remote sensing data, so far available. The trends which are based on remote sensing show similar trends for the increase of the NO_X emissions over mileage for Euro VI ABC vehicles.

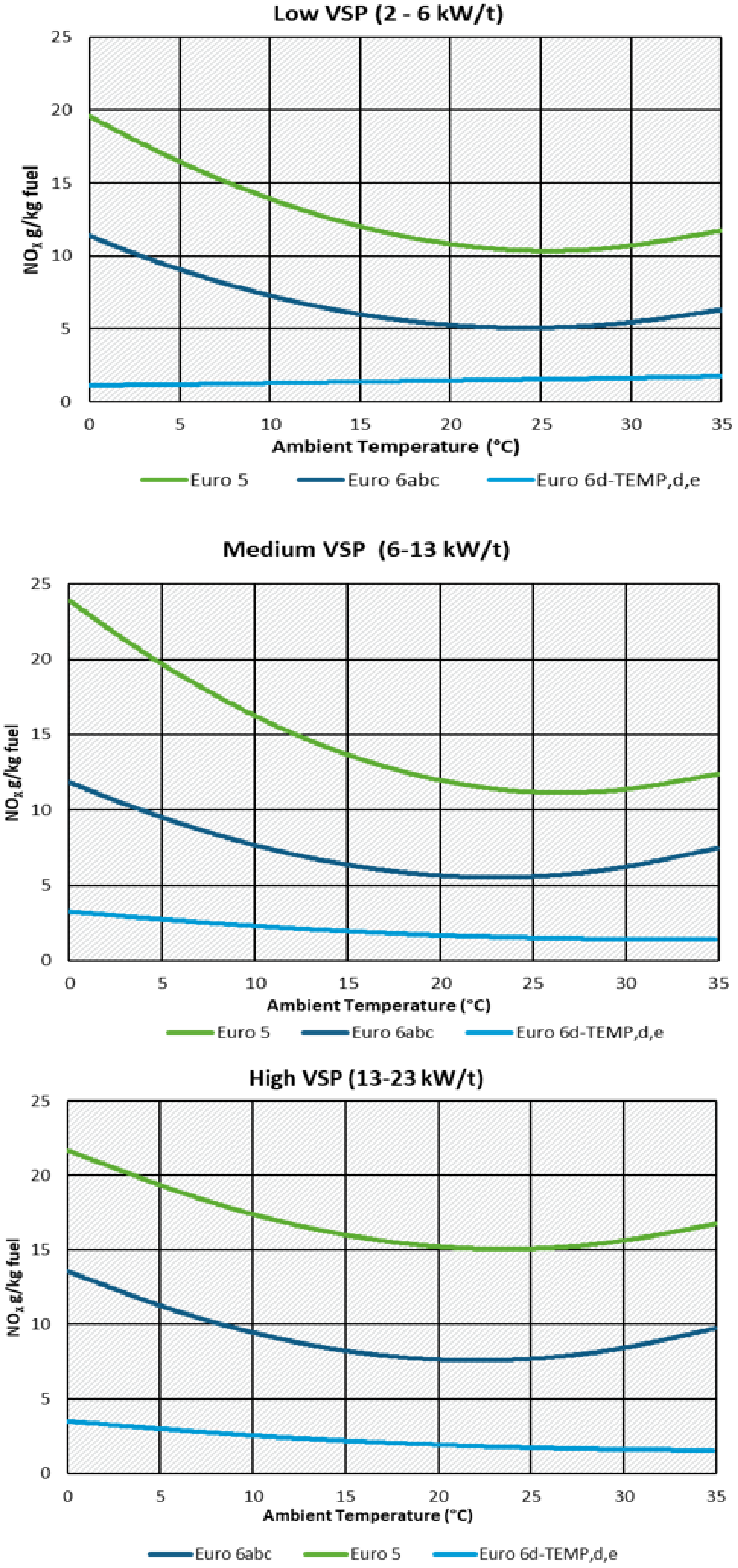
As already explained in chapter 2.1, the multiplicative method has changed to an additive one due to the low base emission levels.

2.3 Temperature correction functions for PC and LDV

Temperature corrections notably for NO_X emissions from diesel cars and light duty vehicles were already included in HBEFA 4.1. Here, pan-European remote sensing data are used to cross-check. Data are processed as already described above. The important issue is to determine the NO_X emissions as function of ambient temperature while controlling for engine load and ageing. Full details will be given in the report "Impact of Engine Loads and Ambient Temperatures on Passenger Car NO_X Emissions across Europe by Potturu and Borken-Kleefeld, which was not yet published at the time of this report. In conclusion, and as seen multiple times before, Euro 5 diesel cars emit least NO_X when the ambient temperature is in the range of 20°C to 25°C. The emissions increase however by 80% to 100% when temperature decreases to 0°C for low and medium engine loads (Figure 7). Given significantly higher emission levels at higher engine loads, the rate of increase is smaller. A similar increase of NO_X emissions with decreasing ambient temperature is also observed for Euro 6abc diesel cars, i.e., homologated still in the laboratory. Only after on-road homologation tests became mandatory onwards with Euro 6d-TEMP emission standard, the engine and after-treatment are performing fully across the temperature range from 0°C to 30°C.

All this has already been properly accounted for – by linearised correction functions - in HBEFA 4.1. It is hereby confirmed also for recent vehicle generations. Note, however, that NO_X emissions from Euro 5 and Euro 6abc cars tend to increase also when ambient temperatures approach 30°C. This behaviour has not yet been represented in HBEFA.

Figure 7: Average NO_X emissions as a function of ambient temperature for diesel cars (Euro 5, Euro 6abc, Euro 6d-TEMP,6d, e) modelled using LinearGAM



Source: own illustration, TU Dresden.

2.4 Integration and plausibility check in the HBEFA application

The **mileage correction** functions were implemented as follows:

- **LDV**: The additive correction factors in g/km are stored in cumulative mileage intervals of 50,000 km up to 300,000 km in the database. In an emission factor request, the cumulative mileage of each subsegment in the respective reference year and country is read in from the fleet model outputs. For these cumulative mileages, correction factor values are linearly interpolated between the values stored in the database at regular intervals. Above 300,000 km, the correction factor value at 300,000 km is used.
- **HDV**: In order to obtain correct absolute additive correction factors in g/km in every traffic situation (with corresponding average speed), the correction function requires the following inputs:

$$CF_{additive} = \frac{m - 50.000\,km}{base_{km} - 50.000\,km} \times (k \times v + d) \times \frac{We_{+}}{1{,}000}$$

with:

- CF = correction factor
- m = mileage [km]
- k = correction parameter 1 [g/(kWh*km/h)]
- d = correction parameter 2 [g/kWh]
- v = average speed of traffic situation [km/h]
- We+ = positive engine work [Wh/km]
- Base_km = base mileage: 300,000 km for rigid trucks (RT), 700,000 km for truck trailer combinations and articulated trucks (TT/AT).

The positive engine work is available from PHEM at subsegment, cycle, load, and gradient level (such as all emission components available as PHEM inputs into HBEFA).
The formula is valid up to the following mileages – above, the additive correction factor for this mileage is used:

- Euro-V: 600,000 km for RT; 1,400,000 km for TT/AT
- Euro-VI A-C: 632,000 km for RT; 2,229,000 km for TT/AT
- Euro-VI DE: 1,189,000 km for RT; 4,725,000 for km TT/AT

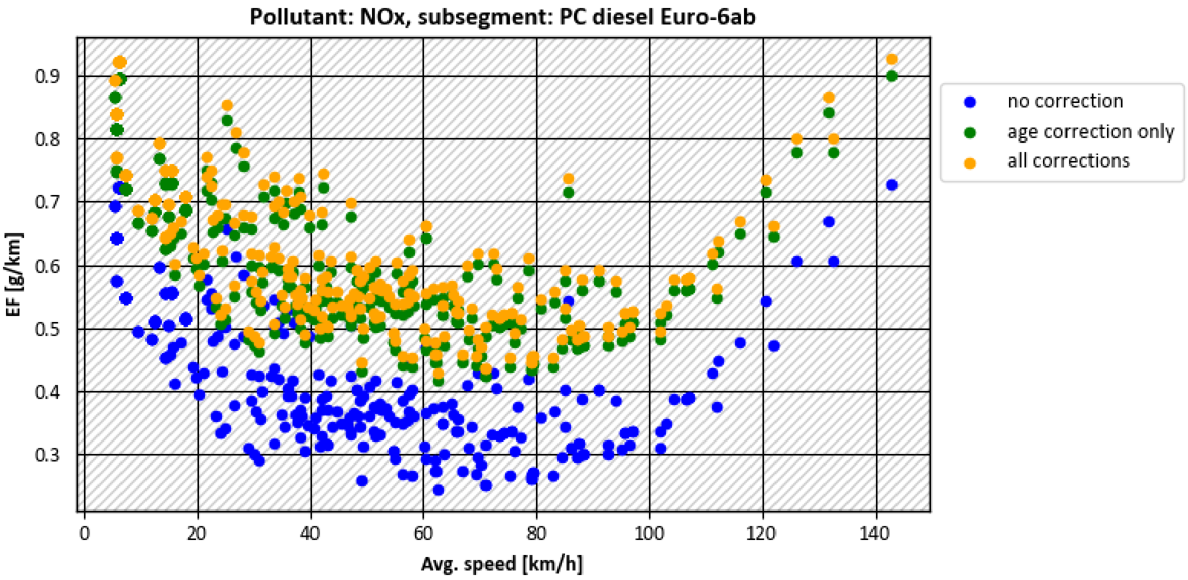
The above inputs are stored in the HBEFA system database. At every emission factor request involving mileage correction, the formula is calculated at level pollutant, subsegment, and traffic situation, and the additive correction factor is added to the uncorrected emission factor.

As the analyses of **temperature correction** functions confirmed the corrections already implemented with HBEFA 4.1, these didn’t have to be updated.

In the HBEFA front-end application, the mileage and temperature correction inputs can be viewed in Menu *Definitions > Correction factors*. There are two GUI forms for each correction factor type and vehicle family, "*in*" and "*out*". On the "*in*" form, the input correction formula values can be viewed; the "*out*" form displays and visualizes the resulting correction factor values by cumulative mileage or temperature.

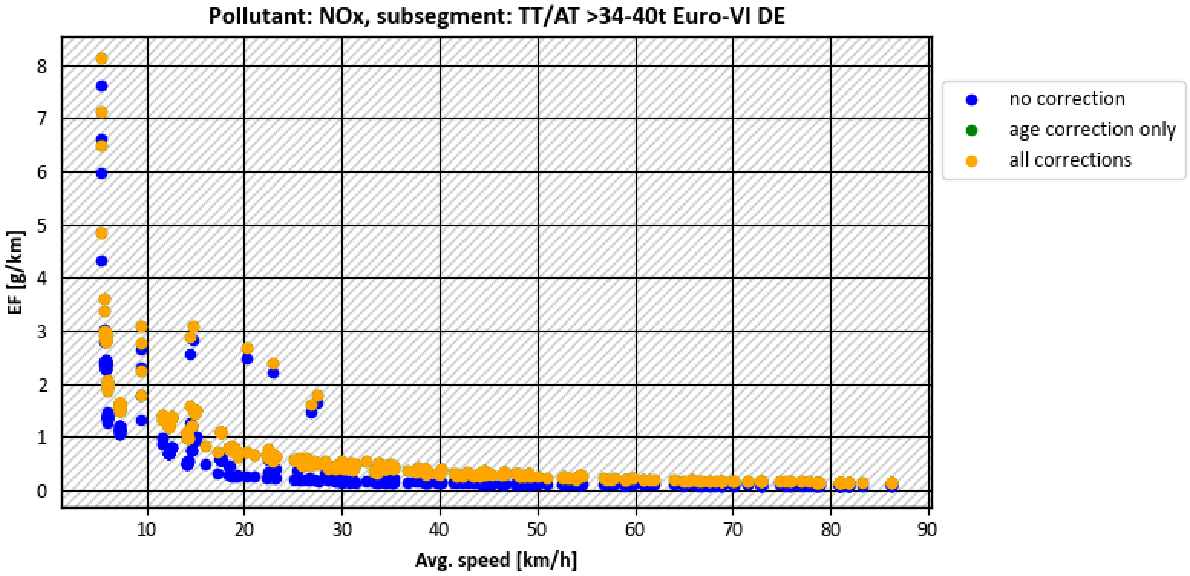
The correction factors were checked for plausibility by querying the emission factors of the affected pollutants and subsegments in HBEFA with and without the corrections and by checking whether the absolute difference (for the mileage correction) or the ratio (for the temperature correction) corresponds to the intended correction factor. The emission factors were also visualized without any correction, with age correction only, and with both corrections. Figure 8 and Figure 9 show this comparison for two example subsegments. In the example of the 40 t TT/AT, the green dots for "age correction only" are not visible because they are covered by the dots for "all corrections", since there is no temperature correction applied for trucks.

Figure 8: **NO_X emission factors by subsegment and average speed of traffic situation, without correction, with age correction only, and with both corrections, for PC diesel Euro-6ab.**



Source: own illustration, based on HBEFA 5.1

Figure 9: **NO_X emission factors by subsegment and average speed of traffic situation, without correction, with age correction only, and with both corrections, for TT/AT >34-40t Euro-VI DE.**



Source: own illustration, based on HBEFA 5.1

3 Emission factors for Euro 7 vehicles

The Euro 7 regulation will come in place in 2026/2027 for passenger cars and light-duty vehicles and in 2028/2029 for heavy-duty vehicles. No such vehicles are on the road yet and thus no test data are available. However, Euro 7 vehicles are integrated in the simulation tool PHEM (Passenger Car and Heavy-Duty Emission Model) for the calculation of the HBEFA emission factors in order to represent the upcoming fleet in the next years. The following section illustrates how the Euro 7 emission models were derived based on the existing Euro 6/VI data and the already enacted Euro 7 limits.

3.1 Passenger cars

3.1.1 Vehicle properties

The average values for diesel and petrol cars of the Euro 6d-TEMP and Euro 6d emission standards are based on existing registration statistics. Since no detailed data are yet available for Euro 7, assumptions were made about the possible development of Euro 7 vehicles. The derivation of Euro 7 for petrol and diesel cars was achieved by extrapolating the developments between Euro 6d-TEMP and Euro 6d. The following table shows the resulting average values for rated power and vehicle unladen weight for the calculated vehicle categories.

As there are no data available for the rated engine speed in the registration statistics, this was determined for conventional cars by weighting the rated engine speed of all vehicles available from the DBEFA using registration numbers.

Table 2: Engine power, speed and empty weight of updated vehicle categories

Technology [-]	Emission standard [-]	Empty weight [kg]	rated engine power [kW]	rated engine speed [1/min]
Petrol	Euro 6d-TEMP	1,312	105	5,472
	Euro 6d	1,347	109	5,472
	Euro 7	1,381	112	5,472
Diesel	Euro 6d-TEMP	1,697	126	3,644
	Euro 6d	1,751	132	3,644
	Euro 7	1,804	139	3,644

The data stored in the DBEFA were used as the basis for determining the driving resistances. As most of the vehicles were measured on the chassis dynamometer, the WLTC driving resistances were available for these vehicles. These data sources were used to elaborate the numbers for the driving resistance parameters for the average diesel and petrol vehicle. The numbers represent the fleet weighted average according to the registration numbers.

Euro 7 was derived from Euro 6d:

- Rolling resistance coefficient Fr0: 5% improvement from Euro 6d
- Cross-sectional area A: Adopted from Euro 6d
- Drag coefficient Cd: improvement Euro 6d/6d-TEMP added to Euro 6d (3.7% improvement)

In order to derive the real driving resistances from the WLTC driving resistances, the factors developed in HBEFA 4.1 were applied. [7], [32]

- Cd correction:
    - Factor 1.05 for proportion of roof rack and trailer usage
    - Factor 1.03 for crosswind effects
    - Factor 1.028 for correction from 20°C WLTP temperature to 12°C average real temperature
- Fr0 correction:
    - 6% rainy days with 30% increase in rolling resistance
    - 30% use of winter tyres with 15% increase in rolling resistance

The derivation of these adjustments was developed and is detailed documented in (Matzer et al, 2019) and (Opetnik, 2019).

The transmission ratios for Euro 6d-TEMP and Euro 6d were recalculated for all vehicles in the DBEFA and adopted for Euro 7. The auxiliary power demand and the share of start-stop systems were taken from the HBEFA 4.2 Euro 7 model without any modifications.

3.1.2 Derivation of Emissions for Euro 7

3.1.2.1 CO_2

The CO_2 map for Euro 7 was derived from the corresponding Euro 6d CO_2 maps. A relative improvement of 2% was assumed over the entire map. The following table shows the average CO_2 emissions normalized to the rated power between the full load and drag curve.

Table 3: Average normalized CO_2 emissions in the created engine maps

Emission standard [-]	Technology [-]	Avg CO_2 map improvement to previous Euro class [%]
Euro 6d-TEMP	Petrol	-
Euro 6d	Petrol	-1%
Euro 7	Petrol	-2%
Euro 6d-TEMP	Diesel	-
Euro 6d	Diesel	-5%
Euro 7	Diesel	-2%

3.1.2.2 Pollutant Emissions

In order to estimate the Euro 7 data, the legal framework conditions must first be clarified.

The limits for the WLTC were adopted from the Euro 6e regulation. All limits have remained the same except for the number of particles. The limit value of $6x10^{11}$ [#/km] for the number of particles has remained the same, but now refers to PN_{10} instead of PN_{23}. The conformity factors for the RDE limits have been reduced from 1.43 to 1.1 for NO_X and from 1.5 to 1.34 for PN (Regulation (EU) 2024/1257).

Furthermore, in Euro 7 the main service life, during which passenger cars must comply with the emission limits, has been increased to 160,000 km. After the main service life, the additional service life is defined as 200,000 km or 10 years, whichever comes first. During the Additional Service Life, the limit to be complied with is multiplied by the durability multiplier 1.2, taken from Regulation 2024/1257.

The above definitions form the framework conditions for the derivation of Euro 7 from Euro 6d. The Euro 7 vehicle model, as explained in 3.1.1, was simulated with the Euro 6d emission maps and Euro 6d cold start effects. The deterioration function was then included. This was derived from Euro 6d. The technology improvements relating to deterioration could only be estimated and are shown in the following table.

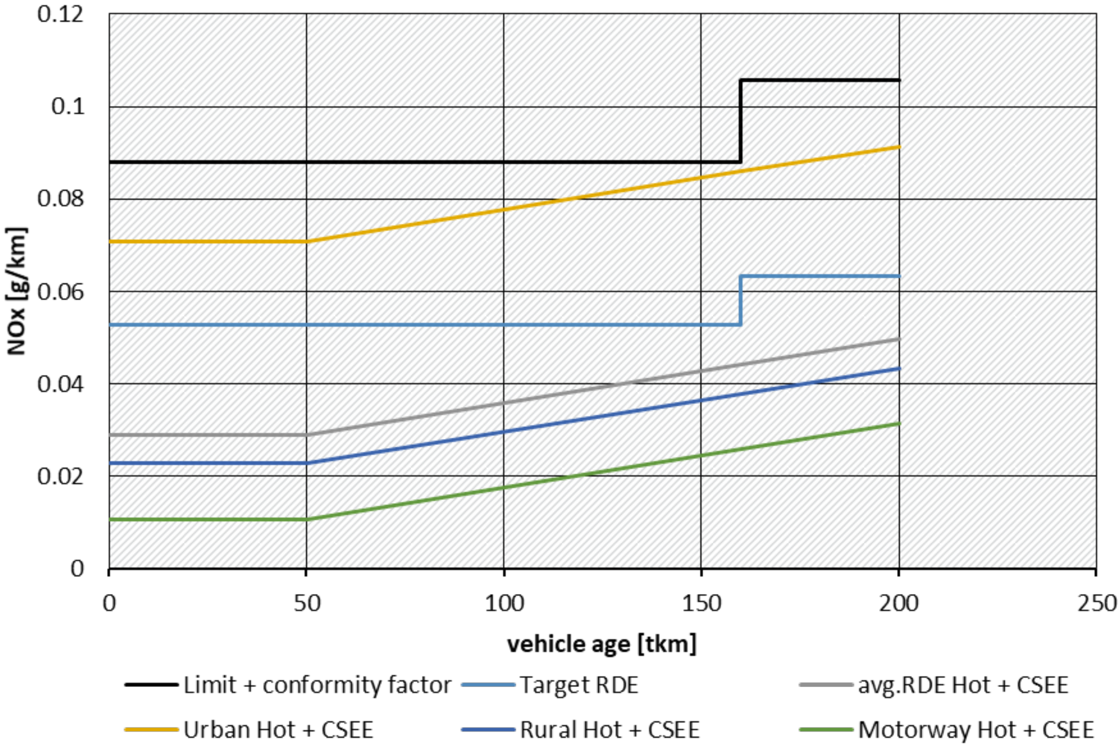
Table 4: Deterioration ratios for the calculation of Euro 7

Technology [-]	Pollutant [-]	deterioration ratio Euro 7/6d [-]
Diesel	NO_X	0.8
Diesel	CO	1.0
Diesel	HC	1.0
Petrol	NO_X	0.8
Petrol	CO	0.8
Petrol	HC	1.0

These parameters were used to simulate the WLTC cycle, three representative RDE cycles (urban, rural, motorway) and an average RDE cycle. A cold start at a temperature of 20°C was defined in the WLTC. The RDE cycles were simulated as a worst-case scenario with an ambient temperature of 0°C. As a target value, the WLTC limit and consequently the RDE Not-to-exceed limits were reduced by a safety margin. One reason for this is that the average Euro 6d map also includes vehicles that emit more than the average vehicle and these must also comply with the WLTC limit in the certification. To define the WLTC target value, the WLTC limit was therefore reduced by 25%. The RDE target value calculated by reducing the Not-to-exceed limit by 40%, as the RDE measurements show more variability in trip dynamics.

The simulated emission values were compared with the above-mentioned target values and the maximum relative exceedance was determined. This relative exceedance was defined as the reduction target from Euro 6d to Euro 7. As an example of this method, the results for NO_X emissions from a diesel passenger car are shown in the following graph.

Figure 10: Euro 7 target values and simulated results for NO_X to derive the Euro 7 model



Source: own illustration

For diesel vehicles, it was assumed that the reduction measures for NO_X will have the same effect in both warm and cold start behavior, so they are divided equally. In the case of petrol vehicles, it was assumed for the gaseous components that approximately 70% of the reductions would be achieved in the hot operating behavior and approximately 30% in the cold start behavior. The resulting reduction measures for deriving Euro 7 from Euro 6d are shown in the following table. These reduction targets were used to calculate both the emission maps and the cold start curves for petrol and diesel Euro 7.

Table 5: Calculated reduction targets from Euro 6d to Euro 7 for diesel and petrol vehicles

	NO_X [%]	CO [%]	HC [%]	PN_{10} [%]
Diesel emission map	46.8%	no reduction		
Diesel cold start	46.8%			
Petrol emission map	13.5%	26.7%	9.9%	6.9%
Petrol cold start	10.4%	18.6%	4.0%	no reduction

The reduction of NO_X and HC also has an effect on the NO_X[7] and HC[8] components. These were reduced by the same ratio.

As already mentioned, the hot emission maps created in this way represent the average emission behavior at 20°C and a mileage of 50,000 km.

---

[7] NO_X components: NO, NO_2

[8] HC components: Methane, 1,3-Butadien, Acetylene, Ethylene, Propane, Propylene, Ethane

3.2 Heavy-duty vehicles

The Euro 7 regulation for HDV will come into force in 2028 for all new models and in 2029 for all vehicles according to Regulation EU 2024/1257. The test cycles will remain the same as for Euro VI. The WHSC and WHTC will continue to be tested on the engine test bench, and emission behaviour in real traffic and operational conformity will be tested using ISC tests (renamed to RDE tests). The boundary conditions for valid ISC tests correspond to the Euro VI E specifications, with the exception of a lower power limit for valid moving average windows (MAWs), which is removing low load parts of a test in the evaluation method of the EMROAD[9]. This enables Euro 7 RDE tests to cover most of the low-load range that is critical in terms of NO_X emissions, which occurs, for example, in urban driving with high traffic volumes or in traffic jams and is therefore particularly relevant in urban areas. Ambient temperatures for valid RDE tests must still be between -7°C and 30°C, with evaluation beginning when the coolant temperature reaches 30°C or after 10 minutes at the latest. Operational conformity must still be demonstrated in ISC tests up to a mileage of 300,000 km for vehicles with a maximum permissible mass of less than 16 t and up to 700,000 km for vehicles with a maximum permissible mass of more than 16 t[10].

Furthermore, the limit values have been adjusted. The Euro 7 limit values for NO_X are 57% lower in the WHTC and 62% lower in the ISC tests than in Euro VI. For CO, the reduction is just under 70%. In addition, limit values have been introduced for other components, such as N_2O and PN_{10}. The limit values for HDV vehicles in Euro 7 are shown in Table 6.

Table 6: Euro 7 HDV limits, Regulation EU 2024/1257

Pollutant emissions	WHSC and WHTC per kWh	Real Driving Emissions per kWh
NO_X in mg	200	260
PM in mg	8	-
PN_{10} in #	$6x10^{11}$	$9x10^{11}$
CO in mg	1,500	1,950
NMOG in mg	80	105
NH_3 in mg	60	85
CH_4 in mg	500	650
N_2O in mg	200	260

Based on the current state of technology, two different systems relating to engine and exhaust aftertreatment technology are being considered for achieving the Euro 7 limits:

- On the one hand, there is the option of using an exhaust aftertreatment system that is very similar in design to that used in Euro VI and achieving the stricter limits with improved

---

[9] The EMROAD evaluation tool is already used in Euro VI but used a 20%/10% threshold for the average power/rated power ratio per window while Euro 7 used a 6% threshold.

[10] The maximum mileage for ISC tests is increased by 25% for the additional lifetime, but the limit values are also adjusted by a factor of 1.2 (current proposal). (Weller, 2025)

components (e.g., more effective catalyst materials) and a reduction in raw emissions from the engine, in the case of NO_X with increased exhaust gas recirculation (EGR).

- The other option is to install an additional SCR catalyst closer to the engine, which is smaller than the SCR catalyst in the Euro VI exhaust aftertreatment box. This SCR catalyst closer to the engine (and thus upstream of the DPF) reaches its operating window earlier during a cold start than the SCR catalyst downstream and ensures higher NO_X conversion rates under low-load driving conditions. At higher engine load the SCR catalyst downstream is in the ideal temperature area and overtakes most of the NO_X conversion. Although this system is more complex, it allows for higher raw emissions and lower EGR rates. This can have a positive effect on fuel consumption and particulate emissions.

At this point in time, it is not yet clear which of the systems will prevail or whether both will be used in parallel. From today's point of view, most OEMs will use the dual SCR system. However, for the assessment of Euro 7 emission levels with the model PHEM, we used the Euro VI E model as basis and increased the entire SCR volume, adjusted the thermal management strategies and conversion efficiencies etc., since a complete optimization of a new system without yet having Euro 7 test data were out of scope of this study. Details are described below. The emission trends simulated with these settings shall show Euro 7 behavior of both possible systems well.

Discussions with manufacturers during the development of the Euro 7 legislation showed that, in addition to the WHTC, the transient test bench test, worst case ISC tests will also be defined for development. Worst case refers to the driving cycle itself on the one hand, but also to the environmental conditions on the other.

To this end, two different cycles were developed based on previously recorded real-world driving. The focus is on the start of the test because in this phase the engine and exhaust aftertreatment are cold, and this part therefore has the greatest influence on overall emissions. The cold start part is weighted at 14% and must be included in the proportion of urban driving.

- The so-called high-load test begins with high-load uphill driving in urban areas. Due to the high load and the resulting high exhaust gas temperatures, the engine and exhaust aftertreatment heat up very quickly, but raw emissions are very high before the operating window is reached.
- The low-load test starts with a very low-load urban drive, with the average power output just above the six per cent of rated power required for a valid test. In this phase, the raw emissions are relatively low, but the system takes longer to heat up due to the lower exhaust gas temperatures. At the end of the low-load drive, the cycle then includes a high-load uphill drive, which places high demands on exhaust aftertreatment, especially in the first few seconds due to the abrupt increase in load.

The cold start phase is followed by a mix of city, interurban and motorway driving in accordance with the ISC framework conditions. This is the same for both tests and this warm test phase is weighted with 86%.

In addition, the ambient temperatures were varied at the start of the test. It is assumed that the temperatures of the vehicles, engine and exhaust aftertreatment have fully adjusted to the ambient temperature due to a sufficiently long standstill period before the start of the test. This is also required in the regulations for valid tests up to a deviation of five degrees Celsius.

- At a starting temperature of -7°C, exhaust gas aftertreatment takes the longest of all possible ISC-compliant test conditions to reach the operating window. These test conditions therefore also result in the highest emissions. However, since the evaluation only begins at a coolant temperature of 30°C or after ten minutes at the latest, a large part of these increased emissions is not taken into account in the evaluation.

- The starting temperature of 30°C is the other extreme, the highest possible starting temperature. At this temperature, the exhaust aftertreatment system reaches its operating window more quickly, but the evaluation begins at the start of the test. This means that all emissions are recorded from the start of the test.

The development target is defined in such a way that, due to dispersion in series vehicle production and safeguarding against driving cycles that are even more challenging than the defined worst-case scenarios, the limit value for the maximum permissible mileage is undershot in all tests by a safety margin in the range of 50%. The slightly higher safety margin in the ISC compared to the RDE test for passenger cars was assumed due to additional statistical uncertainties in the moving average window evaluation method for HDV. In the WHTC, the safety margin can be lower because the cycle is known and only the series dispersion needs to be taken into account.

Table 7 and Table 8 show the comparison with the limit values for the various simulations. The first column shows the test, while the second column indicates whether the ISC tests are for the low-load or high-load urban section. The third column shows the vehicle class, with N2 standing for rigid trucks and N3 for long-haul vehicles. The ambient temperature is also shown. The results are then illustrated as a percentage, showing the proportion of the limit value. This means that 100% corresponds to the emission value exactly matching the limit value, and 10% corresponds to the value being 90% below the limit value.

In order to achieve the NO_X development target in all worst-case test cycles, exhaust gas heating was increased, resulting in higher temperatures in the exhaust aftertreatment system and thus better conversion rates. This has a positive effect on NO_X emissions, especially during cold starts and low-load driving conditions. Furthermore, heat losses in the exhaust system were reduced. This was achieved by improving the insulation of the exhaust system. Another measure is to lower the limit temperature for AdBlue injection, which can be achieved through fundamental system development. In addition, the NH_3 storage capacity of the SCR catalytic converter has been increased based on assumed further developments in catalyst materials. The improvement of the SCR catalytic converter also has an effect through improved NO_X conversion rates and a reduced influence of ageing effects. Increasing the EGR rate also reduces engine NO_X emissions, which is particularly important during cold starts. Compared to the Euro VI DE base model, these measures reduce NO_X emissions by 50 to 90 per cent, depending on the driving situation. This means that the emission value in the most challenging ISC scenario for NO_X (rigid truck, high load in cold start, ambient temperature -7°C) is 40 % of the Euro 7 limit value. In the WHTC at -7°C, NO_X emissions fall below the limit value by one quarter. The measures therefore lead to the Euro 7 development target being met even in worst-case scenarios.

NH_3 emissions were reduced by up to 70% compared to Euro VI DE, mainly due to an assumed improvement in AdBlue dosing control in combination with the slip catalyst and a reduction in ageing-related emission increases through material development. This means that the Euro 7 development targets are achieved in the WHTC and under worst-case ISC test conditions.

N_2O is reduced by means of an improved AdBlue injection strategy and the use of catalyst materials that are less prone to N_2O formation, for example vanadium. Compared to Euro VI DE, these measures result in a 30% reduction in emissions, thereby achieving the Euro 7 development targets.

CO emissions increase by up to approximately 120% compared to Euro VI DE due to the increased heating measures and increased EGR rates. Nevertheless, emissions are still below ten percent compared to the Euro 7 limit value.

The measures listed are not expected to have any significant impact on emission behaviour for PN_{10}, NMHC/NMOG and CH_4. As these emission values for Euro VI DE are already at a low level compared to their respective limit values, no reduction measures were necessary to achieve the Euro 7 limit values for these components.

Table 7: emission levels of the Euro 7 model compared to the Euro 7 limits, part 1

Test	ISC-test base	Vehicle category	Temperature	NO_X	PN_{10}	NMHC/NMOG	NH_3
ISC	high-load	N3[11]	-7°C	42%	34%	33%	4%
ISC	low-load	N3	-7°C	43%	36%	34%	4%
ISC	high-load	N3	30°C	53%	34%	33%	4%
ISC	low-load	N3	30°C	49%	36%	34%	4%
ISC	high-load	N2[12]	-7°C	40%	28%	43%	48%
ISC	low-load	N2	-7°C	40%	29%	43%	48%
ISC	high-load	N2	30°C	54%	28%	43%	48%
ISC	low-load	N2	30°C	47%	29%	43%	48%
WHTC	-	-	-7°C	75%	47%	55%	68%
WHTC	-	-	30°C	62%	47%	55%	68%

Table 8: emission levels of the Euro 7 model compared to the Euro 7 limits, part 2

Test	ISC-test base	Vehicle category	Temperature	N_2O	CH_4	CO
ISC	high-load	N3	-7°C	28%	1%	7%
ISC	low-load	N3	-7°C	30%	1%	7%
ISC	high-load	N3	30°C	27%	1%	7%
ISC	low-load	N3	30°C	30%	1%	7%
ISC	high-load	N2	-7°C	47%	1%	7%
ISC	low-load	N2	-7°C	49%	1%	7%
ISC	high-load	N2	30°C	46%	1%	7%
ISC	low-load	N2	30°C	49%	1%	7%
WHTC	-	-	-7°C	56%	2%	9%
WHTC	-	-	30°C	56%	2%	9%

In addition to adapting the engine and exhaust aftertreatment system, the vehicle data for Euro 7 vehicles were updated based on Euro VI DE data. The most important measures are the reduction of unladen weight, air resistance and rolling resistance, as well as an increase in the efficiency of the engine itself and the auxiliary units. These measures result in a reduction in fuel consumption and are necessary from today's perspective in order to achieve the 2030 CO_2 fleet

---

[11] N3 vehicles are all heavy goods vehicles with a GVW higher than 12 t.

[12] N2 vehicles are all heavy goods vehicles with a GVW lower than 12 t.

targets. For a standard tractor trailer combination travelling on the motorway, the reduction in fuel consumption of Euro 7 compared to Euro VI DE is around ten per cent.

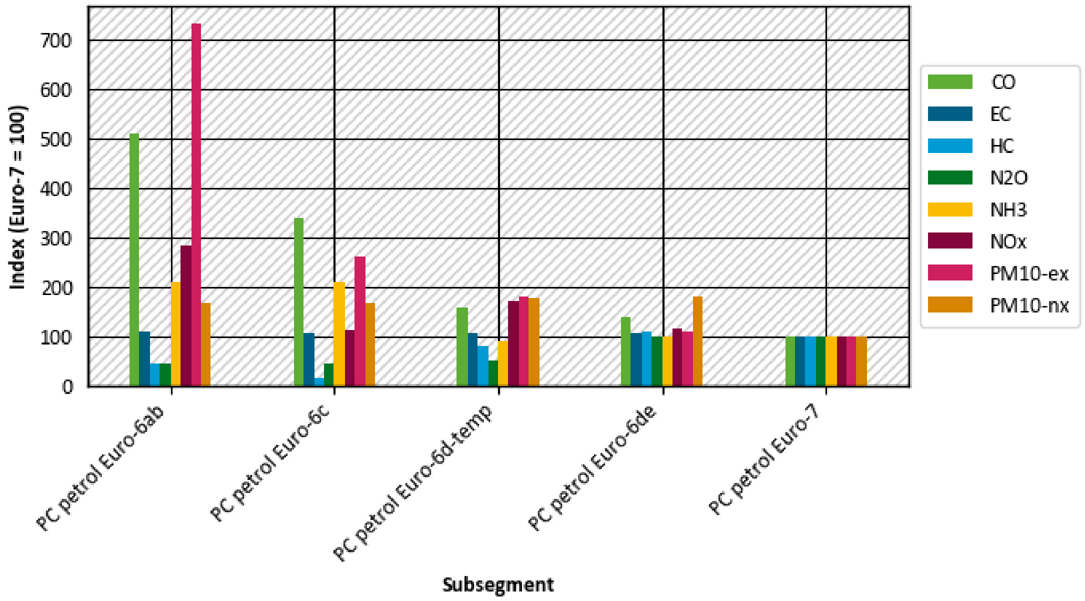
The PHEM emissions model, which is based on truck data, is also used for coaches and urban buses as it is the case for Euro VI[13]. For validation purposes, corresponding driving cycles were simulated in advance and the function of the model was tested. For buses, this leads to similar reduction rates from Euro VI DE to Euro 7 as for trucks. Thus, the model can also be used for these vehicle classes.

3.3 Integration and plausibility check in the HBEFA application

For the integration of the Euro 7 emission factors into the HBEFA database, 147 new subsegments, along with the other data structures necessary, were defined in HBEFA, as a result of the "Euro 7" emission standard combined with all other relevant characteristics, i.e. vehicle categories, main and base technologies, and size classes. The Euro 7 emission factors from PHEM were then imported into the HBEFA application the same way as the emission factors for the pre-existing vehicle types.

The plausibility of the integrated emission factors was checked by querying the Euro 7 emission factors at subsegment level together with the emission factors of older subsegments. Figure 11, Figure 12 and Figure 13 show emission factors of different pollutants affected by the Euro 7 regulation, indexed to the respective Euro 7 emission factors; they thus show the relative improvement of Euro 7 with respect to the different Euro-6/VI steps. For most pollutants, Euro 7 represents an improvement compared to Euro-6/VI. Some pollutants like HC (or HC components, respectively), N_2O, or NH_3, however, exhibit increases from the oldest Euro-6/VI step to Euro 7, most likely due to side-effect of NO_X reduction. Euro 7 mitigates these side-effects at least partially compared to the Euro-6de/VI DE step.

Figure 11: **Emission factors of new petrol PC (average German traffic situation distribution) from Euro-6ab to Euro 7, indexed to Euro 7.**

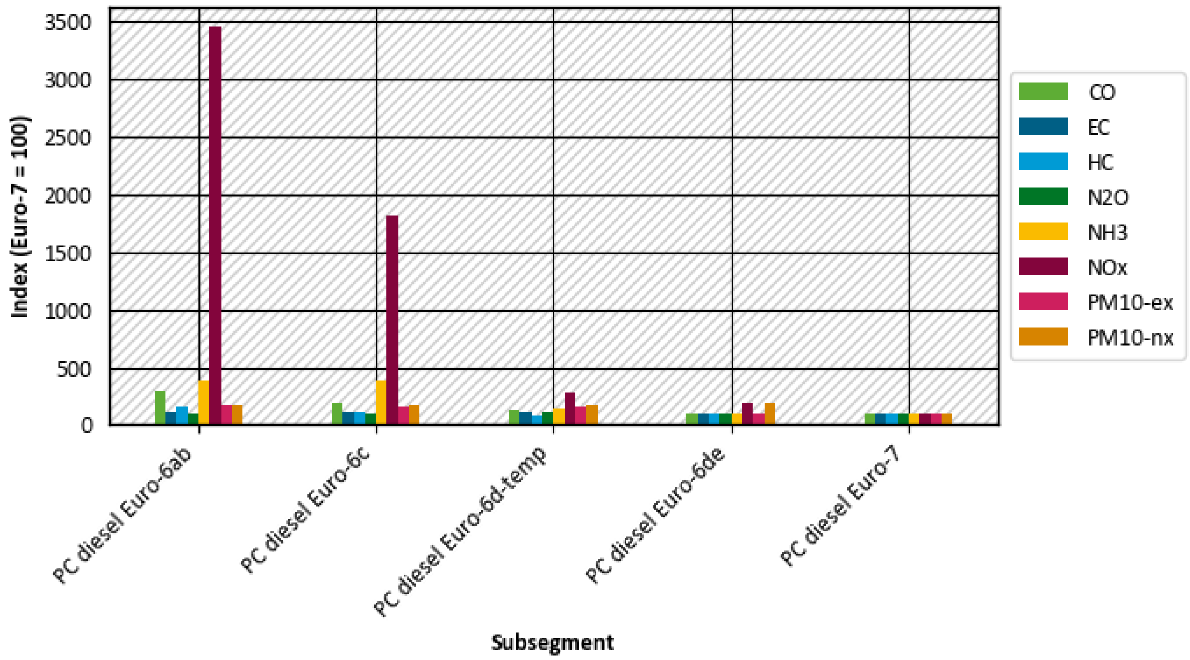


Source: own illustration, based on HBEFA 5.1

---

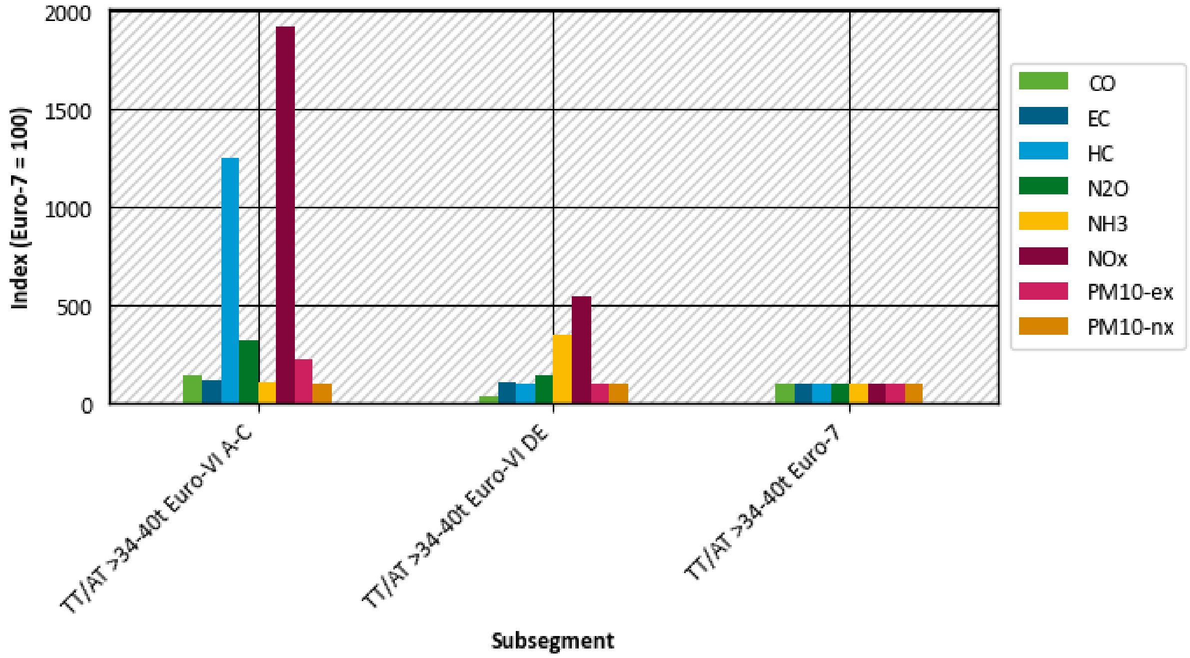
[13] Additional test data for urban busses and coaches starting from Euro VI onwards would enable the elaboration of specific emission models and thus an increasing model accuracy for these vehicle categories.

Figure 12: Emission factors of new diesel PC (average German traffic situation distribution) from Euro-6ab to Euro 7, indexed to Euro 7.



Source: own illustration, based on HBEFA 5.1

Figure 13: Emission factors of new 40 t diesel TT/AT (average German traffic situation distribution) from Euro-VI A-C to Euro 7, indexed to Euro 7.



Source: own illustration, based on HBEFA 5.1

4 Integration of non-regulated pollutants

4.1 Pollutant selection

In a parallel UBA-project “Nationale und internationale Abgasgesetzgebung bei Pkw, leichten und schweren Nutzfahrzeugen” (Hausberger et al., 2025) various non-regulated exhaust gas components from cars and HDVs have been analyzed for their relevance as pollutants. For the analysis all test data measured with FTIR analyzers and available in the DBEFA have been used. Exhaust gas components, with emission levels above the detection limits of the analyzers, either in cold or hot engine conditions and with relevant health risks have been selected to be added to the exhaust gas components covered already in HBEFA 4.2. Four exhaust gas components were selected, which should be newly integrated into version 5.1 of HBEFA:

- Formaldehyde (HCHO)
- Acetaldehyde (CH_3CHO)
- Isocyanic acid (HNCO)
- Nitrous acid (HNO_2)

4.2 Emission factors for Euro 6 /VI vehicles

Since FTIR analysers were used only in recent test campaigns, only test data for Euro 6/VI vehicles were available in the data base DBEFA. From these data the standard procedure was used[14], to produce the emission factors for HBEFA 5.1 with the simulation tool PHEM:

- using all real-world test data in 1 Hz time resolution to set up engine emission maps per vehicle,
- producing weighted average emission maps per vehicle layer (vehicle category, Euro class and SI or CI engine); Weighting was done according to the sales numbers of the vehicle models in the EU,
- using the vehicle emission model PHEM to calculate engine power and engine speed in all HBEFA driving situations for all vehicle layers in 1 Hz time resolution and interpolate the emissions from the average engine emission maps,
- calculating the sum of the 1 Hz emissions divided by the cycle distance gives the emission factor in g/km

4.3 Emission factors for older vehicles

The emission factors for all emission standards older than Euro 6ab / VI A have been derived by “Euro-standard-correction factors”. These correction factors have been elaborated from some single tests performed on Euro 4 and 5 vehicles and from literature data. The details will be described in the report of another UBA project (Hausberger et al., 2025). It has to be noted, that the correction factors are based on a quite small number of test data from vehicles between Euro 1 and Euro 5 while the analysis of the Euro 6 data showed a large spread between lowest and

---

[14] Same method as applied for regulated exhaust gas components like CO and HC.

highest emission values measured. Thus, the factors include a high uncertainty, which we cannot even quantify due to the very limited data set.

Nevertheless, to have these exhaust gas components available in HBEFA, the emission factors for the older Euro classes had to be completed as good as possible, otherwise no fleet average results can be queried from HBEFA. We think, the method is sufficiently robust to provide emission factors for these new components for recent and future years. Fleet emission factors for former years include increasing uncertainties, since the fleet share of the older Euro classes increases.

The “Euro-standard-correction factors” applied in HBEFA 5.1 for the older Euro classes are listed in Table 9 to Table 11.

Table 9: Proposed ratio factors for the new, non-limited exhaust gas components in HBEFA 5.1, applicable to passenger cars and light-duty vehicles of emission stages Euro 0 to Euro 6d, each based on the emission factors of Euro 6d-TEMP

	Cars & LCVs gasoline hot				Cars & LCVs diesel hot			
	HCHO	CH_3CHO	HNCO	HNO_2	HCHO	CH_3CHO	HNCO	HNO_2
ECE 15/04	110.90	7.89	n.a.	n.a.	1.90	0.56	0.28	3.74
Euro 1	17.34	0.95	n.a.	n.a.	1.75	0.56	0.28	3.74
Euro 2	6.80	0.90	n.a.	n.a.	1.60	0.56	0.28	3.74
Euro 3	1.95	0.85	n.a.	n.a.	1.44	0.56	0.28	3.74
Euro 4	1.76	0.78	n.a.	n.a.	1.29	0.56	0.28	3.74
Euro 5	1.50	0.71	n.a.	n.a.	1.14	0.56	0.35	3.74
Euro 6abc	1.24	0.73	n.a.	n.a.	1.07	0.50	0.50	2.37
Euro 6 d-TEMP	1.00	1.00	n.a.	n.a.	1.00	1.00	1.00	1.00
Euro 6 d	0.80	0.71	n.a.	n.a.	0.40	0.56	0.43	0.71

Table 10: Proposed ratio factors for the new, non-limited exhaust gas components in HBEFA 5.1, applicable to passenger cars and light-duty vehicles of emission stages Euro 0 to Euro 6d, each based on the cold start emission factors of Euro 6d-TEMP

	Cars & LCVs gasoline cold				Cars & LCVs diesel cold			
	HCHO	CH_3CHO	HNCO	HNO_2	HCHO	CH_3CHO	HNCO	HNO_2
ECE 15/04	9.86	0.08	n.a.	n.a.	0.28	0.21	0.08	-0.12
Euro 1	6.69	0.64	n.a.	n.a.	0.28	0.21	0.10	-0.15
Euro 2	2.63	0.67	n.a.	n.a.	0.26	0.21	0.12	-0.19
Euro 3	1.05	0.71	n.a.	n.a.	0.26	0.21	0.16	-0.24

	Cars & LCVs gasoline cold				Cars & LCVs diesel cold			
Euro 4	0.66	0.78	n.a.	n.a.	0.22	0.21	0.20	-0.30
Euro 5	0.28	0.86	n.a.	n.a.	0.17	0.21	0.24	-0.50
Euro 6abc	1.23	1.31	n.a.	n.a.	0.69	0.24	0.73	0.60
Euro 6 d-TEMP	1.00	1.00	n.a.	n.a.	1.00	1.00	1.00	1.00
Euro 6 d	0.82	0.90	n.a.	n.a.	0.87	0.54	0.49	1.00

Table 11: Proposed ratio factors for the new, non-limited exhaust gas components in HBEFA 5.1, applicable to heavy-duty vehicles of emission stages Euro 0 to Euro VI E, each based on the hot and cold start emission factors of Euro VI D

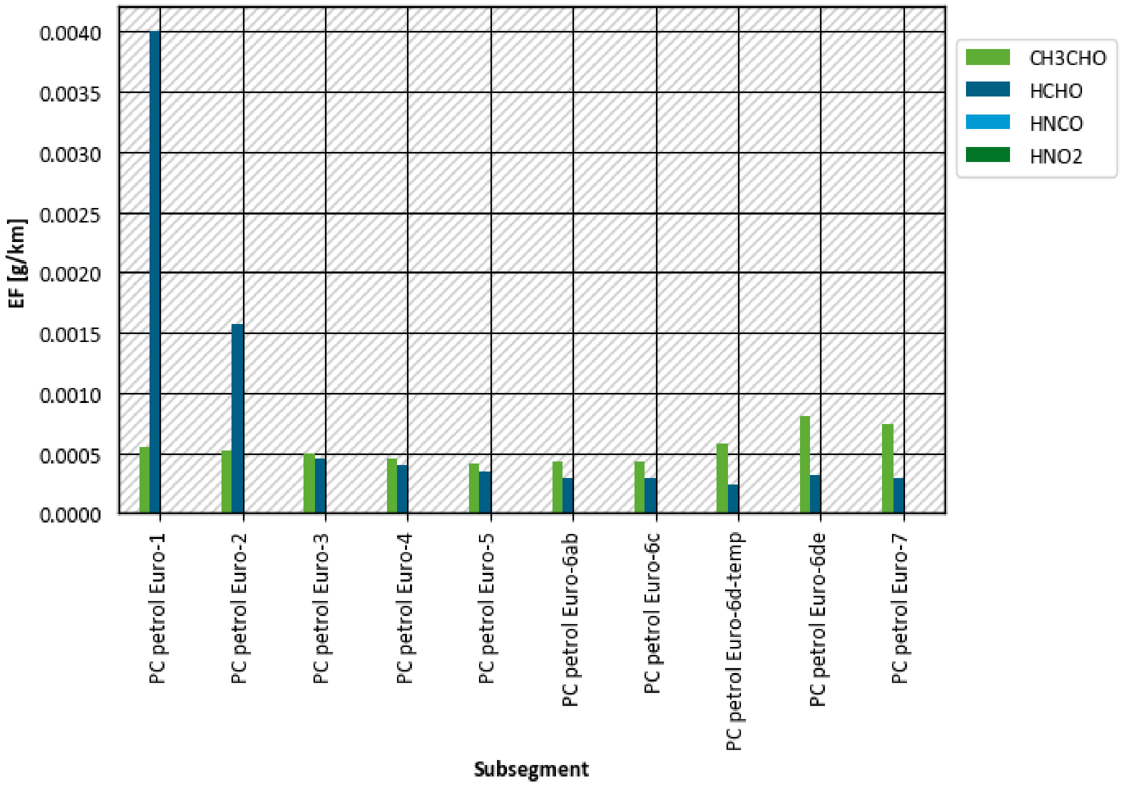
	HDVs diesel hot				HDVs diesel cold			
	HCHO	CH_3CHO	HNCO	HNO_2	HCHO	CH_3CHO	HNCO	HNO_2
ECE 15/04	9.31	1.67	0.28	3.74	0.28	0.21	0.08	-0.12
Euro I	8.69	1.56	0.28	3.74	0.28	0.21	0.10	-0.15
Euro II	5.70	1.02	0.28	3.74	0.26	0.21	0.12	-0.19
Euro II	5.39	0.97	0.28	3.74	0.26	0.21	0.16	-0.24
Euro IV	4.92	1.15	0.28	3.74	0.22	0.21	0.20	-0.30
Euro V	4.46	1.34	0.35	3.74	0.17	0.21	0.24	-0.50
Euro VI ABC	4.00	1.52	0.82	0.99	1.36	1.25	0.50	2.42
Euro VI D	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Euro VI E	0.60	1.11	0.09	0.10	0.64	0.52	0.10	0.24

4.4 Integration and plausibility check in the HBEFA application

The emission factors of the new non-regulated pollutants have been integrated in HBEFA in analogy to the pre-existing components. The Euro-6/VI EF were available from PHEM at subsegment/cycle/load/gradient resolution. For the older vehicle types, the derivation factors from Table 9 to Table 11 were applied. Negative HNO_2 emission factors, which occurred in the PHEM output (resulting from negative measurement values), were set to zero before the database import.

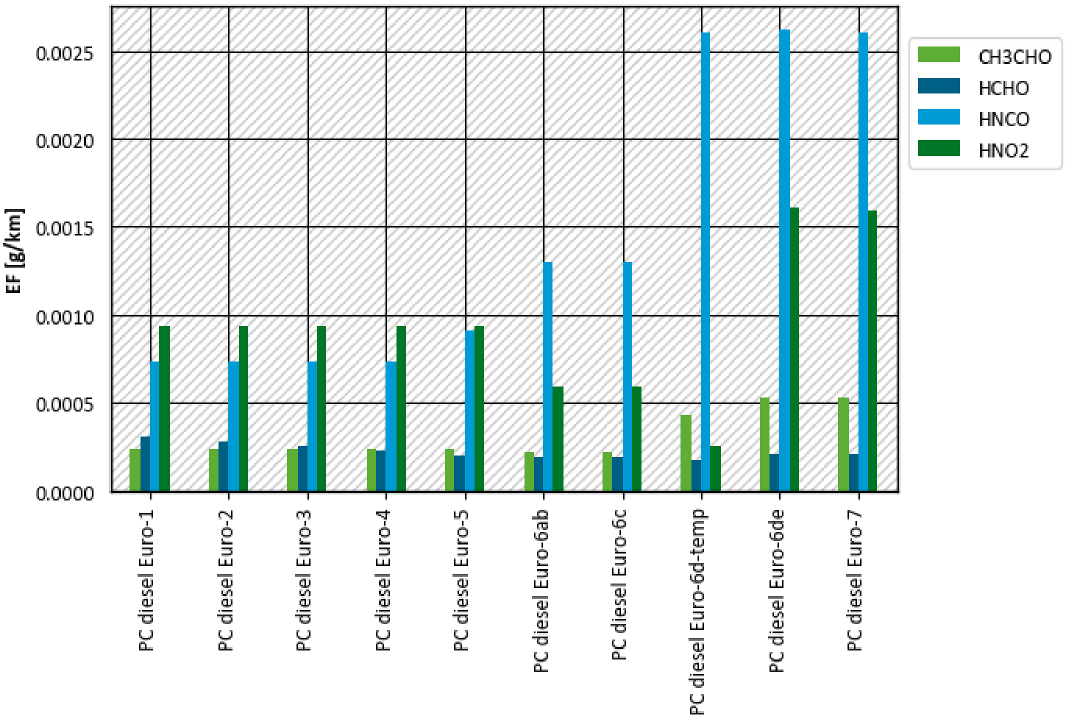
The integrated new non-regulated emission factors were checked for plausibility by querying them from HBEFA server and visualizing the resulting time series. Examples can be seen in Figure 14, Figure 15 and Figure 16. It should be noted that HNCO and HNO_2 emission factors are zero for some vehicle types, e.g. all petrol PC.

Figure 14: **Emission factors of the new non-regulated pollutants for petrol PC (average German traffic situation distribution).**



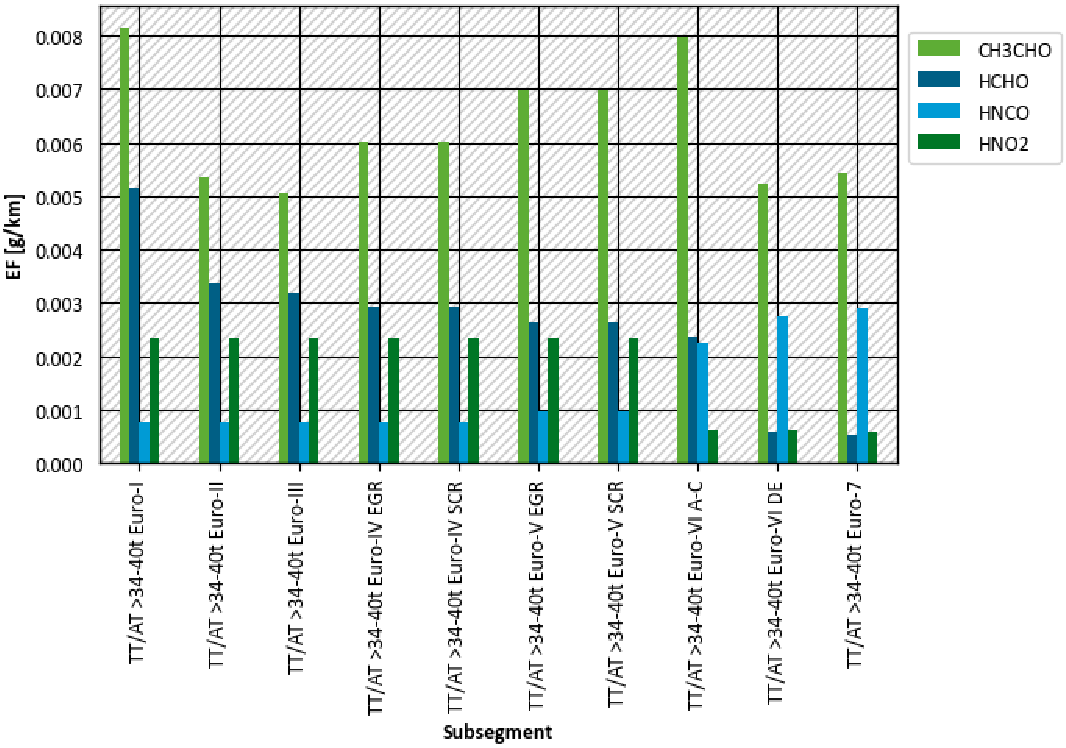
Source: own illustration, based on HBEFA 5.1

Figure 15: Emission factors of the new non-regulated pollutants for diesel PC (average German traffic situation distribution).



Source: own illustration, based on HBEFA 5.1

Figure 16: Emission factors of the new non-regulated pollutants for 40 t TT/AT (average German traffic situation distribution).



Source: own illustration, based on HBEFA 5.1

5 List of references

Borken-Kleefeld, J.; Chen, Y. (2015): New emission deterioration rates for gasoline cars – Results from long-term measurements. In: Atmospheric Environment. Bd. 101, S. 58–64. DOI: 10.1016/j.atmosenv.2014.11.013.

Borken-Kleefeld, J.; Dallmann, T. (2018): Remote sensing of motor vehicle exhaust emissions. The International Council on Clean Transportation (ICCT). https://theicct.org/sites/default/files/publications/Remote-sensing-emissions_ICCT-White-Paper_01022018_vF_rev.pdf [11.11.2025].

Hausberger, S., Allekotte, M., Cuelenaere, R., de Ruiter, J., Eijk, A., Heidt, C., Indrajuana, A., Ligterink, N., Lipp, S., Notter, B., Opetnik, M., Paalvast, M., Tödling, M., Verbeek, R., Weller, K. (2025). Nationale und internationale Abgasgesetzgebung bei Pkw, leichten und schweren Nutzfahrzeugen - Wissenschaftliche Beratung im Rahmen der Entwicklung der Euro 7-Norm. Abschlussbericht. Umweltbundesamt (UBA). (noch nicht veröffentlicht)

Hausberger, S.; Matzer, Claus (2017): Update of Emission Factors for EURO 4, EURO 5 and EURO 6 Diesel Passenger Cars for the HBEFA Version 3.3. Graz University of Technology (Editor). https://www.umweltbundesamt.de/sites/default/files/medien/376/dokumente/bericht_der_tu_graz_zum_hbefa_3.3.pdf [11.11.2025].

Matzer, C.; Weller, K.; Dippolt, M.; Lipp, S.; Röck, M.; Rexeis, M.; Hausberger, S. (2019): Update of Emission Factors for HBEFA Version 4.1. Final report. Graz University of Technology (Editor). https://cdn.prod.website-files.com/6207922a2acc01004530a67e/625e8d14b70af84fba1ef10c_HBEFA41_Report_TUG_09092019.pdf [23.07.2024].

Notter, B.; Cox, B.; Hausberger, S.; Matzer, C.; Weller, K.; Dippold, M.; Politschnig, N.; Lipp, S.; Allekotte, M.; Knörr, W.; André, M.; Gagnepain, L.; Hult, C.; Jerksjö, M. (2022): HBEFA 4.2 Documentation of Updates. Bern/Graz/Heidelberg/Lyon/Göteborg. https://cdn.prod.website-files.com/6207922a2acc01004530a67e/6217584903e9f9b63093c8c0_HBEFA42_Update_Documentation.pdf [03.02.2022].

Opetnik, M. (2020): Messung und Simulation von Euro 6 Otto-PKW Emissionen für das Handbuch Emissionsfaktoren des Straßenverkehrs. Graz University of Technology (Editor). https://cdn.prod.website-files.com/6207922a2acc01004530a67e/64e32257912275f64a4d3ceb_Dissertation_Matzer_Endfassung_18122020.pdf [11.11.2025].

Weller, K.; Hausberger, S.; Plakolmer, B. (2025): Durability of Euro 7 heavy-duty vehicle emissions. Technical report – LOT 2. Graz University of Technology on behalf of the European Commission (Editor). https://euagenda.eu/publications/durability-of-euro-7-heavy-duty-vehicle-emissions [11.11.2025].

A Pairs of cars used for deterioration functions

Table 12: Pairs of diesel passenger cars with low and high mileage to determine the deterioration function

vehicle id	make	model	mileage	Tech-nology	emission standard	rated power	measured cycles
[-]	[-]	[-]	[km]	[-]	[-]	[kW]	
387	Ford	Focus	193,000 (old)	diesel	Euro 6d-TEMP	88	WLTC, Ermes, IUFC
PD6-22	Ford	EcoSport	33,927 (new)	diesel	Euro 6d-TEMP	92	
354	Skoda	Octavia	177,000 (old)	diesel	Euro 6d-TEMP	85	WLTC, Ermes, IUFC
305	Skoda	Karoq	3,000 (new)	diesel	Euro 6d-TEMP	85	
379	Volvo	V60	161,000 (old)	diesel	Euro 6d-TEMP	110	WLTC, Ermes, IUFC
PD6-20	Volvo	XC60	13,719 (new)	diesel	Euro 6d-TEMP	140	
358	BMW	316d	166,000 (old)	diesel	Euro 6d-TEMP	85	WLTC, Ermes, IUFC
373	BMW	320d	6,040 (new)	diesel	Euro 6d	140	
355	BMW	X2	160,000 (old)	diesel	Euro 6d-TEMP	110	WLTC, 2x Ermes, IUFC
304	BMW	218d	2,500 (new)	diesel	Euro 6d-TEMP	110	
396	Skoda	Oktavia	180,100 (old)	diesel	Euro 6d	85	WLTC, Ermes, IUFC
343	VW	Golf	500 (new)	diesel	Euro 6d	85	
412	Hyundai	Tucson	139,300 (old)	diesel	Euro 6d	100	WLTC
302	Kia	Ceed	600 (new)	diesel	Euro 6d-TEMP	100	

Table 13: Pairs of petrol passenger cars with low and high mileage to determine the deterioration function

vehicle id	make	model	mileage	Tech-nology	emission standard	rated power	measured cycles
[-]	[-]	[-]	[km]	[-]	[-]	[kW]	
383	VW	Golf	198,000 (old)	petrol	Euro 6d-TEMP	85	WLTC, Ermes, IUFC
321	VW	T-Roc	1,967 (new)	petrol	Euro 6d-TEMP	85	
411	Ford	Focus	168,700 (old)	petrol	Euro 6d-TEMP	92	WLTC, Ermes, IUFC
301	Ford	Focus	800 (new)	petrol	Euro 6d-TEMP	92	
401	Mercedes	A180	150,000 (old)	petrol	Euro 6d-TEMP	100	WLTC, Ermes, IUFC
PB6-12	Mercedes	B200	5,612 (new)	petrol	Euro 6d-TEMP	120	
406	BMW	218i	122,688 (old)	petrol	Euro 6d	100	WLTC, Ermes, IUFC
PB6-11	BMW	118i	11,370 (new)	petrol	Euro 6d-TEMP	100	
406	BMW	218i	122,688 (old)	petrol	Euro 6d	100	WLTC, Ermes, IUFC
377	Mini	Cooper	30,000 (new)	petrol	Euro 6d	100	
413	Audi	Q3	132,000 (old)	petrol	Euro 6d-TEMP	110	WLTC
PB6-14	Audi	Q2	18,304 (new)	petrol	Euro 6d-TEMP	110	