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Agence de l'Environnement et de la Maîtrise de l'Energie ADEME (FR)
Trafikverket (SE)
Miljødirektoratet (NO)

# **HBEFA 4.1**
# Development Report

Bern, Heidelberg, 21 August 2019

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# Editorial Information

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**Commissioned by**

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# Content

## Summary


The Handbook of Emission Factors for Road Transport (HBEFA) is a database application that provides emission factors for all relevant vehicle categories in road transport (PC, LCV, HDV, buses, coaches and motor cycles). Its first version (HBEFA 1.1) was published in December 1995, a second version (HBEFA 1.2) in January 1999. Version 2.1 followed in January 2004, HBEFA 3.1 in 2010, HBEFA 3.2 in 2014, and HBEFA 3.3 in 2017. This report describes the development of the latest version so far, HBEFA 4.1.

HBEFA 4.1 is a “major” update and includes several new features and updates. They are briefly summarized in the paragraphs below. For further details, please refer to the subsequent chapters of this report.

**Alternative drivetrains**

Alternative drivetrains are a focus of HBEFA 4.1. Electric vehicles (BEV, PHEV) are newly introduced. For CNG/LNG vehicles, emission factors based on measurements and modelled by traffic situation within the PHEM model are available (in previous versions, emission factors were available, but only derived from other subsegments).

**Hot emission factor updates**

All hot emission factors are updated based on:

- Currently available measurements. Due to PEMS and Dieselgate, large amounts of new measurement data have become available since the last HBEFA version. As in previous HBEFA versions, the measurement data base especially the more recent emission standards has been improved.
- A new version of the PHEM (Passenger car and Heavy-duty Emission Model) by the Technical University of Graz), which models the hot base emission factors by driving cycle. It features a new gearshift model and improvements in the simulation of SCR catalysts such as a new NH3 storage module.

Excess emissions/consumption due to air conditioning (AC) are now included in all emission factors by default. The option for the user to select (or deselect) AC emissions/consumption has been disabled in HBEFA 4.1. The percentage of vehicles with AC is the European average by subsegment; the usage has been calibrated based on real-world fuel consumption data.

**New traffic situations and driving cycles**

Several additional traffic situations have been introduced, namely a 5th level of service ("Heavy stop+go", i.e. gridlock with average speeds 5-10 km/h), and speed limits 30 km/h on urban main roads. There are 365 traffic situations differentiated in HBEFA 4.1 (compared to 276 up to HBEFA 3.3).

In addition, all driving cycles for traffic situations have been revised (see report by Steven and Ericsson on http://www.hbefa.net). On average, the new cycles tend to have lower average speed but higher dynamics than the old ones, which in tendency leads to higher emission factors.

**Real-world fuel consumption and CO2 emissions**

The real-world fuel consumption and CO2 emissions of passenger cars have been assessed in detail in a project commissioned by the UBA Germany (research project FKZ 3716 58 180 0, carried out by ICCT, DLR, ifeu, INFRAS and TU Graz). Its results have been integrated into HBEFA 4.1. Fuel consumption is not anymore based on Euro-3 petrol and diesel PC only, but base EF for all technologies and emission standards are included. These are calibrated by country and year based on CO2 monitoring and real-world excess rates.

**WTT emission factors**

WTT emission factors for CO2 equivalents (CO2e) are newly available in HBEFA 4.1. These represent the emissions from the production of fuels/energy and are therefore available for the emission categories that include fuel or energy consumption – i.e. hot and cold start emissions.

**Updates of cold start and evaporation emission factors**

Cold start and evaporation emission factors have been updated:

- For cold start emission factors, the methodology has remained unchanged, but new measurement data have been included.
- The methodology for evaporation emission has traditionally been adopted from the COPERT model. In HBEFA 4.1, it has been updated to the methodology of COPERT V (equivalent to the Tier 3 methodology in the EMEP/EEA 2016 Emission Inventory Guidebook).

**Updates of non-regulated emission factors**

The emission factors of non-regulated pollutants such as HC species, NO2, N2O, NH3, and non-exhaust particles have been updated based on new measurement data and literature. PM-non-exhaust and BC are now available in the Public Version of HBEFA 4.1.

**Simplified segmentation**

The size classes of PC and MC have been simplified in HBEFA 4.1:

- For PC, no size classes are differentiated anymore
- For MC, fewer size classes are differentiated

For users who may miss the three capacity classes distinguished for PC so far, these are the reasons they have been abolished:

- There is no actual information lost by this simplification. For air pollutants, the same EF were used for all three size classes already in the previous HBEFA versions. The fuel consumption and CO2 emission factors, which were differentiated, were not measured, but calibrated – based on the same information still used in HBEFA 4.1, i.e. CO2 monitoring plus secondary information like fuel logs or fuel sales.
- There is no legal differentiation, e.g. regarding limit values, within the PC.
- The capacity classes used so far have more and more lost their meaning. With engine downsizing, engine capacity does not correlate so well with engine power anymore. On the other hand, any obvious classification that would have been well-accepted and for which data to implement it would be available in all HBEFA countries was not available. E.g. the "market segments" used in Germany are not available in the registration databases of any of the other HBEFA countries.

In addition, alternative drivetrains for HGV newly introduced in HBFEA 4.1 (e.g. BEV, CNG, PHEV) are not differentiated by the same detailed size classes as conventional trucks, but only by 3 size classes for rigid trucks and one size class for TT/AT.

**Updated country data**

All country data in HBEFA 4.1 have been updated. The current time series include the years 1990-2050 for most countries, with the following exceptions:

- Germany: 1994-2050
- Switzerland: 1990-2060
- Norway: 1990-2035

**Software updates of Diesel PC**

HBEFA aims to account for the software updates after the Dieselgate scandal. In HBEFA 4.1, emission factors for the Euro-5 diesel cars with an EA189 engine updated in the compulsory update round are available based on the current availability of measurement data.

# 1. Introduction

The Handbook of Emission Factor for Road Transport (HBEFA) is an emission factor database available since the mid-90s for six European countries. It contains emission factors (EF) for all relevant road vehicle categories, differentiated by vehicle layer (subcategory and emission stage) and traffic situation. The hot EF are based on measurements from laboratories within the ERMES group (European Research Group on Mobile Emission Sources) and developed using the vehicle emission model PHEM (Passenger Car and Heavy Duty Model, see e.g. Hausberger and Matzer 2017). Authorities, consultants and researchers use HBEFA for environmental impact assessments, national emission inventories and as a basis for environmental policy.

HBEFA needs to be regularly updated with new versions to account for current developments affecting road transport emissions, such as new technologies or emission standards. The present report describes the development of HBEFA Version 4.1.

The development work was structured in 13 work packages (WPs), which were executed by a consortium consisting of:

- INFRAS Research and Consulting and MK Consulting, Berne/Zurich: Project coordination, WP 1 (Data collection of emission measurements), WP 3b (Software updates of Diesel PC), WP 4 (Cold start emissions), WP 5 (Evaporation emissions), WP 6 (Alternative fuels), WP 8 (Fuel consumption/CO2), WP 10 (Country inputs, in collaboration with national environmental/transport departments). WP 12 (Extended version), WP 13 (model implementation)
- IVT (Institute of Internal Combustion Engines and Thermodynamics) at the Technical University of Graz (TUG): WP 3 (Hot emission factors), WP 3b (Software updates of Diesel PC), WP 7 (electric vehicles), WP 8 (Fuel consumption/CO2), WP 10 (country data Austria)
- ifeu (Institute for Energy and Environment), Heidelberg: WP 8 (Fuel consumption/CO2), WP 9 (Non-regulated pollutants), WP 10 (country data Germany), WP 11 (WTT emissions)
- HSDAC (HS Data Analysis and Consultancy), Düsseldorf, and WSP Sweden: WP 2 (Driving behaviour)

This report is structured in chapters corresponding to the work packages. As in the work plan, WP 13 (model implementation) encompasses general and cross-cutting aspects of model development; the integration of the results of the individual other work packages in the HBEFA application is described in the respective chapters as a subchapter “Implementation in HBEFA”.

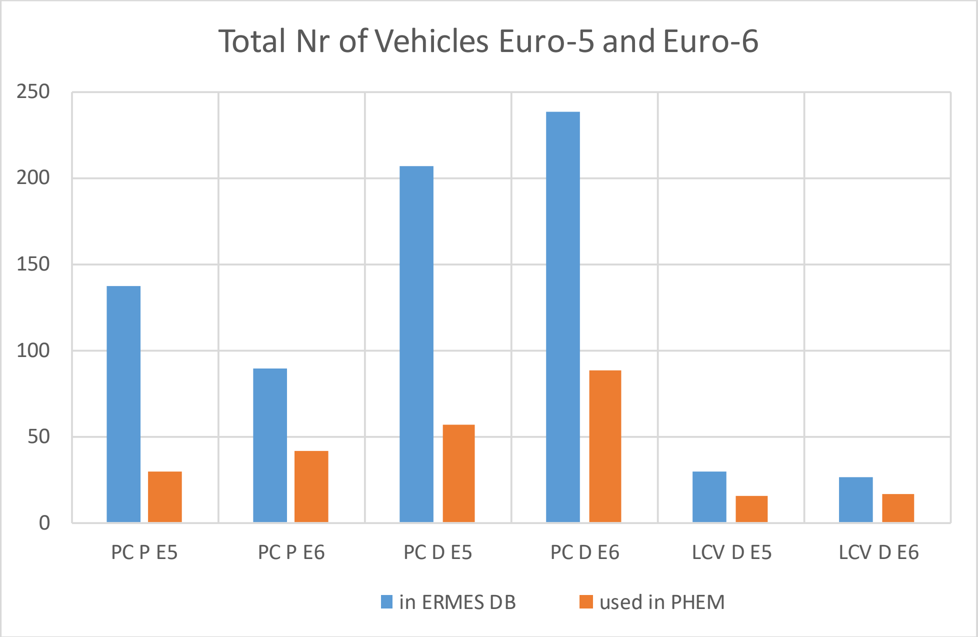
The main work on work packages (WP) 2 and 3 is described in separate reports by the TUG (Matzer et al. 2019) and HSDAC/WSP (Ericsson et al. 2019).

## 2. WP 1: Data collection of emission measurements

For HBEFA 4.1 a considerable number of measurements were collected at several laboratories throughout Europe. The data were stored in the so-called ERMES DB, and the same time a part of them were used for the PHEM model if the emission measurements and RPM-information were available as modal data (i.e. as sec-per-sec data sets). Figure 1 shows the total number of vehicles measured (PC and LCV Euro-5 and Euro-6) as well as the number of vehicles which were used for establishing engine maps for the PHEM model. All vehicles – also those not directly used for the PHEM model – were used for validation purposes. Figure 2 shows which laboratories contributed to this data pool[1]. Figure 3 then shows the different cycles in which the vehicles were measured. The PC Euro-5 data were already used for HBEFA version 3.2. The data collection for EURO 5 was updated for HBEFA 4.1. and was used for validation of the PHEM EURO 5 models. For more details on how these data were used see the TUG report on hot emission factors for HBEFA 4.1.

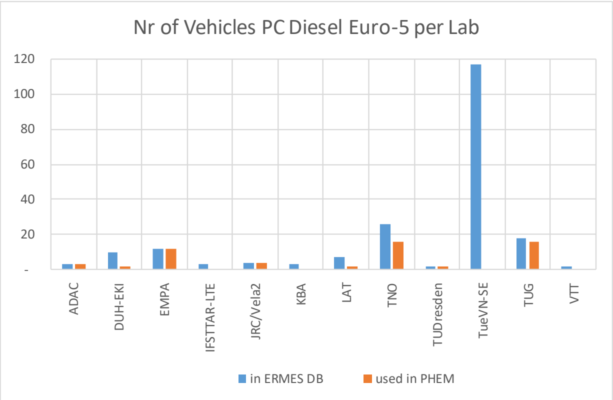
[1] Some data, as e.g. the Euro-5-data from TueVN-SE (measured by TueV Nord on behalf of Sweden) were not directly used for PHEM due to the fact that that there were already enough emission results available for establishing the Euro-5-engine maps and the added data from TueVN-SE did not change the results. However, the data were used for the validation.

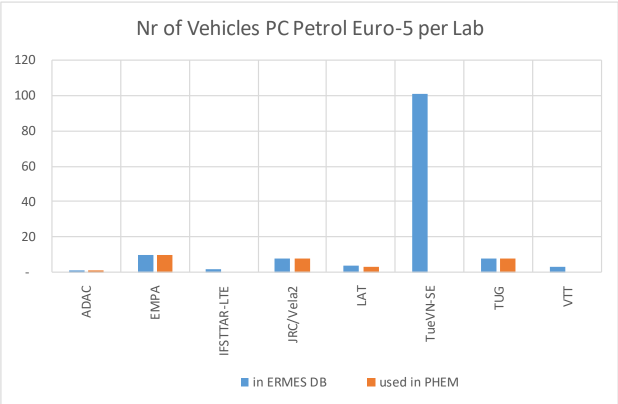
**Figure 1: Number of Euro-5 and Euro-6 vehicles measured at different laboratories on chassis-dynos and/or on the road. A part of the measurements could be used for setting up the PHEM model**

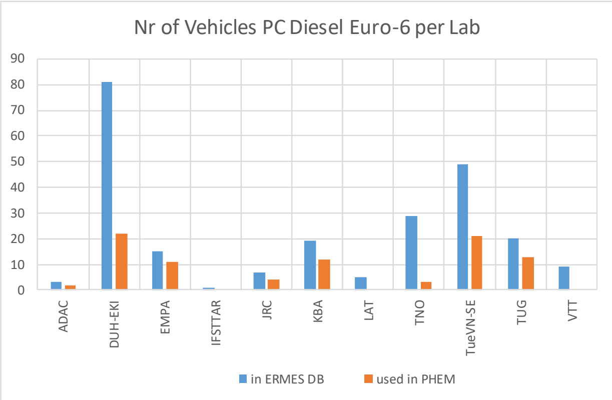


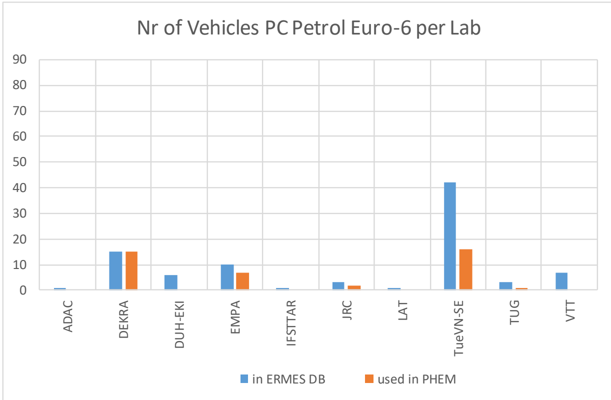

Graphics INFRAS. Sources: ERMES DB, TUG

**Figure 2: Number of PC diesel resp. PC petrol Euro-5 and Euro-6 vehicles measured at different laboratories on chassis-dynos and/or on the road.**



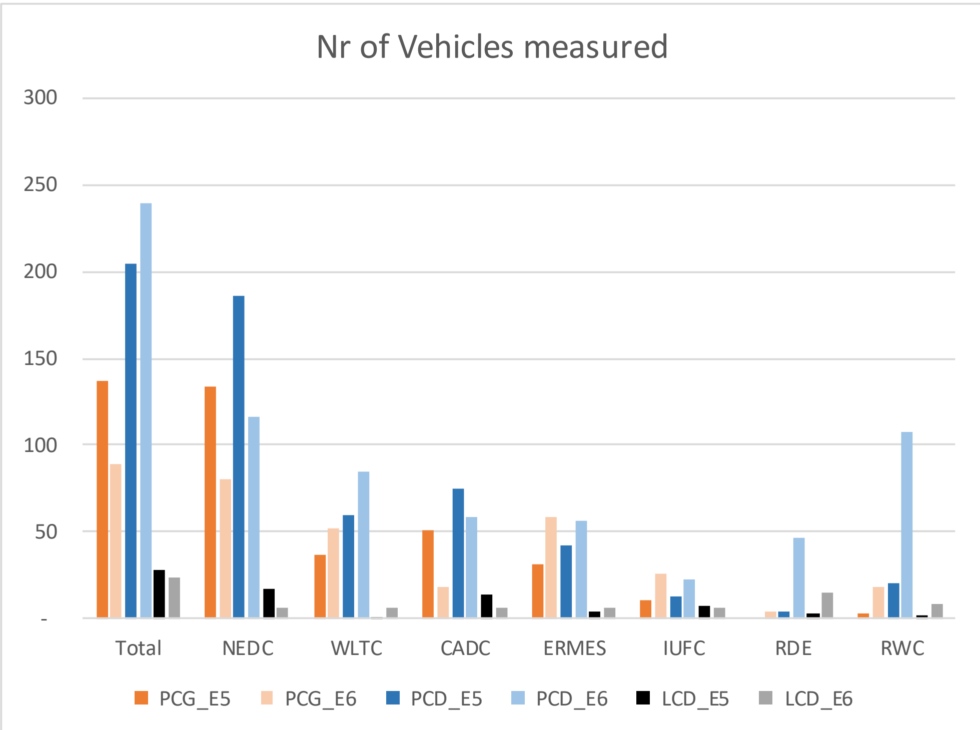



The reason s that there was already enough data for euro 5 and the added data from TueVN-SE did not change the results.

Graphics INFRAS. Source: ERMES DB

**Figure 3: Number of vehicles (PC and LCV diesel resp. PC petrol Euro-5 and Euro-6) measured in different cycles as collected and stored in the ERMES DB**




Graphics INFRAS. Source: ERMES DB

# 3. WP 2: Driving behaviour/traffic situations

## 3.1. Development of new cycles and traffic situations

The main work in WP 2, i.e.

- the review of the traffic situation definitions and descriptions, and
- the development of new cycles and traffic situations for HBEFA 4.1,

is described in a separate report by HSDAC and WSP, "Work programme 2016 - 2018 for HBEFA Version 4.1. Report of the work carried out for work package 2" (Ericsson and Steven 2019).

## 3.2. Implementation in HBEFA 4.1

### 3.2.1. Integration of inputs

Besides defining the new TS in the respective definition tables, the integration of the new cycle data required no change with respect to previous HBEFA versions in either the data structure or the calculation functionality.

The new data can be viewed in the following forms in the HBEFA application:
Expert Version:

- Menu *Definitions > List of Traffic Situations,*
- Menu *Definitions > Cycles of traffic situations*
- Menu *Definitions > Aggregate traffic situations*

Public Version:

- Menu *Info > Individual traffic situations*
- Menu *Info > Average traffic situations*

Whether the same cycle as in HBEFA 3.3 is still used for a given combination of traffic situation and vehicle category, or a new cycle has been assigned, can be viewed in the Expert Version under Menu *Definitions > Cycles of traffic situations*: after a vehicle category and a traffic situation have been selected, this information is displayed in the field "Comment".

The reviewed definitions and descriptions of traffic situations can be obtained from Ericsson and Steven (2019). In the HBEFA 4.1 application, the names and descriptions of road types have been adapted accordingly (i.e. the former "trunk" road is now referred to as "primary non-motorway ('trunk')"). I.e. the term "trunk" is still referred to in order to inform users that this is what used to be referred to as the "trunk road". The short names of the traffic situations themselves were not changed, since the term "trunk" is shorter than the correct new term, and since users might otherwise be confused by the name change.

### 3.2.2. Split of vehicle kilometres between the two "stop+go" LOS

The shares of vehicle kilometres travelled by each vehicle category in the new Level of Service (LOS) 5, "Heavy stop+go", was determined in a first approximation to be 30% of the mileage travelled in the former (LOS) 4, "Stop+go". Therefore 70% of the mileage remains in LOS 4. This is based on the simplifying assumption that about the same time is spent in both LOS (with the higher velocity in LOS 4, a higher share of vehicle kilometres is the result).

This split was communicated as a recommendation to the country data responsibles. Naturally, they are free to come up with new shares if more accurate information becomes available.

# 4. WP 3: Hot emission factors for regulated pollutants

## 4.1. Development of hot emission factors

The main work in WP 3, i.e. the development of hot emission factors using the PHEM model is described in a separate report by TU Graz, "Update Emission factors for HBEFA 4.1" (Matzer et al. 2019).

## 4.2. Implementation in HBEFA 4.1

### 4.2.1. Integration of inputs from PHEM

The base emission factors from PHEM at subsegment/cycle/gradient level were imported to HBEFA as in previous versions. The following steps were carried out additionally:

- For PHEVs (PC, LCV) and HEV urban buses, only fuel consumption was separately modelled in PHEM. The emission factors of air pollutants for running in hybrid mode ("charge sustaining mode") were copied from their ICE counterparts. Emissions during electric driving are zero.
- For the "tampered" HDV subsegments (i.e. those with SCR turned off using emulators), the emission factors for their non-tampered counterparts were imported – except for NOx, for which instead of the PHEM output "NOX tailpipe" the output "NOx Engine out" was used.
- Motorcycles have been modelled in PHEM for HBEFA 4.1 – contrary to previous HBEFA versions, in which motorcycle EF originated from HSDAC.

  For the mopeds, which also this time were not modelled in PHEM, the emission factors from

HBEFA 3.3 were copied, since the results of the ERMES-ACEM study on motorcycles became available too late to be evaluated in-depth and integrated in HBEFA 4.1.

### 4.2.2. Adjustments to the emission calculation functionality

The following adjustments were made to the emission factor calculation functionality in HBEFA:

- The functionality to calculate A/C power consumption separately was deactivated. Since A/C power consumption is now already included in the PHEM consumption factors (in contrast to previous versions of HBEFA), it is obsolete. The HVAC routine in the model PHEM and the assumed shares of vehicle equipped with A/C is described in the TUG report.
  This resulted in the following adaptations:
  - The checkboxes on the user forms that allowed the user to check whether to account for A/C have been deactivated.
  - A/C as an "attribute" has been deactivated in the fleet model.
  - "AC usage" menu in *DataPool (country specific)* and *Library* has been deactivated.
- Fuel consumption is corrected for the different heating values of the certification fuels (used in the measurements of fuel consumption – corresponds to the g/km from PHEM) and the fuel properties in the selected country. This is an improvement in consistency but has little impact on the calculation result (order of magnitude: fractions of a percent).
- The new motorcycle EF from PHEM are differentiated by gradient, in contrast to previous HBEFA versions. Accordingly, the functionality in HBEFA had to be adjusted to read in and process the differentiated EF. After the adjustments, motorcycle EF can be queried from HBEFA 4.1 not only for the gradient class "0%" (flat terrain) but also for the gradient classes "+/-2%", "+/-4%" and "+/-6%".

### 4.2.3. Derived emission factors

Per default, the reference subsegments (i.e. the subsegments from which the EF are derived) as well as the respective adjustment factors were adopted from HBEFA 3.3. The exceptions are listed in Table 2. See also Chapter 8.3 on derived EF for alternative fuels.

The subsegments with derived EF, their reference subsegments and the adjustment factors can be viewed in the HBEFA Expert Version in Menu *Extras > Red Rates EF hot > by NewSubsegment*.

**Table 1: EF derivation for derived subsegments different from HBEFA 3.3. Note: Subsegments which were previously available in the Expert Version as "derived" and are now available in both versions as "measured" (such as BEVs or some CNG vehicles) are not listed here.**

| Derived subsegment | Reference subsegment | Comment |
|---|---|---|
| LCV petrol Conv >1981 (all sizes) | Equivalent <1981 subsegment | Correction factor 1 for now, which results in similar EF to HB3.3 |
| LCV CNG/petrol and LNG/petrol (all emission concepts) | For petrol use, EF from petrol Euro-6d equivalent | |
| LCV FFV (all sizes and emission concepts) | Petrol counterparts; | For "Euro-6", the petrol "Euro-6ab" is used |
| Coach FCEV, Midi and 3-axes | Energy consumption 35% of diesel Euro-III counterpart, air pollutants = 0 | As in previous Expert Version for Standard size |
| UBus HEV Euro-IV (all sizes), size class <15t also Euro-VI | Energy consumption: UBus HEV Euro-V<br>Pollutants: Diesel counterpart, EGR for Euro-IV | |
| UBus Ethanol | Diesel counterparts | |
| E-Bike | Moped <= 50cc (v<30) EU2 | Energy consumption assumed 7% of reference subsegment, air pollutants = 0 |
| eScooter | MC BEV | Assumed 42% of MC BEV energy consumption |

Table INFRAS.

### 4.2.4. Integration of new mileage correction inputs

New mileage corrections for CO, NOx and NO2 (i.e. due to the degradation of catalysts with use) became available for HBEFA 4.1 based on the CONOX project (see e.g. Jenk 2017). They required a new, more flexible way of entering the inputs in HBEFA instead of the equation used up to HBEFA 3.3.

The functions used up to HBEFA 3.3 were implemented as an equation of the following form:

$$\text{Correction factor mileage degradation} = (a * \text{mileage} + b) / (a * \text{mileage\_norm} + b)$$

where: a, b = Parameters differentiated by urban and other roads
mileage = actual mileage
mileage_norm = standard mileage for which the base EF are valid, i.e. 50'000 km

This basic form was furthermore modified based on speed and maximum mileage.

The new functions, in contrast, do not differentiate by road type, and the input consists of correction factors at given cumulative mileages, between which correction factors are interpolated linearly. Below the lowest given cumulative mileage, the correction factor at this lowest mileage is used, and above the highest given cumulative mileage, the correction factor at this highest mileage is used (i.e. there is no extrapolation beyond the range of input values provided).

Therefore, a new database function was implemented to calculate the correction factors using the new inputs, and the user forms for viewing and editing the mileage correction functions were adapted accordingly.

The mileage deterioration functions can be viewed and edited in the Expert Version in the Menu *Extras > CorrFactors MileageDeterioration*.

The main differences between the new and the old mileage corrections for CO, NOx and NO2 can be briefly summarized as:

- The new correction factors continue to increase up to a mileage of 300'000 km, after which they remain constant. Up to HBEFA 3.3, constant factors were assumed from >150'000 km.
- The correction factors reach higher values, mainly due to the higher maximum mileage. For very old vehicles with a high mileage, maximum correction factor values for NOx of > 4 are achieved.

For HC, the CONOx data did not contain robust results. Therefore the mileage correction factors used up to HBEFA 3.3 were aggregated by road type and converted into the new structure of HBEFA 4.1.

### 4.2.5. Integration of new ambient temperature correction functions

Besides mileage corrections, the CONOX data also yielded new ambient temperature correction functions. These could be integrated in the structures existing already from HBEFA 3.3. Ambient temperature correction functions are now also available for LCV (in HBEFA 3.3 only for PC).

The ambient temperature correction functions can be viewed/edited in the Expert Version via Menu *Extras > CorrFactors AmbientTemperature*.

# 5. WP 3b: Diesel PC software updates

## 5.1. Introductory remark

WP "3b" on Diesel PC software updates was not yet included in the original work plan for HBEFA 4.1. It was commissioned as an additional work package by the German Umweltbundesamt (UBA) in the second half of 2018, as a reaction to the political relevance of these updates in Germany.

## 5.2. Development of emission factors and ambient temperature correction functions

The development of emission factors and ambient temperature correction functions for updated Diesel PC is described in a separate report by TU Graz (Matzer et al. 2019).

For HBEFA 4.1, emission factors for the Euro-5 diesel cars with an EA189 engine updated in the compulsory update round are available due to the current availability of measurement data. Additional update rounds may be included in later HBEFA versions.

## 5.3. Activity data

The following input activity data are required in HBEFA:

- Total number of (potentially) affected vehicles in vehicle stock in a given year – for the Euro-5 compulsory SW update, these include the EA189 vehicles from the VW group.
  This can be input either as an absolute number of vehicles, or as a share of all Euro-5 vehicles affected;
- Total number of vehicles out of the above number for which the software update has been conducted by the middle of the year. This is the cumulative number, i.e. it includes the numbers of vehicles updated in previous years.
  The reason why the number of updated vehicles in the middle (and not at the end) of the year has to be input is that the emissions should be representative for the year in question. The number in the middle of the year is usually the best approximation of the average over the year.

Both figures are required for all years from the first year in which the affected vehicles enter the market until the present, or the year in which all affected vehicles are updated (or the software updates are discontinued).

## 5.4. Implementation in HBEFA 4.1

### 5.4.1. Concept

Based on the requirements by the German Umweltbundesamt (UBA) who commissioned this additional work package, software updates for Diesel PC were implemented in such a way that not only emission factors for the updated PC are available in addition to the "normal" emission factors, but also the effect of vehicles being updated on the non-updated rest of the fleet is accounted for.

This is achieved by differentiating three subsegments for every source subsegment in which software updates take place:

- The vehicles not affected by the update (i.e. essentially the non-VW cars)
- The affected vehicles before the update
- The affected vehicles after the update

This way, when querying HBEFA at subsegment levels, EF for all three subsegments are produced. When HBEFA is queried at more aggregated levels (e.g. emission concept, Diesel Euro-5), the effect of the software updates becomes visible by changing emission factors over time.

The concept is implemented generically as "technology updates" in HBEFA. This means that further software updates, but also other types of technological updates, e.g. concerning the hardware, can be integrated using the same functionality.

### 5.4.2. New categories for software updates

The following subsegments were defined to hold the emission factor data for software-updated Euro-5 diesel PC:

- PC diesel Euro-5 SU before update (IDSubsegment 121952)
- PC diesel Euro-5 SU after update (IDSubsegment 121953)

These can be viewed under Menu *Definitions > Subsegments*.

The corresponding emission concepts can be accessed via Menu *Definitions > Emission concepts*.

The corresponding ambient temperature correction functions can be viewed/edited (in the Expert Version only) via Menu *Extras > CorrFactors AmbientTemperature*.

Corresponding subsegments and emission concepts have already been created for Euro-6ab and Euro-6c diesel PC, but they are not yet activated and thus not visible in the HBEFA User Interface.

### 5.4.3. Input user interface for activity data

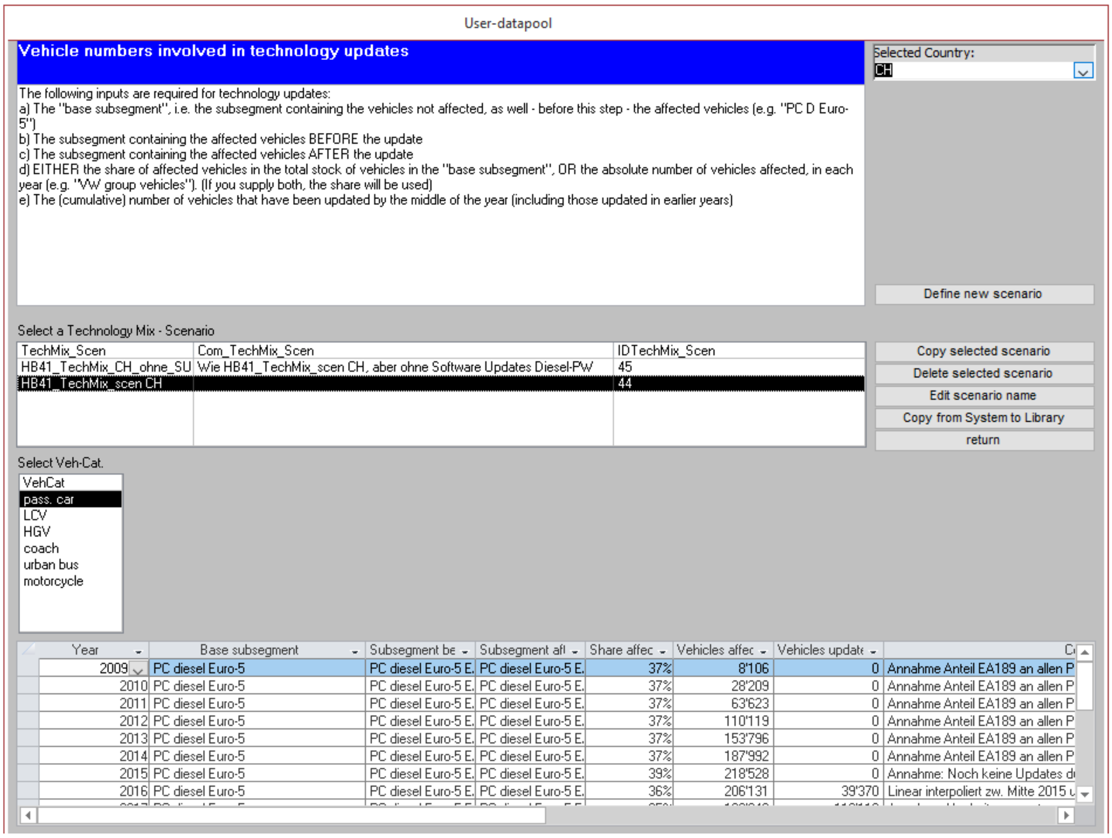
A new input form in the Expert Version, accessible via Menu *FleetModel > SubTechnology scenarios > Technology updates* allows data entry and editing of activity data (Figure 4). The following input activity data are required:

- The total number of (potentially) affected vehicles in vehicle stock in a given year – for the Euro-5 compulsory SW update these include the EA189 vehicles from the VW group.
  This number can be input either
  - expressed as a percentage of the total stock in the base subsegment,
  - or expressed as an absolute number of vehicles.

  If both options are given and they are contradictory, then the percentage is preferred. In either case the other option is also calculated by the fleet model.
- The total number of vehicles out of the above number for which the software update has been conducted by end of the year. This is the cumulative number, i.e. it includes the numbers of vehicles updated in previous years.

Both values must be input for all years from the first year in which the affected vehicles enter the market (i.e. 2009!) until the present, or the year in which all affected vehicles are updated (or the software updates are discontinued)

**Figure 4: User form in the Expert Version for data entry/editing of technology update activity data.**




Graphics by INFRAS. Source: HBEFA 4.1

## 5.4.4. Calculation methodology in the HBEFA fleet model

The following calculations are performed as a new additional post-processing step in Step 3 of the Fleet Model, in order to create the inputs for emission factor calculation:

- For each year, the share of affected and updated vehicles in the vehicle stock of the respective base subsegment (i.e. Euro-5 Diesel PC) is calculated.
- This share is multiplied with the number of vehicles as well as the vehicle kilometres in each year, for the total of all road categories as well as for each road category (MW, Urban, Rural). In other words, it is assumed that all Euro-5 Diesel PC (i.e. the unaffected, the affected with and those without software update) drive the same annual mileage on the same shares of MW, urban and rural roads.
- For the years after which the input stops, the same methodology is applied to the affected base subsegment (i.e. the Euro-5 Diesel PC) until the year that all vehicles of this layer have disappeared from the stock. In other words, the survival probability is assumed the same for

all Euro-5 Diesel PC (i.e. the unaffected, the affected with and any remaining without software update)

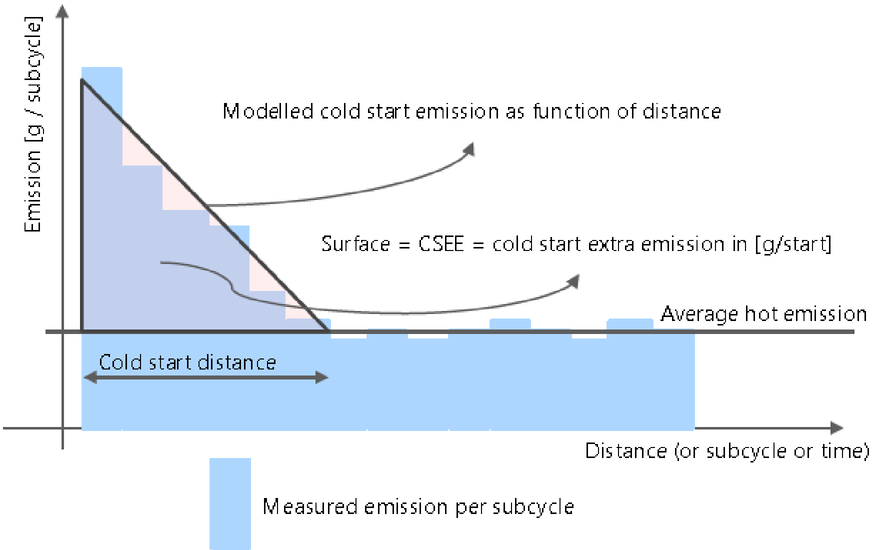
- In case the numbers of vehicles entered for the affected or the updated vehicles exceeds the number of vehicles in the entire base subsegment, they are capped at the latter number.

# 6. WP 4: Cold start emission factors

## 6.1. The approach

The level of emissions produced with a cold engine differ from hot engine conditions (in general they are higher). HBEFA takes into account this fact by providing excess emissions (in g/cold start), also termed CSEE (cold-start excess [or extra] emissions). These cold start excess emissions (Figure 5) depend on the engine temperature which in turn depends on the ambient temperature, the parking time before a start and the travel distance (since the excess emission tends toward 0 after a certain distance travelled). As the hot emissions, the cold start emissions also depend on the vehicle resp. engine and fuel type (petrol/diesel, legislation class). HBEFA version 3.1 up to 3.3 provided cold start emission factors for passenger cars and light duty vehicles only (due to lack of reliable data for the other vehicle categories). These factors rely on an approach developed by EMPA for version 3.1 (EMPA 2008); updates were made for version 3.2 based on the same approach but extended data. For version 4.1 the values up to the concepts Euro-4 remain unchanged while the same approach was applied again for updating the concepts Euro-5 and Euro-6. As in version 3 cold start emission factors are provided for passenger cars and light duty vehicles only.
In real life the CSEE depends on ambient temperature, driving dynamics, trip distance (if the trip is shorter than the warm-up phase) and the stop time (parking time) before the trip.

**Figure 5: Schematic diagram of the emissions during cold start including modelling approach**



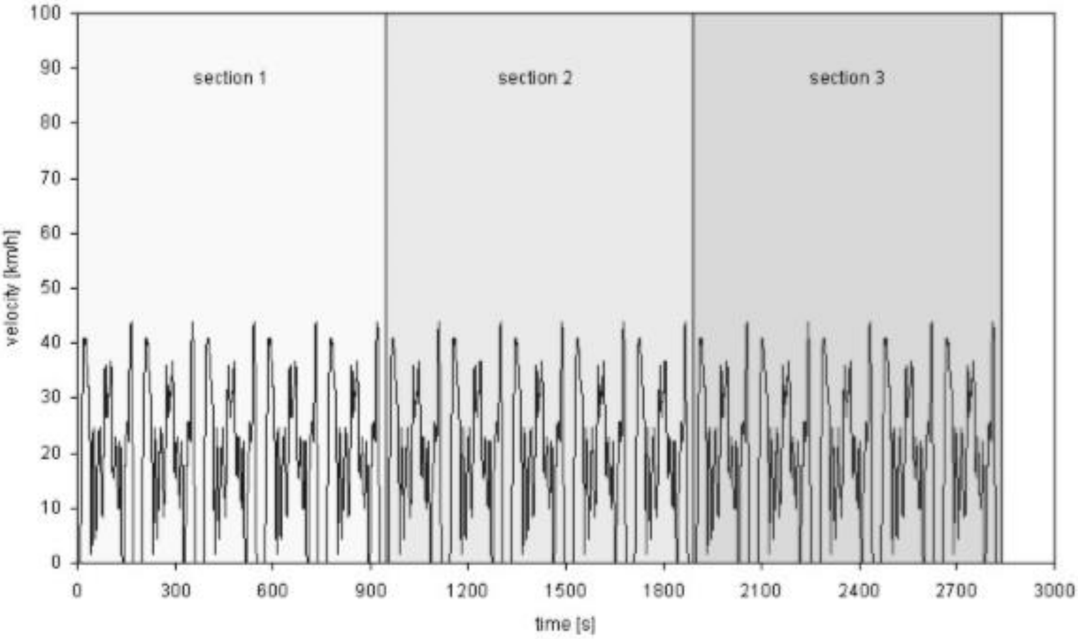

Graphics by INFRAS. Source: EMPA 2008

Mathematically the CSEE can be expressed with the following function of ambient temperature T, averaged velocity V (representing driving dynamics), trip distance d and stop time (=parking time) t:

$$\mathrm{EE}_{\mathrm{cold}}(T, V, \delta, t) = \mathrm{EE}_0 e(T) f(V) h(\delta) g(t)$$

where $EE_0$ is the standard CSEE at a temperature of 23° C (standard test temperature), V at 20 km/h, d at $d_c$ (the vehicle warms up completely in the test) and t at12 h (the vehicles was completely cooled down before the test). The function e(T) expresses the influence of the ambient temperature, while f(V), h(d) and g(t) are the influence functions of averaged velocity, trip distance and stop time, respectively. However, the term f(V), i.e. the influence of averaged velocity, is ignored in this context since there is only one empirical basis available for deriving the parameters for the model, the so-called IUFC, developed by INRETS in the context of the ARTEMIS project (ARTEMIS 2007). IUFC stands for “Inrets urbain fluide court”, i.e. short free-flow urban, and consists of 15 repetitive subcycles with a duration of 1 km per subcycle and an average speed of 19 km/. The 15 subcycles can be aggregated to 3 sections (= 3 bags) with 5 subcycles per section resp. per bag (Figure 6). This also indicates that the model applied is a fully empirical method relying mainly on the data available.

**Figure 6: The IUFC-cycle ('Inrets urbain fluide court', i.e. short free-flow urban cycle)**




Graphics by INFRAS.

The idea behind this breakdown is– apart from deriving the parameter $EE_0$ – to model the influencing functions e(T), h(d) and g(t) with data from small samples and to apply the models to larger samples for which only data for standard conditions are available. When applying the model to fleets of cars, e.g. on a country level for a certain year, the function above is applied over yearly temperature distributions, trip length distributions as well as parking time distributions for each vehicle category; the results are then added to the hot emissions.

## 6.2. The empirical basis

As mentioned above emission measurements of the IUFC cycle are the basis for updating the emission factors for PC and LCV Euro-5 and Euro-6 concepts. Measurement campaigns were performed at several labs, predominantly at EMPA, where all cars were tested on a chassis dynamometer test bench installed in an air-conditioned chamber at different temperatures (in general at +23° C, -7° C and -20° C.). Supplementary measurements were performed at TU Graz. Based on these measurement results first of all the overall excess cold start $EE_0$ (i.e. the triangle area in Figure 5 from the start up to the cold start distance) is derived. By deriving the cold start distance the influencing functions h(d) is implicitly given being assumed as a linear function. In addition, the data allow also to derive indications on the effect of different ambient temperatures at the start; this influencing function e(T) is assumed as a linear function set by the cold start emissions at the temperature levels +23° C and -7° C and – as far as available – -20° C. For the influencing functions g(t), i.e. the influence of stop time, no additional empirical data are available; hence this influence function is taken from a previous study (EMPA 2009) as already done for HBEFA Version 3.

The following table shows the number of vehicles measured in the IUFC as the empirical basis for updating the cold start excess emissions:

**Figure 7: Number of vehicles measured in the IUFC-cycle as basis for updating the cold start excess emissions of the Euro-5 and Euro-6 concepts**

| VehCat | Technology | EuroClass | Lab | +20 / +23°C | +5°C | -7°C | -20°C |
|---|---|---|---|---|---|---|---|
| pass. car | petrol | E5 | EMPA | 10 | | 6 | 6 |
| pass. car | petrol | E6ab | EMPA | 6 | | 6 | |
| pass. car | petrol | E6cd | EMPA | 3 | | 3 | |
| pass. car | petrol | E6cd | TUG | 2 | 2 | | |
| | | | | | | | |
| pass. car | diesel | E5 | EMPA | 12 | | 6 | 6 |
| pass. car | diesel | E5 | TUG | 1 | | | |
| pass. car | diesel | E6ab (EGR/SCR) | EMPA | 15 (9/6) | | 15 (9/6) | |
| pass. car | diesel | E6cd (EGR/SCR) | TUG | 6 (1/5) | 6 (1/5) | | |
| | | | | | | | |
| LCV | diesel | E5 | EMPA | 6 | | | |
| LCV | diesel | E5 | TUG | 1 | 1 | | |
| LCV | diesel | E6 (EGR/SCR) | EMPA | 6 (1/5) | | 6 (1/5) | |

Graphics by INFRAS.

The table illustrates that the data set had to be split into different segments in order to capture the differences in emission behaviour, in particular for Euro-6 where the vehicles were split along the technologies EGR resp. SCR. This is of particular relevance for the NOx-emissions of diesel vehicles: vehicles with EGR show negative cold start excess emissions due to the fact that they have lower NOx emissions right after the start at still low engine temperatures compared to “hot” emissions when the engine has reached the operating temperature. Vehicles with SCR on the other side produce high emissions right after the start as long as the SCR system has not yet reached its normal operating temperature. In addition, the influence of very low temperatures (-20°C) was captured by the EMPA samples of Euro-5, but not for Euro-6 anymore (the measurement program for Euro-6 was reduced to the 2 temperature levels of 23° and -7°C due to high costs and limited relevance since the share of km driven at temperatures below -7°C is limited).

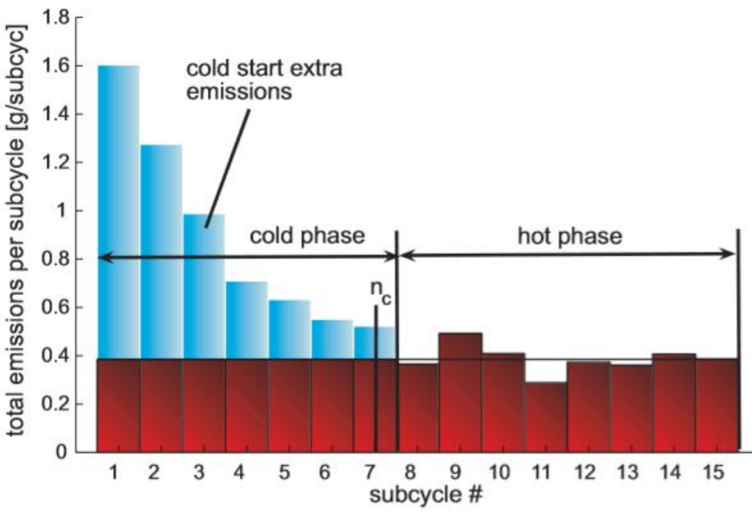
## 6.3. Parameter estimation methods

For parameter estimations there are several methods which can be applied (EMPA 2008):

**Subcycle analysis method**

This method requires a repetitive cycle, such as the IUFC with 15 subcycles. In a first step the cycle has to be split into a warm up phase (=cold phase) and a hot stabilised phase (= hot phase), see Figure 8. This can be computed by a 'standard deviation method'[2]. The idea behind this method is to detect increased emissions compared to the hot phase emissions. The method therefore computes the standard deviation backward, i.e. on the last two subcycles, then on the three last subcycles and then on all the following consecutive subcycles. It is considered that during the hot phase the emissions are stable, except some small variations in the emissions. In this case the standard deviation decreases as a function of the increasing number of subcycles considered. As soon as cold start emissions appear the standard deviation increases more distinctly. Thus, at a certain subcycle a minimum standard deviation emerges. This subcycle is defined as the first hot subcycle (in this case, numbered as $n_c + 1$), which leads to $n_c$ which specifies the last subcycle of the cold phase. The idea of the 'enhanced standard deviation method' (for details see EMPA 2008) is similar but uses a more refined term for identifying the increase of cold emissions. This 'enhanced' method was applied for updating the cold start EF for HBEFA 4.1.

**Figure 8: Evolution of emissions as a function of subcycles. Separation of the cycle into a cold and a hot phase.**




Graphics by INFRAS. Source: EMPA 2008

[2]The 'standard deviation method'' was originally developed at INRETS (INRETS 2005). EMPA developed a similar but more robust method, referred to 'enhanced standard deviation method' (EMPA 2008).

Once $n_c$ is determined, the CSEE (cold-start excess emissions) of the subcycle method is given by

$$EE_{cold} = E_{cyc} - E_{hot} = \sum_{i=1}^{15} E(i) - \frac{15}{15-n_c} \sum_{i=n_c+1}^{15} E(i)$$

where E(i) is the total emission of subcycle i, $E_{cyc}$ is the total emission of the cycle and $E_{hot}$ is the sum of the hot emission part of the cycle.

**Bag analysis method**

A more simple method to assess CSEE (resp. $EE_{cold}$) has to be applied if only bag information for the 3 sections, but no subcycle information is available. By assuming that the cold phase ends before the start of the third bag the emission is given by

$$EE_{cold} = E_{bag1} + E_{bag2} – 2E_{bag3}$$

Alternatively, if one assumes that the cold phase ends before the start of the second bag (and if only 2 sections were measured as in the case of the TUG measurements), the emission can be derived from

$$EE_{cold} = E_{bag1} - E_{bag2}$$

This method can also be applied with other cycles with cold as well as hot phases, as e.g. the US FTP with a cold phase in the first part and a hot start in the third part, where the emission can be derived from

$$EE_{cold} = E_{bag1} - E_{bag3}$$

This approach was used in earlier HBEFA versions (HBEFA 1 and 2).

**Modal analysis method**

The first method (subcycle analysis method) provides in a first step the cold start distance. As Figure 8 indicates, the term $n_c$ will be an integer value, and the smallest possible value will be 1 which is equivalent to subcycle nr 1 resp. 1 km for $n_c$. In some cases as e.g. HC or CO of newer petrol cars the cold start distance is below 1 km, hence an alternative method has to applied by referring to modal data (sec-per-sec data). This method sums up continuously the emissions over the whole cycle and then calculates the gradients accordingly. The point where the gradient drops distinctly corresponds to the cold start distance. For HC of petrol cars Euro-4 this value is about 0.35 km. In the context of HBEFA these values (below 1 km) are of limited relevance since the distance resolution used in HBEFA is only 1 km. Hence, the cold start distances for the concepts Euro-5 and Euro-6 (if below 1 km) were assumed to be identical as those of the concepts Euro-4.

## 6.4. Resulting cold start emission factors

Figure 9 shows the updated cold start emission factors for concepts Euro-5 and Euro-6 (in g/start). The values of the Euro-4-concept are taken from the HBEFA Version 3 and are included in the table for comparison reasons only. The concept Euro-5 has been updated as one overall concept. For the petrol cars the Euro-6 concept was split into to subconcepts ('Euro-6ab' resp. 'Euro-6cd'); the corresponding cold start emission factors could be derived from the underlying measurement samples. For diesel cars, the different technologies (EGR resp. SCR) were assigned to the three classes 'Euro-6ab' resp. 'Euro-6c' resp. 'Euro-6d' by weighting the sample values as follows:

- Euro-6ab: weighted average of 60% EGR and 40% SCR (sample E6ab)
- Euro-6d: 100% SCR (sample E6cd)
- Euro-6c: weighted average of 50% Euro-6ab and 50% Euro-6d.

By this weighting the negative NOx values Euro-6ab diesel cars are reduced (in absolute terms) compared to the Euro-5 cars (due to a certain share of SCR equipped vehicles), and for the Euro-6c vehicles the influences of the two technologies EGR and SCR compensate each other, so that the resulting net value is zero.

For the LCV the samples are too small to allow subtle differences within the concepts. Hence the values Euro-5 reflect the entire sample Euro-5 while the values Euro-6 reflect the SCR-vehicles of the Euro-6 sample.

Figure 10 lists in addition the updated correction factors for cold start EF at ambient temperature of -7°C compared to +23°C. The values for ambient temperatures in-between are assumed to follow a linear function.

**Figure 9: Updated cold start emission factors for the concepts Euro-5 and Euro-6**

| g/Start | | HC | CO | NOx |
|---|---|---|---|---|
| PC Petrol | | | | |
| PC P Euro-4 | *for comparison* | 1.061 | 6.660 | 0.300 |
| PC P Euro-5 | | 0.795 | 3.494 | 0.257 |
| PC P Euro-6ab | | 0.560 | 3.270 | 0.257 |
| PC P Euro-6cd | | 0.560 | 3.270 | 0.257 |
| PC Diesel | | | | |
| PC D Euro-4 | *for comparison* | 0.381 | 1.140 | -0.880 |
| PC D Euro-5 | | 0.100 | 0.950 | -0.880 |
| PC D Euro-6ab | | 0.074 | 0.950 | -0.360 |
| PC D Euro-6c | | 0.068 | 0.780 | - |
| PC D Euro-6d | | 0.063 | 0.600 | 0.330 |
| g/Start | | HC | CO | NOx |
| LCV Petrol | *unchanged* | | | |
| LCV Diesel | | | | |
| LDC Euro-4 | *for comparison* | 0.381 | 1.482 | -0.880 |
| LDC Euro-5 | | 0.100 | 1.235 | -0.540 |
| LDC Euro-6 | | 0.070 | 0.780 | 0.660 |

Graphics by INFRAS.

**Figure 10: updated correction factors for cold start EF at ambient temperature of -7°C compared to +23°C**

| Factor -7°/+23°C | HC | CO | NOx |
|---|---|---|---|
| PC Petrol | | | |
| PC P Euro-5 | 5.79 | 7.60 | 1.82 |
| PC P Euro-6ab | 6.20 | 7.60 | 1.82 |
| PC P Euro-6cd | 6.20 | 7.60 | 1.02 |
| PC Diesel | | | |
| PC D Euro-5 | 2.32 | 3.17 | -2.65 |
| PC D Euro-6ab | 4.52 | 4.13 | 0.48 |
| PC D Euro-6c | 2.93 | 3.21 | 0.03 |
| PC D Euro-6d | 1.32 | 1.91 | 1.91 |
| LCV Diesel | | | |
| LDC Euro-5 | 0.44 | 3.12 | -0.40 |
| LDC Euro-6 | 0.44 | 3.12 | -0.40 |

Graphics by INFRAS.

# 7. WP 5: Evaporation emission factors

## 7.1. Task

The methodology for the calculation of evaporation emission factors in HBEFA is adopted from the COPERT model, and the corresponding EMEP/EEA Guidebook chapters on gasoline evaporation (Mellios et al. 2012, Mellios et al. 2013, Mellios et al. 2016). The task of WP 5 basically was to update HBEFA to the current version, i.e. COPERT 5 or the 2016 EMEP/EEA Guidebook version, respectively. HBEFA 3.3 still corresponded to the 2012 edition/COPERT 4.

The most important change from COPERT4 to COPERT 5 was the inclusion of carbon degradation factors, which resulted in significant increases in diurnal evaporation emission factors. Furthermore, parking time distributions were adapted and differentiated up to 46 hours.

## 7.2. Approach

The following changes were implemented in HBEFA:

- Adaptation of the code for evaporation emissions to include the changes in calculation formulae and parameter values between EMEP/EEA Guidebook version 2012 (Mellios et al. 2012) and 2016 (Mellios et al. 2016), Tier 3 method;
- Update of the subsegment properties relevant for evaporation emissions, such as tank size, canister size etc. to match COPERT 5;
- Adaptation of code and input data so that parking time distributions from the ambient pattern conditions in HBEFA are used in the calculation of evaporation emissions. Up to HBEFA 3.3, the parking time distribution of COPERT (see Mellios et al. 2012) was actually used, although country-specific input data were available already for cold start. For the current update, it was decided to use the country-specific HBEFA inputs also for evaporation, as this leads to improved internal consistency compared to the approach up to HBEFA 3.3.
- Evaporation emissions are calculated for all LDV and MC subsegments using petrol, either exclusively or as part of a fuel mix or multi-technology.

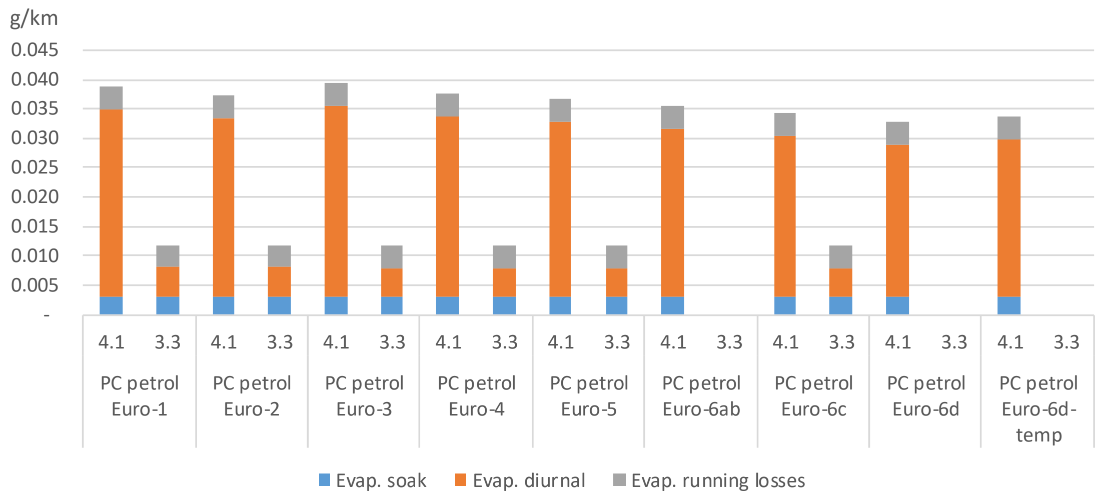
It should be noted that differences in evaporation emissions due to the ethanol content of fuels are explicitly considered in the calculation methodology.

## 7.3. Results

The resulting emission factors for petrol PC, compared to their HBEFA 3.3 counterparts, are visualized in Figure 11. Whereas evaporation soak and running losses are nearly identical in HBEFA 4.1 to HBEFA 3.3, the diurnal evaporation emissions are higher by about a factor of 5.

Compared to COPERT 5, the emission factors in HBEFA 4.1 are in a similar range but not identical, due to different country-specific input data such as climate data, traffic activity inputs such as trip length and parking time distributions, or fuel properties (RVP).

**Figure 11: Evaporation emission factors for petrol PC converted to g/km for all evaporation types, comparing HBEFA 4.1 and 3.3.**




Graphics by INFRAS. Source: HBEFA 4.1, HBEFA 3.3

# 8. WP 6: Alternative fuels

## 8.1. Concept

WP 6 deals with alternative fuels that require technological adaptations in vehicles when used alone or as the main component of a fuel mix (such as FFV, Ethanol, or bi-fuel vehicles). This is handled in HBEFA by defining separate vehicle segments which can be assigned separate emission factors.

In contrast, for the case of minor shares of biofuels blended with traditional fuels in a fuel mix, it is assumed in HBEFA that the biofuels have the same TTW emission factors as their fossil counterparts – only the WTT EF are different (see Chapter 13). The only exception is CO2, where the share of biofuel is counted with zero CO2 emissions.

Against this background, the following steps are followed to implement alternative fuel use:

- Define the necessary segments, along with the required technologies, emission concepts, and subsegments (Chapter 8.2);
- Define the emission factors:

- In some cases, such as vehicles using CNG, enough measurements are available to model emission factors for vehicles using alternative fuels in PHEM. See Chapter 2, or the separate report by TUG (Matzer et al. 2019), for details on this topic.
- In most other cases, only few measurements are available. In this case, EF by traffic situation can be derived from subsegments with available EF from PHEM, with adjustment factors that reflect the difference between the target and the reference subsegment (Chapter 8.3)

## 8.2. New segments for alternative fuels

The following segments were introduced for alternative fuels:

- Passenger Cars: CNG/petrol bifuel, LPG/petrol bifuel, FFV
- LCV: CNG/petrol bifuel, FFV
- HDV: CNG and LNG
- UrbBus: CNG and LNG, Ethanol

For coach and MC, no additional segments for alternative fuels were introduced.

They can be viewed in the HBEFA Expert Version under Menu *Definitions > Segments*, in the Public Version under *Info > Vehicle segments*.

## 8.3. Derived emission factors

As mentioned above, the EF for most CNG vehicles are available from PHEM. For the rest of the subsegments using alternative fuels, EF are derived from other subsegments. Table 2 provides an overview.

The subsegments with derived EF, their reference subsegments and the adjustment factors can be viewed in the HBEFA Expert Version in Menu *Extras > Red Rates EF hot > by NewSubsegment*.

**Table 2: EF derivation for non-measured subsegments different from HBEFA 3.3. Note: Subsegments which were previously available in the Expert Version as “derived” and are now available in both versions as “measured” (such as BEVs or some CNG vehicles) are not listed here.**

| Alternative fuel subsegment | Reference subsegment | Comment |
|---|---|---|
| PC CNG/petrol, Euro 2-3 | Petrol counterparts | As in HBEFA 3.3<br>(Euro 4-6 now available from PHEM) |
| PC LPG/petrol (all emission concepts) | Petrol counterparts | All adjustment factors = 1 (except PM/PN = 0) |
| PC FFV (all emission concepts) | Petrol counterparts | All EF assumed equal to petrol counterparts; same as in previous HBEFA Expert Version |
| LCV CNG/petrol and LNG/petrol (all emission concepts) | For petrol use, EF from petrol Euro-6d equivalent | All EF assumed equal to petrol counterparts; same as in previous HBEFA Expert Version |
| LCV FFV (all sizes and emission concepts) | Petrol counterparts; | For “Euro-6”, the petrol “Euro-6ab” is used |
| UBus CNG Euro II-IV | Diesel counterparts (EGR where EGR/SCR differentiated) | (Euro V-VI now available from PHEM) |
| UBus LNG Euro II-IV | Diesel counterparts (EGR where EGR/SCR differentiated) | |
| UBus LNG Euro V-VI | Diesel counterparts (EGR where EGR/SCR differentiated) | Should be CNG counterparts which are now available from PHEM → will be corrected for final HBEFA release |
| HGV CNG Euro IV (all size classes) | HGV CNG Euro V (respective size class) | EF of Euro-IV assumed equal to Euro-V |
| HGV LNG | CNG counterparts | |

Table INFRAS.

# 9. WP 7: Electric vehicles

## 9.1. Development of energy consumption factors

The development of energy consumption factors using the PHEM model is described in a separate report by TU Graz, “Update Emission factors for HBEFA 4.1” (Matzer et al. 2019).

## 9.2. Integration of energy consumption factors in HBEFA

The consumption factors for electric vehicles were provided by the TU Graz in the same format as the hot emission factors and were imported into the same structures in HBEFA (see Chapter 4.2.1).

Electricity consumption was imported in the Unit Wh/km (i.e. PHEM output in kWh/km * 1000) and stored this way in the column "FC" in the base EF tables. The conversion to MJ/km takes place during hot EF calculation when querying EFs from HBEFA.

## 9.3. Segments for electric vehicles

New segments have been introduced for electric vehicles, or newly activated in the Public Version (i.e. those that already existed, but were only activated in the Expert Version in previous HBEFA versions). They are listed in Table 3.

Please note the following:

- For BEV, the consumption factors modelled in PHEM are based on the assumption that the same real-world excess factors as for conventional vehicles apply, i.e. heavy loads, use of roof boxes or high motorway speeds. As a result, the energy consumption from PHEM is quite high compared to other values found in literature. We explain this discrepancy by the assumption that current BEV drivers are likely on the "more ecological" end of the spectrum of drivers, and thus same real-world excess factors as for conventional vehicles won't apply until BEV have further penetrated the fleet and BEV drivers can on average be characterised the same as conventional vehicle drivers.
  For this reason, in the HBEFA country-specific parameters a base correction factor is applied to adjust BEV energy consumption to be around 200 Wh/km (not including charging losses) for the average traffic situation mix of Germany. This matches the currently available "real world" data. The resulting base correction factor value is 0.8184.
  For the future, we assume that future fuel efficiency improvements to BEV will roughly be cancelled out by increasing correction factors due to more operation by "average drivers", thus, no future improvement (reduction rates) for BEV energy consumption is included.
  For PHEV, the same base correction factors apply for the electric mode as for BEV; a future reduction rate is included, however, since the assumption of the "more ecological" drivers does likely not apply to PHEV.
- eScooters are not allowed to drive on roads with a speed limit above 80 km/h. Energy consumption factors are nevertheless provided for the respective traffic situations in HBEFA 4.1, based on the assumption that if an eScooter were to drive in these traffic situations, its driving pattern would correspond to the analogous traffic situation with speed limit 80 km/h.
  In order to implement this, the eScooter consumption factors could not be derived "live", i.e. using a constant adjustment factors, from those of the MC BEV (as e.g. the subsegments in Table 2). Instead, they had to be derived outside HBEFA so the factors of traffic situations

with speed limits >80 km/h could be manually replaced with their counterparts under speed limit 80 km/h, and imported like measured consumption factors. Therefore, the eScooter appears as "measured" subsegment although it is actually derived from the MC BEV.

**Table 3: Segments for electric vehicles in HBEFA 4.1.**

| Segment | Technology |
|---|---|
| PC BEV | electricity |
| PC PHEV petrol | Plug-in Hybrid petrol/electric |
| PC PHEV diesel | Plug-in Hybrid diesel/electric |
| LCV BEV M+N1-I | electricity |
| LCV BEV N1-II | electricity |
| LCV BEV N1-III | electricity |
| LCV PHEV petrol M+N1-I | Plug-in Hybrid petrol/electric |
| LCV PHEV petrol N1-II | Plug-in Hybrid petrol/electric |
| LCV PHEV petrol N1-III | Plug-in Hybrid petrol/electric |
| LCV PHEV diesel M+N1-I | Plug-in Hybrid diesel/electric |
| LCV PHEV diesel N1-II | Plug-in Hybrid diesel/electric |
| LCV PHEV diesel N1-III | Plug-in Hybrid diesel/electric |
| Coach Electric Std <=18t | electricity |
| Coach Electric 3-Axes >18t | electricity |
| Coach Electric Midi | electricity |
| Ubus Electric Midi <=15t | electricity |
| Ubus Electric Std >15-18t | electricity |
| Ubus Electric Artic >18t | electricity |
| eBike | electricity |
| eScooter | electricity |
| MC BEV | electricity |
| TT/AT BEV | electricity |
| RigidTruck BEV <=7.5t | electricity |
| RigidTruck BEV >7.5-12t | electricity |
| RigidTruck BEV >7.5-12t | electricity |
| RigidTruck PHEV <=7,5t | Plug-in Hybrid diesel/electric |
| RigidTruck PHEV >7,5-12t | Plug-in Hybrid diesel/electric |
| RigidTruck PHEV >12t | Plug-in Hybrid diesel/electric |
| TT/AT PHEV | Plug-in Hybrid diesel/electric |

Table INFRAS.

## 9.4. Charging losses

### 9.4.1. Basic handling of charging losses

While losses from charging the battery with energy recuperated while driving are included in the electricity consumption from PHEM, losses from charging the battery from grid are not included. These are added in HBEFA.

It has been subject to discussion whether to include charging losses with TTW or WTT emissions/consumption or to output them separately in HBEFA. Different arguments for and against each option have been brought forward and considered. INFRAS decided to include charging losses with TTW (direct) consumptions, based on the following considerations:

- Charging losses are a part of electricity consumption while operating the vehicle.
- Charging losses also occur when the battery is recharged while driving with recuperated energy; for the vehicle, there is no difference between losses when charging from the grid or from recuperated energy.
- Consumption measurements like the WLTP[3] or the ADAC EcoTest (ADAC 2016) measure power consumption from the plug and therefore include charging losses.
- Taking the labels "WTT" and "TTW" literally would imply that charging losses should be counted with WTT, i.e. indirect consumption, since the battery is the equivalent to the tank. However:
  - Some authors state that for electric vehicles "TTW" should therefore be renamed "GTW", i.e. "grid-to-wheel" (e.g. Karlsson und Kushnir 2013) so charging losses are clearly counted with direct consumption
  - In HBEFA 4.1, reporting charging losses under WTT emissions would be unsuitable since only CO2 equivalents have been decided to be made available WTT emissions (see Chapter 13) – so if charging losses were also reported under WTT, electricity consumption and, in extension, primary energy consumption would have to be made available generally.
- There are two practical arguments against a separate output for charging losses:
  - If the column "EFA" in the output table of the HBEFA public version does not contain the charging losses, they may tend to be forgotten by the user;
  - Given the current limitation of memory in MS Access that affects HBEFA (see Chapter 0), a separate output for charging losses would require larger arrays for storing this additional output, and therefore contribute to reaching the memory limit sooner.

Transmission losses within the power grid are accounted for in the WTT emission factors (Chapter 13).

[3] See e.g. https://www.vda.de/en/topics/environment-and-climate/Global-WLTP-roll-out-for-more-realistic-results-in-fuel-consumption/WLTP-How-are-plug-in-hybrids-and-electric-cars-measured.html

### 9.4.2. Differentiation of charging losses

The amount of electricity lost while charging can vary based on a number of factors, including charging station type/voltage, cables used, or the batteries. The information available on the relative losses by all these factors is currently still very limited. Therefore, a single value for charging losses of 14% of electricity obtained from the grid is assumed in HBEFA 4.1.

In the HBEFA application, however, the structures have already been set up so charging losses can be varied by three charging station types:

- 220V (household) < 3.6kW
- <45 kW
- >45 kW

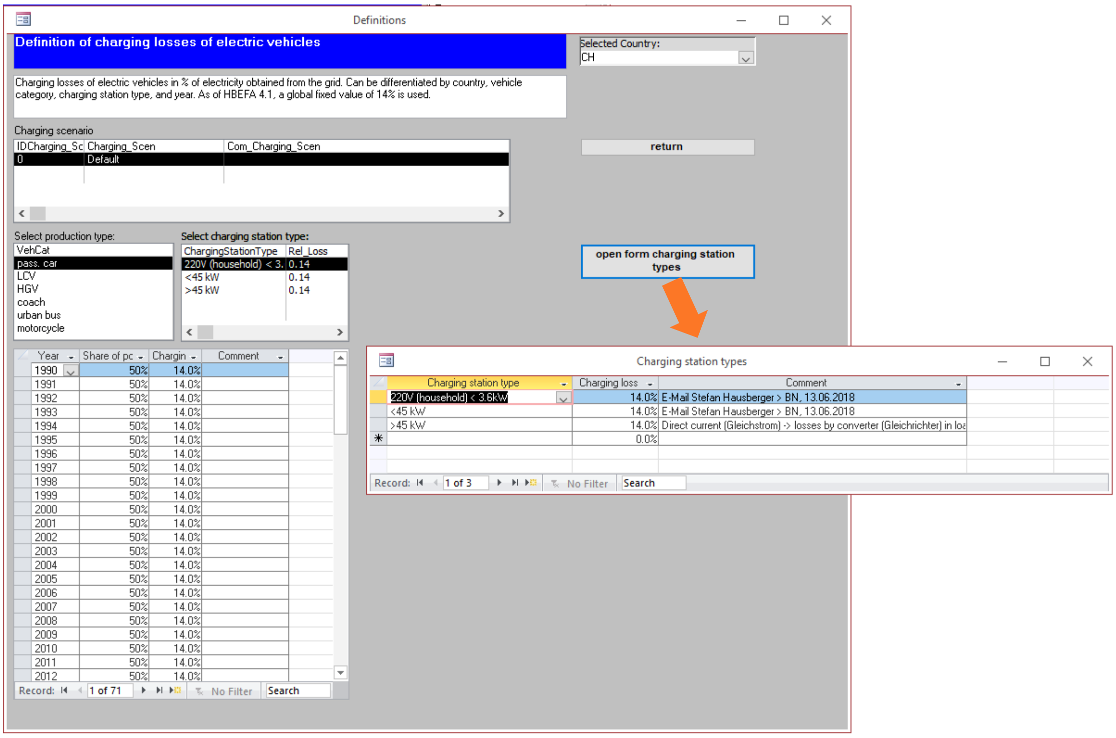
The share of electric vehicle power consumption obtained from each charging station type can be varied by country, vehicle category, and year. At the moment, a constant 50% charging from household 220V plugs, 30% from <45 W charging stations and 20% from >45% charging stations is assumed for all vehicle categories and countries.

### 9.4.3. User interface

The inputs for charging losses can be viewed and edited in the Expert Version via Menu *Fuel/Energy > Energy losses > Charging losses* (see also Figure 12).

In the Public Version, the inputs can be viewed via Menu *Info > Electric vehicles > Energy losses*.

**Figure 12: User form to view and (in the Expert Version) edit charging losses of electric vehicles. Click on the button "Open form charging station types" opens the small subform listing charging station types and associated assumed losses.**




Graphics by INFRAS. Source: HBEFA 4.1

## 9.5. Electric driving shares for PHEV

For PHEVs, the shares of vehicle kilometres travelled with electricity from the grid are required to calculate aggregated emission factors or emissions.

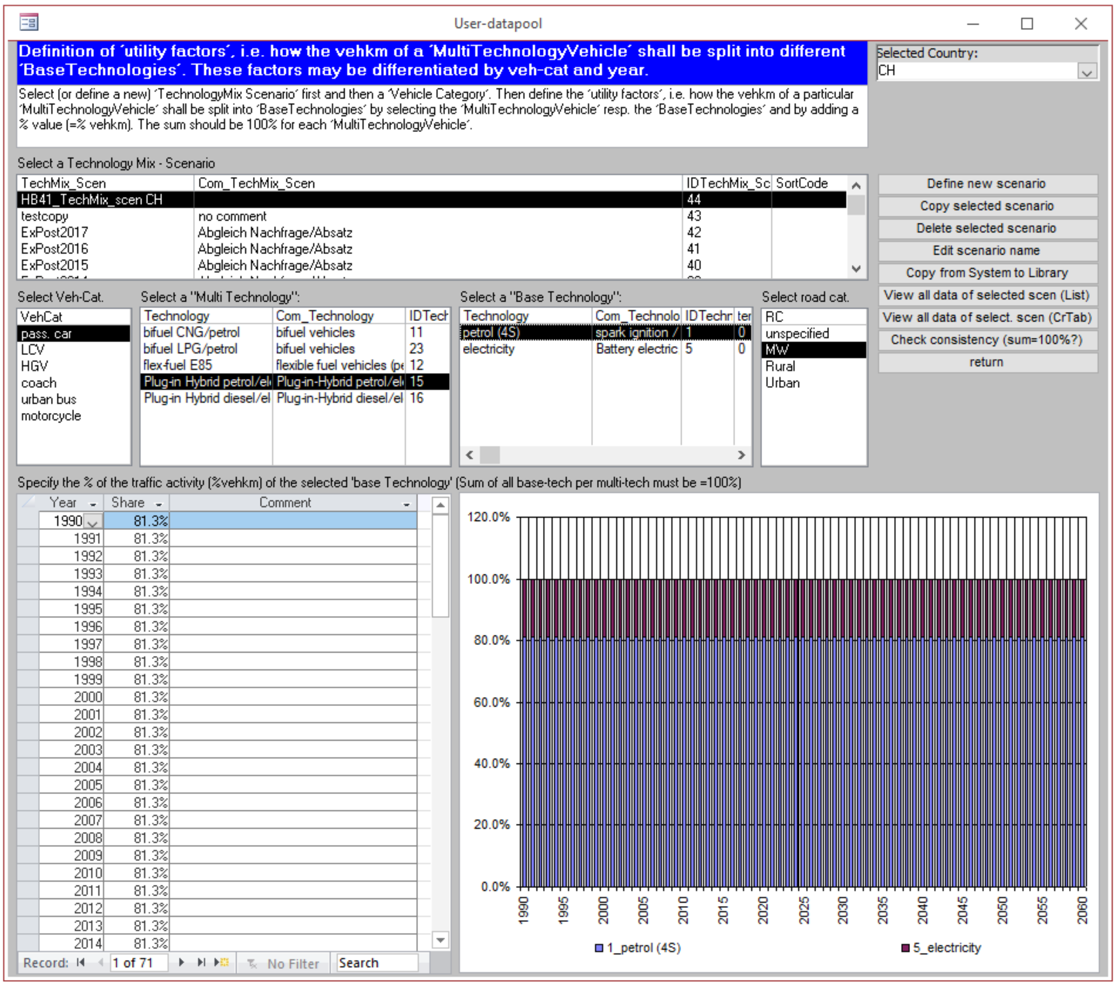
Electric driving shares have been derived by TUG by typical average velocities for urban, rural, and motorway driving (Matzer et al. 2019).

The corresponding shares have been implemented in HBEFA, i.e. at the level of vehicle category and "RC" (road category, i.e. urban/rural/motorway). PHEV's are thus handled in HBEFA like other "multitechnologies" (e.g. bi-fuel vehicles) – separate subsegments are available that represent the single technologies (in the case of PHEVs, the HEV charge-sustaining mode and the electric driving mode). Therefore, not only the emission factors, but also the shares of vehicle kilometres travelled in both modes can be extracted when querying emission factors at subsegment level.

The user interface for viewing, and in the Expert Version, editing electric driving shares can be accessed:

- In the Expert Version: Menu *FleetModel > SubTechnology scenarios > TechnologySplit (MultiTech)*
- In the Public Version: Menu *Info > Multitechnologies > Technology shares*

**Figure 13: User interface for viewing and editing electric driving shares of PHEVs in HBEFA.**




Graphics INFRAS. Source: HBEFA 4.1

# 10. WP 8: Fuel consumption and CO2 emission factors

## 10.1. Introduction

The improvement of fuel consumption and CO2 emission factors in HBEFA has partially been dealt with in a separate, parallel project commissioned by the German Umweltbundesamt (UBA), entitled “Development of a method for the derivation and modelling of CO2 emissions of motorized traffic” (Eisenmann et al. [forthcoming]). The focus of the project is on the real-world consumption of PC and LCV. Its methodological results are integrated into HBEFA 4.1. The central outputs of this project used in HBEFA include:

- The “real-world excess”, i.e. the relative difference between real-world fuel consumption, derived from an analysis of fuel logs in the above-named project, and type-approval averages, determined via the statistical CO2 monitoring of new registrations in the EU. This can now be used as a direct input into HBEFA 4.1 (see next Chapter).
- The breakdown of this “real-world excess” into influence factors that can be modelled with PHEM. The fuel consumption factors of PC and LCV from PHEM for HBEFA 4.1 (see Chapter 4) have been developed based on this knowledge.

## 10.2. Methodology

### 10.2.1. Fuel efficiency parameters in HBEFA 4.1 and previous versions

Fuel consumption and CO2 emissions in HBEFA of new registrations are calibrated with the following model parameters:

- **Base correction:** This factor corrects the fuel consumption of the new registrations of an entire HBEFA segment up- or downwards, for the entire time series of a given countries. It is tied to a base year, which basically can be chosen freely, but 2002 has so far been used since this corresponds to the start of compulsory CO2 monitoring of newly registered PC in EU countries. The base correction accounts on one hand for the real-world excess in the base year, and on the other hand, for differences in fuel consumption between countries due to different average vehicle size and power.
- **Reduction rate and use factor:** The reduction rate is input individually for each year of the time series (at segment level) and accounts for the temporal development of fuel efficiency of new registrations over the years. Optionally, it can be scaled a “use factor”, which account for the share of the reduction actually resulting in real-world use.

These parameters have already been in use in previous versions of HBEFA and continue to be the relevant input in HBEFA 4.1.

### 10.2.2. New preprocessor for vehicle categories with CO2 monitoring

The results of the UBA real-world consumption project could theoretically already be implemented in HBEFA with the existing fuel efficiency parameters described in Chapter 10.2.1. However, the translation of CO2 monitoring and real-world excess into these parameters would be a tedious process if done manually.

Therefore, pre-processing functionality to

a) carry out the calibration of PHEM values to country- and segment-specific fuel consumption values, and
b) convert the resulting calibration factors to the "classical" HBEFA fuel efficiency parameters as described in Chapter 10.2.1.

has been developed within HBEFA.

It uses the following input data:

- Base consumption factors in g/vehkm or MJ/vehkm by HBEFA subsegment and traffic situation from the PHEM model (see Chapter 4);
- CO2 monitoring data from EU statistics (EEA 2018) for new registrations, by year, vehicle category and technology;
- "Real-world excess" values, expressed in % of the corresponding CO2 monitoring values, by year, vehicle category and technology;
- The distribution of traffic situations expressed in % shares of the total vehicle kilometres by vehicle category, which are available in HBEFA as part of the traffic activity scenarios of the fleet model;
- The shares of the emission concepts in the new registrations by year and technology, available in HBEFA as part of the emission concept scenarios of the fleet model.

The following calculation steps are carried out:

- in a first step, calibration factors are calculated by year and segment, as the ratio of
  - the average base consumption factor resulting from the traffic situation- and emission concept-weighted average of the PHEM consumption factors, and
  - the target consumption factor, corresponding to the CO2 monitoring value plus the real-world excess

  In the former, optionally a cold start share can be considered if the real-world excess input values include cold start (which is the case with fuel log data):

$$Calibration\ factor_{Segment,Year} = \frac{\frac{\sum Vehkm_{Subsgm,Year,TS,Country}\ x\ Consumption\ factor_{Subsgm,Year,TS}}{\sum Fzkm_{Subsgm,Jahr,Land}}\ x\ (1+\ cold\ start\ share)}{CO2Monitoring_{Segment,Year,Country}\ x\ (1+Real-world\ excess)_{Segment,year,country}}$$

where:
$Vehkm$ = vehicle kilometres
$Subsgm$ = HBEFA Subsegment
$TS$ = Traffic situation
$CO2Monitoring$ = $CO_2$ emission/vehkm in NEDC

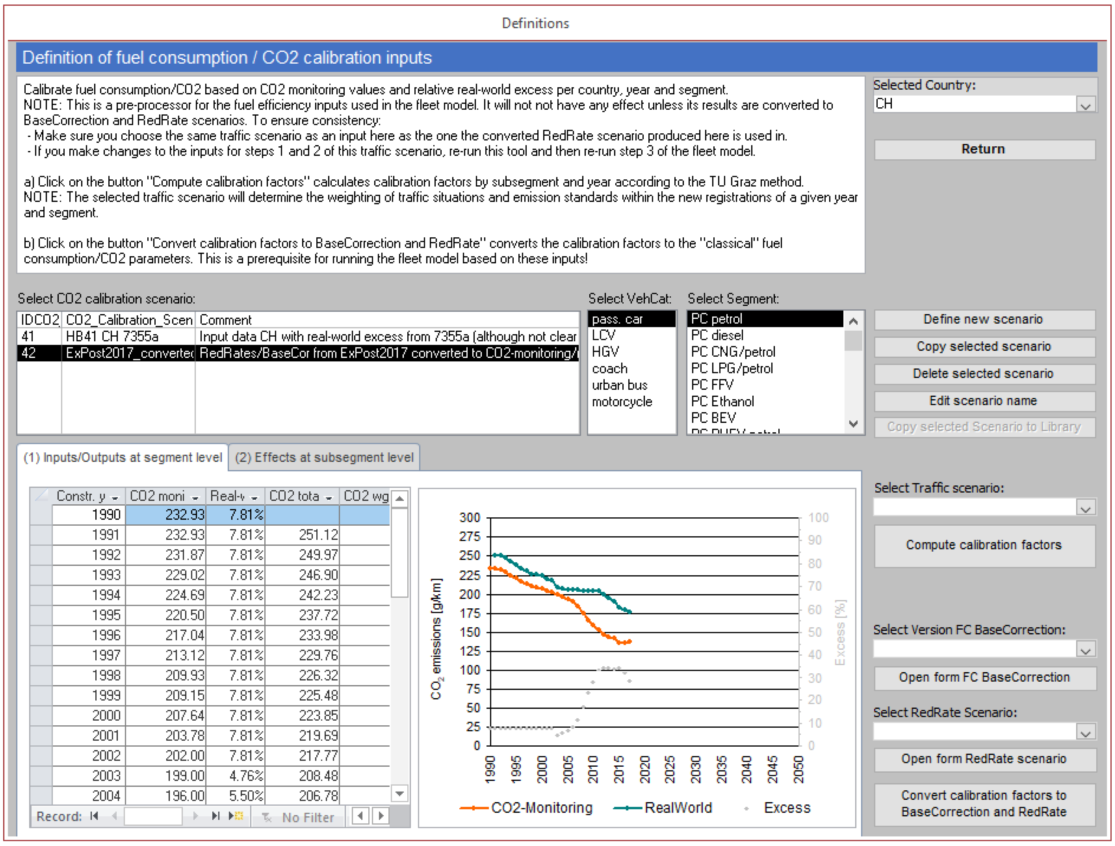
- In a second step, the calibration factors resulting from the first step are converted to the "classical" HBEFA fuel efficiency parameters as described in Chapter 10.2.2. The base correction equals the calibration factor in the base year (i.e. 2002), and the reduction rates correspond to the annual relative changes in the calibration factors.

After application of the pre-processor, the "classical" HBEFA fuel efficiency parameters are available as in previous versions and form the required input to the fleet model.

The implementation of the methodology as a pre-processor has the following advantages:
- For vehicle categories with CO2 monitoring (i.e. PC and LCV), the new pre-processor offers a simpler and more transparent method of fuel efficiency calibration than so far.
- For vehicle categories without CO2 monitoring, assumed future efficiency improvements can be input as relative reduction rates as in previous versions of HBEFA.
- The functionality of the HBEFA fleet model did not have to be adapted.

The user interface to the pre-processor is accessible in the HBEFA 4.1 Expert Version via the menu *Fleet model > FuelEfficiency scenarios > CO2 calibration*.

**Figure 14: Interface of the CO2 calibration pre-processor in the HBEFA Expert Version.**




Graphics INFRAS. Source: HBEFA 4.1

# 11. WP 9: Non-regulated pollutants

## 11.1. Introduction

The HBEFA has emission factors for several pollutants including different non-regulated pollutants (see Table 24 in the annex). For the HBEFA 4.1 only a number of non-regulated pollutants were selected for a review, depending on their priority for the HBEFA and the availability of new data. An overview of the pollutants and information on the emission factors' methodology is given in Table 4.

Contrary to the regulated pollutants, most non-regulated pollutants are calculated in a simplified approach, e.g. as percentage on other pollutants and in an aggregated manner in terms of vehicle technology and driving behaviour (Table 4).

Therefore, vehicle concepts for non-regulated pollutants have separate definitions:

- Concept_nonregulated: vehicle category, fuel type and concept, e.g. LDV petrol Euro 5
- Concept_nonregulated (aggregated): vehicle category and fuel type, e.g. LDV petrol

**Table 4: Overview of selected non-regulated pollutants in the HBEFA and the calculation methodology**

| **Pollutant** | **Emission factors unit** | **Emission factor differentiation** | **Last update** |
|---|---|---|---|
| NO2 | f NO2/NOx (%) | Concept_nonregulated; Road category | HBEFA 3.2 |
| CH4 | f CH4/HC (%) | Concept_nonregulated (aggregated); Emission category (hot, cold, evaporation) | HBEFA 2.1 |
| NMHC | f NMHC/HC (%) | | |
| Benzene | f Benzene/HC (%) | | |
| Toluene | f Toluene/HC (%) | | |
| Xylene | f Xylene/HC (%) | | |
| N2O | N2O (g/km) | Concept_nonregulated Road category Fuel sulfur content Cumulative mileage | HBEFA 3.1 |
| NH3 | NH3 (g/km) | | |
| PM (non-exhaust) | PM10, PM2.5 mg/km | Vehicle category Road category | Only in Expert Version |
| BC | f BC/PM2.5 (%) | | Only in Expert Version |

Table ifeu.

The objective of the review was to analyse new data sources and, if necessary, update the emission factors and calculation approach. Relevant data sources were emission test data from the ERMES database and literature. The results for each pollutant are described in the following chapters.

## 11.2. N2O and NH3

The latest update of the N2O and NH3 emission factors was done for HBEFA 3.1. The emission factors base on the approach of COPERT 4[4] Pastramas et al. 2014 . The guidebook remarks existing uncertainties especially for Diesel cars with catalysts, i.e. SCR. The emission factors were

[4] An update of the emission factors for N2O and NH3 was not carried out for the latest COPERT (version 5) when writing this report.

compared with measurements from the ERMES on N2O and NH3 for newer vehicles, namely Euro 5 and 6 passenger cars (see Table 25 in the annex).

**N2O**

According to (Ntziachristos et al. 2017) N2O emissions can be generated in vehicles with SCR when slip ammonia is not fully oxidized to N2. In this case the N2O emission factors can be higher than for concepts without SCR, which was also observed in the test data from the ERMES DB. Depending on the cycle the new data showed even higher N2O emissions than the previous emission factor. Therefore, we propose to adapt the emission factors for N2O of Euro 5 and 6 diesel cars as shown in Table 5.

**Table 5: Update of N2O emission factors for Diesel PC in HBEFA 4.1**

| Concept | Urban_cold* | Urban_hot | Rural_hot | Highway_hot |
|---|---|---|---|---|
| | | Unit: mg/km | | |
| **Diesel Euro 3/4/5** | 15.0 | 9.0 | 4.0 | 4.0 |
| **Diesel Euro 5** | 15.0 | **14** (9) | **7** (4) | 4.0 |
| **Diesel Euro 6** | **13.0** (9.0) | **16.0** (11.0) | **14** (4.0) | **7** (4.0) |

Remark: updated emission factors are given in bold, previous emission factors in brackets. * ERMES DB data for Urban_cold based on the WLTC_cold
Table ifeu.

**NH3**

These previous NH3 emission factors for Euro 5 and 6 Diesel cars were based on few data and can only be considered as broad estimates according to Ntziachristos et al. (2017)[5]. The test results from the ERMES DB show some differences:

- Euro 5 diesel cars have much lower and Euro 6 diesel cars have much higher NH3 emissions in hot operation and also vary due to the driving cycle.
- Euro 5 and 6 petrol cars have significantly higher NH3 emissions in urban and rural driving. In urban driving, the emissions increase for newer concepts (Euro 6 > Euro 5 > Euro 4).

The findings from the ERMES DB were compared with additional data from JRC tests (Suarez-Bertoa et al 2014, 2015a-c, Suarez-Bertoa & Astorga 2016). These showed comparable results for Diesel cars with 0.5 mg/km for Euro 5 and 9 mg/km for Euro 6 and for Petrol cars with 14 mg/km for Euro 5 and 35 mg/km for Euro 6.

[5] For example the same factor was used for Euro 5 and 6, also the road category and cold emissions were not distinguished

Based on the new sources it is proposed to update the NH3 emissions factors as shown in Table 6.

**Table 6: Update of NH3 emission factors for Diesel PC in HBEFA 4.1**

| Concept | Urban_cold* | Urban_hot | Rural_hot | Highway_hot |
|---|---|---|---|---|
| | Unit: mg/km | | | |
| **Diesel Euro 4** | 1 | 1 | 1 | 1 |
| **Diesel Euro 5** | **1** (1.9) | **0.3** (1.9) | **0.1** (1.9) | **0.1** (1.9) |
| **Diesel Euro 6** | **1** (1.9) | **3** (1.9) | **8** (1.9) | **8** (1.9) |
| **Petrol Euro 4** | 4.4 | 1.6 | 29 | 65 |
| **Petrol Euro 5** | 12.7 | **14** (3.9) | **12** (7.8) | 21.8 |
| **Petrol Euro 6** | **30** (12.7) | **28** (3.9) | **12** (7.8) | 21.8 |

Values of Petrol cars for new vehicles (no mileage effect) and sulphur level of 0-30 ppm;* ERMES DB data for Urban_cold based on the WLTC_cold
Table ifeu.

## 11.3. CH4 and BT(E)X

HC components in the HBEFA are differentiated in CH4, NMHC, Benzene, Toluene and Xylene. Their emissions are calculated by their share in total HC-emissions. The shares are differentiated by aggregated emission concept (vehicle category and fuel type) and emission category (hot, cold start, evaporation). The last update was carried out for HBEFA 2.1 based on EMPA measurements for petrol cars. Therefore, most of the previous emission factors base on older sources.

For the review we used test data by EMPA which includes CH4, Benzene and Toluene for light duty vehicles with Euro 4-6. The share of each component in HC was calculated and the average percentages compared to the assumptions from HBEFA 3.3

A difficulty in the data was that in several cases the sum of CH4, Benzene and Toluene was higher than total HC. Different test procedures (mainly bag tests for HC and partly CH4, and modal tests for other components) could lead to such results. For example, the CH4-levels for modal tests were approximately double in comparison to bag tests. The CH4, Benzene and Toluene values were corrected so that their sum accounted for total HC components at maximum. Measurements for Xylene were not available from the EMPA tests. Test data of other labs in the ERMES database did not allow this differentiation and were therefore not considered. Additional data was taken from the literature to supplement the EMPA measurements.

**Table 7: Overview of the number of tested LDVs for CH4, Benzene, Toluene and Xylene in the EMPA data**

| Concepts | CH4 (bag and modal) | Benzene (modal) | Toluene (modal) | Xy-lene |
|---|---|---|---|---|
| **Diesel all concepts** | **52** | **24** | **18** | **-** |
| Diesel EURO-4 | 16 | | | |
| Diesel EURO-5 | 12 | 6 | | |
| Diesel EURO-6 | 24 (18 bag, 6 modal) | 18 | 18 | |
| **Petrol (4S) all concepts** | **48** | **22** | **16** | **-** |
| Petrol EURO-4 | 26 | | | |
| Petrol EURO-5 | 10 | 10 | 4 | |
| Petrol EURO-6 | 12 | 12 | 12 | |

Table ifeu.

**CH4**

The analysis of the new sources data underline that the previous approach of HBEFA assuming a constant percentage of CH4 in HC bears uncertainties with modern concepts: EMPA tests show that CH4 emissions decrease to a lower extent than HC emissions for Petrol cars and even increased for Diesel cars from Euro 4 to 6 (see Table 8).

It is proposed to adjust the CH4/HC-fractions for hot emissions accordingly to the percentages given in Table 8 in order to match better to test data of newer concepts[6]. The newer concepts from Euro 2 on are updated based on test data and further assumptions and the previous percentages for conventional cars and GKAT are kept until Euro 1.

The resulting CH4 emissions in mg/km for petrol cars match quite well with the emission factors in COPERT (when weighting hot urban, rural and highway driving 1:1:1) and for Euro 6 with an average 3 mg/km measured by (Liu et al 2017).

For Euro 6 diesel cars the EMPA data delivered rather high CH4 values with ~11 mg/km and slightly lower values were found in studies from (Liu et al 2017) with ~8 mg/km and (Heijne et al, 2016) with ~ 3-7 mg/km in the CADC cycle. The COPERT emission factors for Euro 4-6 diesel cars are much lower but those factors base on older literature data and therefore were not considered.

[6] However, the new percentages remain a rough estimate, e.g. the effect of driving behaviour was not differentiated.

**Table 8: Proposed CH4-percantages (bold) by emission concept and absolute CH4 values in comparison with EMPA tests and COPERT emission factors**

| Source and Unit | | Conv/ PRE-ECE | Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
|---|---|---|---|---|---|---|---|---|
| Petrol | HC (HB33) | 1159 | 111 | 40 | 18 | 7 | 8 | 5 |
| | **CH4 (% HC)** | **3.4%** | **8.4%** | **20%** (8.4%) | **30%** (8.4%) | **40%** (8.4%) | **40%** (8.4%) | **40%** (8.4%) |
| | CH4 calc (mg/km) | 39 | 9.4 | 7.9 | 5.5 | 2.8 | 3.2 | 2.0 |
| | CH4 measured EMPA* (mg/km) | | | | | 2.2 | 3.4 | 1.5 |
| | CH4 COPERT* (mg/km) | 86 | 18.7 | 13.7 | 3 | 3.5 | 3.5 | 3.5 |
| Die-sel | HC (HB33) | 178 | 62 | 35 | 19 | 10 | 7 | 7 |
| | **CH4 (% HC)** | **2.4%** | **2.4%** | **5.0%** (2.4%) | **10.0%** (2.4%) | **15.0%** (2.4%) | **60.0%** (2.4%) | **90.0%** (2.4%) |
| | CH4 calc (mg/km) | 4.3 | 1.5 | 1.8 | 1.9 | 1.5 | 4.4 | 6.6 |
| | CH4 measured EMPA* (mg/km) | | | | | 1.1 | 5.2 | 11.1 |
| | CH4 COPERT* (mg/km) | 16 | 7.7 | 4 | 1 | 0.4 | 0.4 | 0.4 |

* COPERT values were weighted in similar shares for urban/rural/highway driving. Previous CH4-percentages in brackets.
Table ifeu.

For CNG the HBEFA so far assumed a CH4/HC fraction of 92% for LDV and HGVs. Test data which was collected within the ERMES DB on 11 CNG cars showed an average CH4/HC-fraction of approximately 70% but high spreads between the tests. Therefore, we do not propose a change of the CH4-ratio for CNG due to the uncertainty of the limited test. For LPG cars and 4-stroke motorcycles the CH4/HC-fraction of the related Petrol car concepts was assumed due to a lack of test data.

For the percentages of cold start and evaporation emissions we propose no change.

### Benzene, Toluene and Xylene

Table 9 shows the levels for the BTX ratio in HC from the EMPA tests in comparison to the previous HBEFA 3.3 assumptions. Additionally, data from the EMEP/EEA guidebook and data from (Louis et al 2016) for Euro 4 and 5 and (Liu et al. 2017) for Euro 6 cars were considered.

**Table 9: Percentages of Benzene, Toluene and Xylene in HC-emissions of Petrol and Diesel cars from different sources**

| Pollutant | Fuel type | HBEFA 3.3 | EMPA, 2018 | Liu et al. 2017 | EMEP/EEA 2016 |
|---|---|---|---|---|---|
| | | Unit: % in HC | | | |
| **Benzene** | Petrol | Conv: 4.38%<br>GKAT: 12.93% | Euro 5: 50%<br>Euro 6: 10% | Euro 6: 1.0% | Conv: 6.83%<br>Euro 1 & on: 5.61% |
| | Diesel | 1.67% | Euro 5: 66%<br>Euro 6: 4% | Euro 6: 0.6% | 1.98% |
| **Toluene** | Petrol | Conv: 10.65%<br>GKAT: 9.25% | Euro 5-6: 10% | Euro 6: 1.3% | Conv: 12.84%<br>Euro 1 & on: 10.98% |
| | Diesel | 0.32% | Euro 5-6: 8% | Euro 6: 0.1% | 0.69% |
| **Xylene** | Petrol | Conv: 8.5%<br>GKAT: 7.7% | n.a. | Euro 6: 1.3% | Conv: 11.18%<br>Euro 1 & on: 7.69% |
| | Diesel | 0.80% | n.a. | Euro 6: 0.3% | 0.88% |

Remark: except for the EMEP/EEA guidebook the given percentages refer to hot emissions.
Table ifeu.

The EMPA measurements for Euro 5 cars result in much higher benzene shares both for Petrol and Diesel cars and higher toluene shares for Diesel cars. Despite being corrected to the total measured amount of HC, such high benzene and toluene fraction seem unlikely in comparison to literature data. More recent tests with Euro 4-6 cars show a much lower sum of BTX emissions around 1% of HC for all ARTEMIS cycles[7] (Louis et al 2016 and Liu et al 2017). In contrast to the recent EMPA data, the percentage is even lower than previously in the HB33. The EMEP/EEA guidebook suggests higher BTX fractions for conventional concepts and significantly lower benzene shares for petrol cars from Euro 1 on. Basing on older data sources these factors are only used for approximate comparison.

This bandwidth demonstrates the BTX-shares in HC are highly uncertain. Therefore, we propose to keep the current BTX-fraction until Euro 3 and to adapt the values for Euro 4-6 based on the findings from (Louis et al 2016 and Liu et al 2017). Despite having a larger number of tests the EMPA data for BTX was not used, as there seems to be high uncertainties in the modal test data. The results are given in Table 10.

[7] but greater differences occurred in cold start with gasoline cars having the highest emissions

**Table 10: Proposed BTX-percentages in HC for HBEFA 4.1**

| Pollutant | Fuel type | Conv | GKat (for Euro 1-3) | Euro 4-6 |
|---|---|---|---|---|
| | | Unit: % in HC | | |
| **Benzene** | Petrol | 4.38% | 12.93% | 1.0% |
| | Diesel | 1.67% | 1.67% | 0.8% |
| **Toluene** | Petrol | 10.65% | 9.25% | 1.3% |
| | Diesel | 0.32% | 0.32% | 0.2% |
| **Xylene** | Petrol | 8.50% | 7.70% | 1.3% |
| | Diesel | 0.80% | 0.80% | 0.3% |

Table ifeu.

## 11.4. PM non exhaust

Until version 3.3 the HBEFA provides emission factors for PM10 non exhaust only within the expert version. The German Environment Agency (UBA) commissioned a study from Lohmeyer Düring und Schmidt 2016 with the objective to elaborate PM non-exhaust emission factors (both PM10 and PM2.5) for the HBEFA. This chapter summarizes some of the work of this study and provides additional analysis in order to incorporate the emission factors in HBEFA 4.1.

**PM non-exhaust in the previous HBEFA expert Version**

The PM10 factors are based on measurements from Gehrig et al. 2003. To distinguish between tailpipe emissions and emissions from abrasion and resuspension, two size fractions PM10 and PM1 immissions were measured separately, with PM1 interpreted as direct tailpipe emissions and PM10 as total PM emissions. The difference between PM10 and PM1 thus represents the emissions from abrasion and resuspension. Individual emissions caused by tire, road and brake wear as well as resuspension cannot be distinguished.

Even if individual vehicle categories are listed, the non exhaust emission factors are only distinguished between light and heavy vehicles Gehrig et al. 2003. Motorcycle factors, due to the lack of measurement data, correspond to a rate of 25% according to light vehicles. In terms of driving behavior only average patterns for three areas (urban, rural, motorway) are distinguished. Figure shows the current PM10 non exhaust emission factors according to HBEFA 3.3 expert version Keller et al. 2017.

**Table 11: PM10 non exhaust emission factors from HBEFA 3.3 expert version Source: HBEFA 3.3 expert version**

| Vehcat | Unit | EFA_Urban | EFA_Rural | EFA_MW |
|---|---|---|---|---|
| pass. car | mg/vehkm | 54,00 | 22,00 | 47,00 |
| LCV | mg/vehkm | 54,00 | 22,00 | 47,00 |
| coach | mg/vehkm | 540,00 | 144,00 | 74,00 |
| urban bus | mg/vehkm | 540,00 | 144,00 | 74,00 |
| motorcycle | mg/vehkm | 13,50 | 5,50 | 11,75 |
| HGV | mg/vehkm | 540,00 | 144,00 | 74,00 |

Table ifeu.

**Analysis from the Lohmeyer study**

Düring und Schmidt 2016 compared the methodology and emission factors of various sources for validity as well as their ability to integrate them into the HBEFA. A short summary of the different sources is listed here:

- EEA – Tier II (2013): The EEA Tier - II method offers a more detailed approach to calculate tire, brake and road abrasion emission factors. Factors for resuspension instead, are not considered. The evaluation of heavy commercial vehicles is based on different load factors and the number of axles in use. In addition, three different speed ranges are distinguished. With average speed values, in principle different driving situations can be calculated. In addition, a distinction between different vehicle categories takes part. However, according to Düring und Schmidt 2016 in some cases the obtained calculation results significantly differ, in comparison with PM10 immission measurements.
- MOVES EPA (2014): MOVES method focuses on the calculation of PM2.5 non exhaust emission factors caused by brake and tire abrasion. In a next step the emission factors for PM10 can be calculated based on a PM10/PM2.5 ratio. Different vehicle weights, the numbers of wheels or axles in use, as well as different driving patterns are considered. However, no effects of resuspension were taken into account.
- AP-42 EPA (2011): This method contains a detailed formula for calculating PM10 emissions caused by resuspension. However, the important parameter silt load (sL) can only be determined with great effort and the provided standard sL values lead to high uncertainties. In addition, the AP-42 method does not include emissions from brake or tire abrasions.
- APART (2010): With the APART project, the investigations from Gehrig Gehrig et al. 2003 were continued. By statistical analysis of existing immission measurement data, tire or roadway abrasion could not be quantified satisfactorily. Furthermore, this approach has little differentiation in traffic situations of HBEFA 3.3.
- Düring et al (2011): Düring et al. 2011 compared immission measurement data from different studies, which were published between 2000 and 2010. They derived emission factors

and assigned them to the appropriate HBEFA 3.3 traffic situations. For this reason, this approach is compatible with the classification in traffic situations in the latest version of HBEFA (including the distinction between levels of service). Further on, according to the authors the application of PM10 non exhaust emission-factors lead to good "hit rates", compared with immission data. A disadvantage of this method is the fact, that emissions-factors are only distinguished in light and heavy vehicles. For a more detailed breakdown as well as the inclusion of motor-cycles, it lacks valid measurement data.

- NORTRIP (2012): The NORTRIP calculation model was developed by Scandinavian countries (Norway, Sweden, Finland and Denmark) and is based on detailed investigations in 2012 Denby und Sundvor 2012. In comparison with other methods, it provides a high level of detail in terms of the calculation method. Calculations on different tire types, road conditions, road geometry and weather data are implemented. NORTRIP is a time series data based calculation method (1h average values). Therefore it requires high demands on input data. Moreover, in terms of vehicle categories there is no differentiation. Emission factors can be used for the traffic-mixed fleet only, so far. In comparison with immission measurement data the calculated factors of NORTRIP correspond well for inner-city applications. For rural-traffic-situations, the application is currently not suitable, because the investigations were carried out up to speeds of 70 km/h only. In order to calculate emission factors for middle Europe, country-specific and more detailed measurement data would be required.

In order to determine updated non exhaust emission factors, various methods can be considered. For the updated version of HBEFA 4.1, transferability and validity of the factors are most important. According to Düring und Schmidt 2016 this means that the emission factors should be applicable in the HBEFAs existing structure on vehicle categories and driving behavior. Figure 15 summarizes and compares the most relevant methods in terms of the most relevant model parameters compatible with the current version of HBEFA (version 3.3). However, especially country specific influences, e.g. use of snow tires/spikes, frequency and intensity of rainfall cannot be considered without adding additional parameters to the HBEFA.

**Figure 15: Comparison of the most relevant methods**

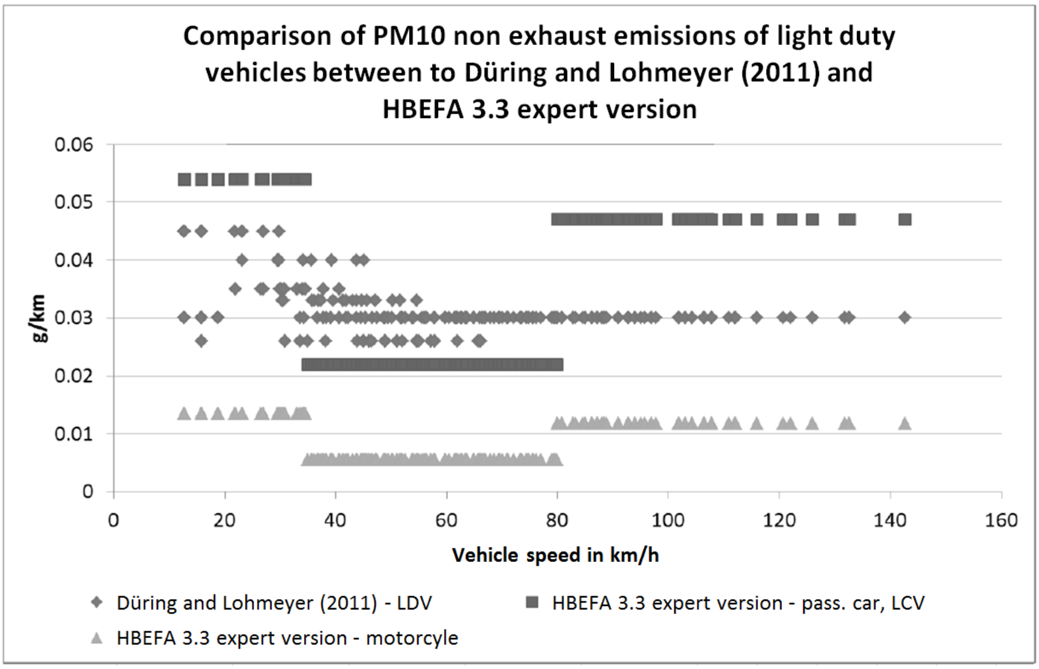
| Model parameters | | HBEFA 3.3 (expert) | EMEP/EEA Tier II | MOVES 2014 | AP-42 EPA | APART | Düring & Schmidt 2016 | NORTRIP |
|---|---|---|---|---|---|---|---|---|
| Type of emission | Tyre wear | | ■ | ■ | | | | ■ |
| | Road wear | | ■ | | | | | ■ |
| | Brake wear | | ■ | ■ | | ■ | | ■ |
| | Resuspension | | | | ■ | ■ | | ■ |
| | Total PM non exhaust | ■ | | | | ■ | ■ | ■ |
| Vehicle categories | MC, PC, LCV, Bus, HGV | | ■ | ■ | | | | |
| | LDV/HDV | ■ | ■ | ■ | | ■ | ■ | ■ |
| Driving behavior | Area/Road type | ■ | | ■ | | ■ | ■ | ■ |
| | Average Speed | | ■ | ■ | | ■ | ■ | ■ |
| | Traffic Situations | | | | | | ■ | |
| Additional parameters | Meteorology | | | | ■ | | | ■ |
| | Type of tyre | | | | | | | ■ |
| | Road dimensions | | | | | | | ■ |
| | Road dust load | | | | ■ | | | ■ |

Graphics ifeu.

Düring und Schmidt 2016 propose integrating PM10 non exhaust emission factors, for both light duty vehicles and heavy duty vehicles, according to Düring et al. 2011 into the HBEFA. The factors show the greatest differentiation of traffic situations. Further on, they are derived from a wide range of immission measurement data from different traffic situations and countries (Germany, Austria, Switzerland).

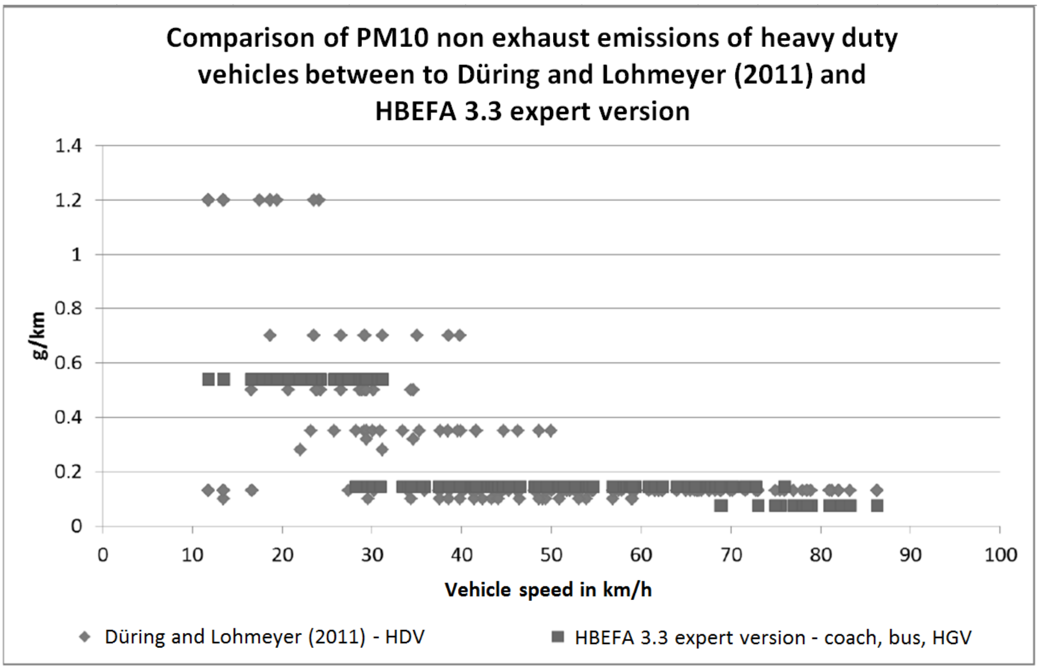
Figure 16 and Figure 17 compare the PM10 non exhaust emission factors proposed by Düring et al. 2011 with the current factors of HBEFA 3.3 expert version. The large number of data points at same speeds, according to Düring et al. 2011, result from the subdivision of traffic situations according to HBEFA 3.3. While the factors of light duty vehicles according to Düring et al. 2011 are low in comparison to HBEFA, they are high for heavy duty vehicles. At slow speed and especially with heavier vehicles, the bandwidth of the PM10 non exhaust emission factors is very large. By comparison of the two methods, no major differences stand out.

**Figure 16: Comparison of PM10 non exhaust emissions of light duty vehicles**




Graphics ifeu. Source: Düring und Schmidt 2016

**Figure 17: Comparison of PM10 non exhaust emissions of heavy duty vehicles**




Graphics ifeu. Source: Düring und Schmidt 2016

In opinion of the authors, the application of these emission factors leads to good "hit rates", compared with immission data. It is described as a quick and pragmatic interim solution for the calculation of non exhaust related PM10 emissions. For disadvantage, the approach according to Düring et al. 2011 does not represent a fundamentally new model of PM10 emission calculation, based on physical factors. Such a long term solution is to be striven for.

Given the fact, Düring et al. 2011 only derive PM10 non exhaust emission factors for light and heavy vehicle categories, we propose to include additional factors for motorcycles. Instead of a defined motorcycle/LDV ratio (25 % in case of HBEFA 3.3), the calculation of emission factors with EEA - Tier II method, has been chosen. With this calculation method, the factors can be applied to the traffic situations according to HBEFA 3.3. Further on the calculated emission factors are in the same range, when compared with the factors from HBEFA 3.3. As mentioned before, the EEA – Tier II method does not include emissions caused by resuspension. As previous studies such as APART indicate that the latter tends to be more relevant for heavy vehicles, the emission factors for motorcycles should be sufficient for an approximate result.

For integrating PM2.5 non exhaust emission factors into HBEFA 4.1, Düring und Schmidt 2016 recommend using the factors from Bretschneider et al. 2012. These factors are based on calculation formulas from EEA - Tier II (2013) method. In contrast to the proposed method for the determination of PM10 particles from Düring et al. 2011, only emissions from tire, brake and road wear can be calculated in EEA – Tier II. Emissions from resuspension are not part of the calculation. According to Düring und Schmidt 2016 this is sufficient for the determination of the emission factors, because the proportion of small PM2.5 particles compared to the total amount of resuspended particles is assumed to be low.

With EEA – Tier II, PM2.5 emission factors can be calculated for passenger cars, light commercial vehicles, heavy commercial vehicles and motorcycles. A differentiation in all traffic situations is determined for every vehicle category. The calculation is based on the average travel speeds depending on the driving cycles, according to HBEFA 3.3. In comparison with immission data, the calculated emission factors for light duty vehicles and heavy duty vehicles provide good "hit rates".

The resulting emission factors are only valid for central Europe, due to a lack of input data and validation for other countries. This is highlighted by a disclaimer in the handbook when PM non-exhaust is selected.

**Uncertainties of incorporating the emission factors into HBEFA**

The proposed non exhaust emission factors from Düring et al. 2011 base on emission factors calculated with NOx- and PM emission factors from HBEFA 3.1. A direct calculation of non exhaust emission factors from the measured concentration differences is not readily possible.

They can vary greatly, depending on the meteorological conditions, even for comparable traffic situations. Therefore, the derivation of the emission factors, either by analysis of a tracer substance or the knowledge of the variation of the air circulation behavior, is necessary Bretschneider et al. 2012.

The tracer-method assumes the emission factors of the tracer substance to be known. In general, NOx is used to calculate PM10 emissions factors. NOx emission factors are the best studied, traffic related emission factors and the ratio between traffic related additional load and background load can be measured in a secure manner. The relation between NOx emission density and NOx additional load represents the so called dilution ratio. According to Düring et al. 2011, PM10 spreads like gas and therefore the NOx-derived dilution ratio also applies to PM10, due to its small particle sizes. When measured, additional traffic related PM10 is multiplied by the NOx dilution factor, the PM10 emission density can be obtained. By dividing the PM10 emission density by the vehicle quantities, the desired emission factor can be obtained. The traffic related additional emissions were calculated then, by subtracting background pollution from PM10 total emissions. These additional emissions were used to calculate the total PM10 emission factors (exhaust, resuspension and abrasion emissions). The majority of datasets Düring et al. 2011 analyzed, non-exhaust related PM10 emissions were determined by subtracting the exhaust emission rate from the total emission factors.

According to an interview with Mr. Düring, the influence of the updated NOx- and PM-emission factors is relevant for the average vehicle fleet used for the tracer-method. With the Update from HBEFA 3.1 to HBEFA 3.3 the NOx emission factors for the 2010 passenger car fleet in Germany changed according to the traffic situation between -2% (URB/Distr/50/Heavy) +28% (RUR/MW/>130/Freeflow). PM_exhaust emission factors changed contrary from -24% (URB/MW-City/70/Freeflow) up to +58% (URB/MW-City/90/St+Go). Consequently, as NOx increased in most traffic situations, such traffic situations with decreased PM_exhaust would have higher PM_Non Exhaust emission factors. However, a detailed analysis such as carried out by Düring et al. 2011 would be necessary to quantify the final emission factors accordingly.

As uncertainties also occur in other sources for PM non-exhaust emission factors, i.e. the HBEFA expert version, we propose to use the emission factors. With HBEFA version 4.1, both NOx- and exhaust PM-emission factors will be updated. These changes directly impact the derived PM10 non exhaust emission factors by Düring et al. 2011. Changes in traffic situations or driving cycles will also affect the PM non-exhaust emissions, i.e. PM2.5 factors are calculated for certain values of average speed for each traffic situation. The latter can be relatively easily updated using the proposed formula by the EMEP/EEA approach. A review and possibly an update might be considered in a new study after HBEFA 4.1 has been finalized.

## 11.5. Black Carbon

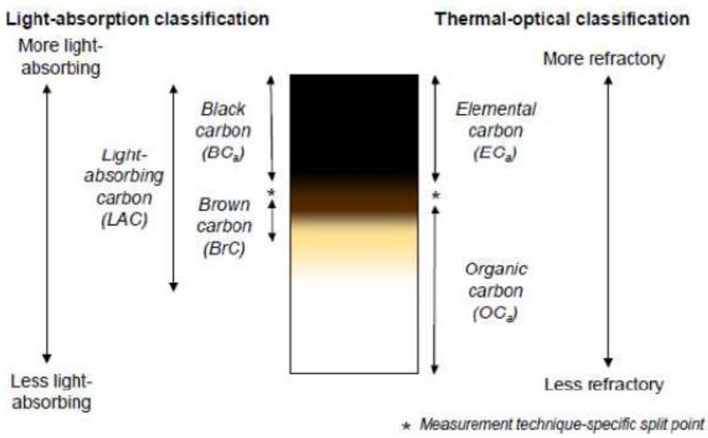
**Background**

Exhaust PM emissions mainly consist of elemental carbon (EC), organic carbon (OC) and inorganic components [Ntziachristos / Samaras, 2017]. The nomenclature for the different components of carbon PM emissions is rather operationally defined, depending on the method utilized for the determination of each carbon component. Hence, there is no strict definition between the exhaust carbon fractions, at least based on their physical or chemical properties. Black Carbon (BC) corresponds to the light attenuation elements of carbon and it is determined by aethalometers. Black carbon is mainly considered to be Elemental Carbon (EC), which is determined by thermal optical methods. However, it also includes some highly refractory elements of Organic Carbon (OC), which desorbs when PM is heated at high temperature (i.e. 600-900°C) in inert atmosphere [Keller, 2011].

For practical applications one can basically distinguish two classes:

- One major class of methods are thermal or thermal-optical techniques, distinguishing refractory and non-refractory carbon as EC and OC, respectively.
- The second major class of methods, optical methods, quantifies the light absorbing component of particles as BC, which can be used to estimate BC concentrations [Keller, 2011].

**Figure 18: Measurement of the carbonaceous components of particles**




Graphics ifeu. Source: [Keller, 2011]

High uncertainties in the measurement of, in particular, organic carbon (OC), indicate that exhaust PM speciation is bound to be highly uncertain. Because of this uncertainty, mean EC and BC values are considered practically equal. Although it is known that EC and BC definitions and determination methods differ, this is considered to be of inferior importance compared to the overall uncertainty in determining either of them per vehicle emission control technology

[Ntziachristos / Samaras, 2017]. Further on, as a fraction of PM, Black Carbon emissions often vary drastically e.g. as a function of vehicle category, type of fuel, emission concept, engine load or of driving patterns, of ambient temperatures, of cold start patterns etc. Keller 2011. The total amount of PM2.5 and thus BC emissions considerable decreased with new emission concepts and the integration of particulate filters.

**BC emission factors in the previous HBEFA Expert Version**

So far, the HBEFA provided emission factors for exhaust related Black Carbon (BC) only within the expert version. In HBEFA the implemented factors can be listed by choosing Switzerland as "selected country". Factors for other countries are not implemented in the HBEFA, yet.
Given the fact, Black Carbon is a share of particles, it can be determined by BC/PM ratios Notter und Wüthrich 2015. The sources of data, and the methodology which estimates the values listed in HBEFA 3.3 expert version, is given in Ntziachristos et al. 2007. Investigations in the 1998-2007 time period were analyzed and thus BC/PM2.5 ratio derived. The data was collected from tunnel, roadway and dynamometer studies.

Based on calculations with the GAINS calculation Model Klimont 2011, Notter und Wüthrich 2015 derived and added ratios for new emission concepts (Euro V, Euro VI, Euro 5, Euro 6) and alternative technologies (CNG, Ethanol, LPG, Electric, Hybrid) to HBEFA.
The BC/PM2.5 ratio in the current version of HBEFA 3.3 correspond to average driving conditions, with no distinction between driving modes or hot and cold-start operation.

**Proposal for BC emission factors in HBEFA 4.1**

In recently published reports by Keller 2011, Notter und Wüthrich 2015 and Knörr et al. 2016, the listed BC/PM2.5 ratios are equal to the ratios derived by Ntziachristos et al. 2007. In addition to these ratios, the new studies provide BC/PM2.5 ratios for Euro 5 and Euro 6 passenger cars, light duty vehicles and alternative fuel technologies as well. These ratios were again, estimated by the ratios from Ntziachristos et al. 2007 which is also the basis for  the latest version of the EMEP/EEA Guidebook 2016 Ntziachristos und Samaras 2017. (Louis et al, 2016) carried out studies on BC emissions of Euro 4 to Euro 5 cars with different after treatment technologies and in different driving conditions. The produced similar ratios of BC/PM10 (exhaust) of 10-20% for petrol cars and ~8% for diesel cars with DPF as an average for different operation conditions.

Given the fact, all evaluated BC/PM2.5 ratios of the examined reports base on the investigations from [Ntziachristos et al., 2007], ifeu proposes to maintain these ratios in HBEFA 4. Moreover, the integrated BC/PM2.5 ratios should be available for every "country selection" in HBEFA.  Minor changes involve the following emission factors:

- We propose to assume BC/PM2.5 ratios of modern Petrol cars (Euro 3-6) for LPG, CNG and Ethanol. Petrol- and Diesel-Hybrids should be treated similarly as Petrol and Diesel vehicles. Zero BC emissions – as previously considered – will only be assumed for electric driving (BEV, PHEV).
- Urban busses can use similar BC/PM2.5 ratios as HDVs, but since DPFs retrofits are common here, separate BC/PM2.5 ratios for Euro I-IV vehicles with a DPF are defined basing on the BC-ration of Euro VI HDVs.

Table 12 shows the BC exhaust emission ratio according to HBEFA 3.3 expert version.

**Table 12: BC/PM2.5 ratios for motorcycles, light vehicles and heavy vehicles according to HEBFA 3.3 expert version**

| Vehicle category | Technology | Emission concept | BC/PM2.5 [%] |
|---|---|---|---|
| **Light duty vehicles** | Petrol and Petrol Hybrid | Conventional | 16 |
| | | Euro 1-2 | 25 |
| | | Euro 3-6 | 15 |
| | Diesel and Diesel Hybrid | Conventional | 55 |
| | | Euro 1 | 70 |
| | | Euro 2 | 80 |
| | | Euro 2 (DPF) | 15 |
| | | Euro 3 | 85 |
| | | Euro 3 (DPF) | 15 |
| | | Euro 4 | 87 |
| | | Euro 4 (DPF) -6 (DPF) | 15 |
| | CNG, Ethanol, LPG | all | 15 (0) |
| **Heavy duty vehicles** | Diesel and Diesel Hybrid | Conventional | 50 |
| | | Euro I-II | 65 |
| | | Euro III | 70 |
| | | Euro IV-V | 75 |
| | | Euro I-V (DPF) | 15 (like Euro I-V) |
| | | Euro VI | 15 |
| | CNG, Ethanol, LPG, LNG | all | 15 (0) |
| **Motorcycles** | Petrol | 2S petrol conv | 10 |
| | | 2S petrol EU 1 & on | 20 |
| | | 4S petrol conv | 15 |
| | | 4S petrol EU 1 & on | 25 |

Note: assumptions from the previous HBEFA version 3.3 are given in brackets
Table ifeu.

### BC non-exhaust emissions

The previous HBEFA 3.3 expert version had also BC non-exhaust emission factors. Similar to the exhaust emission factors they base on the BC/PM2.5 emission ratio. According to (Notter, 2015) a constant ration of 10% was used for all vehicle categories except motorcycles for which a ratio of 12% BC/PM2.5 non-exhaust is used. This complies with the approach from the EMEP/EEA Guidebook 2016 (part "n1.A.3.b.vi-vii Road tyre and brake wear") for the BC/PM ratio of brake and tire wear. The guidebook also proposes a BC/PM ratio of 1.06% for road wear which was not incorporated in the HBEFA yet.

As described in the previous chapter, the PM2.5 non-exhaust emission factors for the HBEFA base on a Tier 2 approach which provides emission factors for each emission category, vehicle category and traffic situation (based on average speed). Technically, a similar differentiation could be adapted for BC non-exhaust, but the EMEP EEA guidebook is not clear on whether BC non-exhaust is to be calculated on the PM10 or PM2.5 ratio. Also the proposed ratio of 1.06% due to road wear is negligible in comparison to break and tire wear.

The BC non-exhaust emission factors (ratio in PM2.5) from the previous expert version HBEFA 3.3 should be adopted for HBEFA 4.1. This simplified approach complies with the EMEP/EEA 2016 (without the negligible part of road wear) and aims at giving a consistent set of PM and BC emission factors including exhaust and non-exhaust. It should be noted that there is a considerable uncertainty related to the PM2.5 non-exhaust emission factors and their BC fraction. Both approaches lack in measurements when taking into account the relevant parameters for non-exhaust emissions (see chapter 11.4).

## 11.6. Implementation in HBEFA 4.1

### 11.6.1. Integration of inputs

The inputs described in the above-subchapters have been integrated into HBEFA 4.1. The following adaptations needed to be implemented:

- A new "Version_nonreg" and a "Scen_nonreg", each with ID 41, were defined and assigned as standards (i.e. defaults selected when opening the application) in HBEFA 4.1.
- The base values for the non-exhaust pollutants (PM10, PM2.5, and BC) are stored in a new table that differentiates traffic situations instead of the three road categories motorway, urban and rural. The necessary modifications to code and data structure were made to accommodate the new data structure.
- As requested at the October 2018 DACH meeting, a disclaimer message has been programmed to warn users of the uncertainties in the non-exhaust emission factors. It appears after the user clicks "Calculate" on the emission factor query form if any of the non-exhaust pollutants has been selected.
- The VOC splits are now differentiated by "Concept_unreg" instead of "Concept_unregAggr", i.e. Euro emission standards are additionally differentiated. The necessary modifications to code and data structure were made to accommodate the new data structure.

- Minor adaptations in the model code were necessary in order for the NH3 emission factors of HDV to be handled at the same level of detail as the N2O emission factors (in HBEFA 3.3 they were only differentiated at a very aggregated level).
- Gaps in inputs (e.g. for alternative fuels) were filled based on EMEP/EEA (2018).
- NH3 emission factors for Euro-VI HDV are based on recent measurements by TU Graz

The new non-regulated emission factor inputs can be viewed and edited in the HBEFA 4.1 Expert Version via Menu *Extras > EF unregulated*.

#### 11.6.2. Special case: NO2/NOx ratio

The NO2/NOx ratios used to derive NO2 EF were supplied by the TU Graz. Also here, some additional differentiations are made, which required the introduction of the following additional "Concept_unreg":
- LDV diesel Euro-5 SU (software update)
- LDV CNG EU0-4
- LDV CNG EU5
- LDV CNG EU6

# 12. WP 10: Country inputs

## 12.1. Data collection using a dedicated template

HBEFA requires a significant amount of country-specific inputs, which are supplied by the participating countries themselves. INFRAS coordinated the collection of these inputs and integrated them into HBEFA 4.1.

To make this process as efficient as possible, a data collection template in Microsoft Excel format was developed and distributed to the responsible persons for HBEFA country data in each country. At the same time, functionality for the automated import and export of the datasets was developed within HBEFA.

To make the adaptation of existing data as easy as possible, the country data available were exported in the template format for each country and sent to the respective country data responsibles. This way, they only had to apply punctual changes and additions, instead of having to prepare the entire datasets afresh. The export of the data also aggregated all data related to PC and MC to the new simplified segmentation (see Chapter 15.2).

The following datasets were collected with the Excel template:

- vehicle stock by segment and age (for historic period, or optionally for entire timeseries)
- vehicle stock with DPF by segment and age (for historic period, or optionally for entire timeseries)
- Absolute number of new registrations (for projected time period)
- Shares of segments in new registrations (for projected time period)
- Traffic activity (individual mileages, road category and traffic situation distributions, load patterns, HGV transformation patterns, ambient condition patterns) at vehicle category and segment level
- Introduction schemes of emission concepts
- Technology mixes:
  - For multi-technologies (e.g. CNG-petrol bi-fuels, PHEVs), shares of vehicle kilometres travelled on each technology)
  - EGR/SCR split for HGV
- Fuel quality, i.e. CO2, SOx, Pb emission factors by fuel type
- Fuel mix i.e. shares of fossil fuels/biofuels by fuel type
- Energy mix, i.e. shares of production types in the production of fuels and electricity (for WTT emission factors, see Chapter 13), and transmission losses of electricity
- Distribution of vehicle kilometres by traffic situation and gradient, by vehicle category
- Inputs for the country "BAU" TDS (traffic dataset): These were derived automatically from the above-listed inputs in the template and could optionally be modified manually.

## 12.2. Fuel efficiency parameters

The fuel efficiency parameters were not supplied by the countries themselves; INFRAS implemented them based on the methodology described in Chapter 10.

The real-world excess values resulting from Eisenmann et al. ([forthcoming]), valid for Germany, were adapted to the other countries based on the ratio of the vehicle kilometre-weighted average of the traffic situation-specific consumption factors of a PHEM average vehicle for each country to the corresponding value for Germany (formula developed by TU Graz):

$$Adaptation\ factor_{Segment,Country} =$$

$$\frac{\frac{\sum Vehkm_{\emptyset-Veh,Year,TS,Country}\ x\ Cons.factor_{\emptyset-Veh,Year,TS}}{\sum Vehkm_{\emptyset-Veh,Year,Country}}}{\frac{\sum Vehkm_{\emptyset-Veh,Year,TS,Germany}\ x\ Cons.factor_{\emptyset-Veh,Year,TS}}{\sum Vehkm_{\emptyset-Veh,Year,Germany}}}$$

# 13. WP 11: WTT emission factors

## 13.1. Introduction

Because electricity-production leads to indirect emissions, the electro-mobility requires to consider WTT emission factors in HBEFA. Decisions taken:

- The format of WTT emission factors will be CO2 equivalents (CO2e, as one value)
- CO2e will also be added as "pollutant" resp. "component" in HBEFA for TTW emissions
- Global Warming Potentials (GWP) according to the IPCC 2006 guidelines will be applied to CH4 and N2O
- For both fuels/gases and electricity, one or several default values (or time-series, respectively) will be provided (sources e.g. Renewable Energy Directive RED, or Biograce Project); in addition, country-specific values will be allowed
- Production types should be available to differentiate emissions for electricity as well as for fuels. For the latter, mainly the different generations of feedstocks for biofuels influence WTT emission factors significantly.
- All WTT emission factors must be provided as time series (again up to 2050)
  - 

## 13.2. Fuels and gases

### 13.2.1. Background on EU policies concerning biofuels

**The Renewable Energy Directive (RED), 2009/28/EC**

The RED sets a 20% share of RES in final energy consumption together with a 20% increase in energy efficiency by 2020). Concerning transport, it ambitions a market share of 10% renewables (based on the net calorific value). It has been completed by the iLUC directive (see below). Currently only 2 countries achieve their transport target: Finland and Sweden European Commission 2017. Some points within the current version of the RED II directive still need to be clarified. The present version defines that Member State should reach a share of renewable energy in the final energy consumption in the transport sector of at least 14% by 2030. They may decide to include in such a minimum share also the contribution from recycled carbon fuels. Within this total share, the contribution of biofuels and biogas produced from feedstock listed in part A of Annex IX[8] or the so called "advanced biofuels" shall be at least [0.3%] of the transport fuels supplied for consumption as of 1 January 2021, increasing up to at least 3,5% by 2030 Council of the European Union 2017. The current version of the RED II (presented in Interinstitutional File: 2016/0382 (COD)) limits the amount of biofuels of the first generation to 7% by 2030 and the share of part B of Annex IX incl. UCO (used cooking oil) to 1,7%. All these targets can make use of the double counting principle: factor 2 for biofuels listed in Annex IX part A and B of the directive.

**The Fuel Quality Directive, 98/70/EC, 2009/30/EC and (EU) 2015/1513**

Fuel suppliers will have to gradually reduce specific fuel GHG emissions by 6% by 2020 based on a life cycle analysis of GHG emissions per unit of energy[9]. Member States may choose to expand this reduction up to 10%. They may also choose to set the intermediate targets of 2% by 2014 and 4 % by 2017.

The directive introduces also sustainability criteria to be fulfilled by biofuels while calculating GHG emission saving. GHG savings of at least 35% should be achieved in comparison to fossil fuels (standard value: 94g CO2e/MJ). This saving requirements rise to 50% in 2018 (60% for installations starting to operate after Ocrober 2015). The European law rules out biofuels originating from the following: primary forest, protected areas, highly biodiverse grassland and raw materials with high carbon stock or peatland (for more detail concerning biofuels).

This directive introduces a cap of 7% on the contribution of biofuels produced from 'food' crops (also called 1st generation), putting a greater emphasis on the production of ad-vanced biofuels (from waste, residue, non-food cellulosic or lignocellulosic biomass), which are counted twice toward the renewable energy target in the transport sector.

It also requires that biofuels emit fewer GHG than fossil fuels. It gives a list of feedstocks for biofuels across the EU whose contribution would count double towards the 2020 target of 10% for renewable energy in transport. Renewable electricity consumed for road transport is also favoured through the calculation of the RES share, counting 5 times while the factor of 2.5 is used for renewable electricity in the rail sector Grinsven und Kampman 2015.

[8] See EU 2015

[9] According to the Directive: "It should amount to at least 6% by 31 December 2020, compared to the EU-average level of life cycle GHG emissions per unit of energy from fossil fuels in 2010, obtained through the use of biofuels, alternative fuels and reductions in flaring and venting at production sites".

## 13.2.2. Constraints and environmental potential of biofuels

Various technical options exist to use biofuels as blends in conventional petrol or diesel in vehicles. Table 13 gives some examples of the blending grades used in different EU countries. The European Standard EN 15376 permits a maximum of 5% ethanol and 15%v/v for ETBE[10], while EN 590 permits biodiesel blends up to 7% of FAME. HVO can be blended to FAME without limit.

**Table 13: Example of blending grade used in EU countries (Status as of 2014)**

| Blending | EU Member State | Brief description |
|---|---|---|
| **E10** | France | Up to 10%v/v ethanol blending in gasoline |
| **E85** | Austria, France, Sweden | Up to 85%v/v ethanol blending in gasoline for so-called flexi-fuel vehicles |
| **B7** | France | Up to 7%v/v FAME blending in diesel fuel |
| | Germany | Plus 3% of renewable diesel |
| **B20** | Poland | For captive fleets |
| **B30** | France | For captive fleets |
| | Czech Republic | For captive fleets |
| **B100** | Germany, Austria, Croatia, Spain, UK | For captive fleets<br>(partly specially adapted vehicles) |
| **HVO 100** | Largely Sweden | Theoretically can be used as diesel but all engine manufacturers do not give authorisation |

Table ifeu. Source: Edwards et al. 2014 and CIVITAS[11]

The environmental impact of different biodiesels varies significantly. The most widespread biofuels i.e. biodiesel and bioethanol have emissions ranging from 16 to 50 g $CO_2$-eq/MJ, depending on their feedstock e.g. if they are produced from used cooking oil (UCO, app. 16 g $CO_2$-eq/MJ) or from wheat (around 50 g $CO_2$-eq/MJ). The future technologies such as biofuel from ligno-cellulose (LC Ethanol, from e.g. these include agricultural residues such as corn stover, wheat straw, sugarcane straw, bagasse or forestry residues (woody biomass), municipal solid waste or energy crops planted in non-productive areas.) and BTL (biomass to liquid) are still expensive, but their costs should decrease in the future. They should also enable to overcome the current limitation of amount of feedstocks if a proper value chain and logistic are adapted Their GHG emissions savings are in average higher than the classical biofuels.

Overall synthetic fuels and waste fuels have the best potentials to fulfil the strengthened regulations. The emissions given above do not take the iLUC emissions into account (also not considered for the moment in the FQD), which means that the real emissions may be higher.

[10] ETBE: Ethyl-tert-butylether
[11] https://civitas.eu/

According to ifeu it could more than the double the global impact, for example FAME (fatty acid methyl ester) from palm oil could jump from approximately 39.5 g $CO_2$-eq/MJ to 109 g $CO_{2eq}$/MJ (with iLUC emissions), which would exceed the emissions of fossil fuels amounting to 98 g $CO_2$-eq/MJ.

Besides classic biofuels (FAME) another product, namely HVO, is currently increasing its market share. It can be produced from many kinds of vegetable oils and fats. This includes triglycerides and fatty acids from vegetable oils (e.g. rapeseed, soybean and corn oil) and tall oil (a co-product from the pulp and paper industry) in addition to the use of animal fats. HVO is also known to have a positive effect on exhaust emissions (NOx and PM), which is primarily due to the high cetane number and low aromatics, this is primarily true for HVO 100 (CE Delft und TNO 2013 and **Suarez-**Bertoa & al. 2019). Currently, the installed HVO capacity in Europe reaches 2 million tons (The energy and water agency 2015).

Another option for using biomass in transport is bio methane, which requires similar refuelling[12] and vehicle technology than natural gas. Thus, for markets without any existing NG fleet, their use should rather be considered in the mid-term (after 2020). Due to its chemical similarity to fossil methane bio methane can be combusted in NG engines in any ratio, having no technical limitation for blending. GHG emissions savings (WTW) from biomethane can be higher than other biofuels, but also depend on the type of feedstocks.

**The current sources to quantify the emissions of biofuels**

According to international standard, the biofuel TTW $CO_2$ emissions are conventionally set at zero due to the fact that plants have used $CO_2$ to grow, counterbalancing the emissions released through their use. The WTW EF are therefore based on the WTT emissions (growth, transport and production of the fuel). This does not consider the iLUC emissions.

Different values are given for the GHG emissions of fuels in:

- EU2015/652: Average life cycle GHG intensity default values (in g $CO_{2\ eq}$/MJ) for fuels, e.g. petrol, diesel, CNG, are given in Part 2. Paragraph 5.
- Directive 2009/30/EC, Annex IV: rules for calculating life cycle GHG emissions from biofuels, according to feedstock, given in the form of typical or default GHG emissions saving in % (compared with a baseline of 83,8g $CO_2$/MJ given in Annex IV too)
- BioEM : Aktualisierung der Eingangsdaten wesentlicher biogener Energienutzungspfade ( funded by the German Environenmantal Agency -UBA)

[12] Besides refuelling station technology, an infrastructure for biomethane distribution is required, e.g. it can be a profitable Bio LNG business for small scale producers it if they can inject their biomethane production in an existing gas grid.

BioEM is in line with the RED directive (2009/28/EC) and the Fuel Quality Directive (2009/30/EC) includes an excel tool giving the GHG emissions of biofuels. This includes the cultivation, transport and production phases.
Default values according to the feedstocks are provided, but all input parameter e.g. fertilisers used or energy consumption of the storage can be changed if more precise official data are available.

### 13.2.3. Possible methodology to include WTW EF for biofuels into HBEFA

They are 3 main categories of blending options with biofuels:
- Diesel blend with:
- FAME[13]
- HVO[14] or both

These biofuels can nevertheless be used pure for specific vehicles (for example in the agriculture) as well as PVO[15]
- Petrol blend with:[16]
  - Ethanol
  - ETBE: Bio-ETBE is produced from bioethanol (47% v/v) and isobutylene (53%), where the latter fraction cannot be marked as biofuel

- CNG blend:
  - Biomethane

Bio LNG is also considered as a potential in the future to lower GHG emissions of transport but the consumption of LNG in the transport sector (for HDVs) is currently very low.

In parallel to the above mentioned blends, pure biofuel i.e. not blended to petrol or gasoline are used such as pure biogas, pure HVO.

The biofuels can be categorised into 3 generations (first, second and advanced). Biofuels specific emissions factors are strongly influenced by feedstocks and production paths.

A possibility to come up with a value for all the different fuels would be to predefine the average EU fuel mix. But according to ePure 2016 in the EU 28 the incorporation rate of

[13] Fatty Acid Methyl Ester
[14] Hydrotreated Vegetable Oils
[15] Pure vegetable oil
[16] https://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf

ethanol has been relatively constant in the last years at 3.3%. The biodiesel incorporation in the diesel pool has fluctuated over the last 5 years and reached 5.1% (low heating value) in 2014.

The problem is that the share of biofuels varies between the countries, as presented below:

**Table 14: Example of blending grade used in EU countries (Status as of 2014)**

| 2014, energy based | Austria | France | Germany | Sweden |
|---|---|---|---|---|
| **Share ethanol (%)** | 4 | 5,5 | 4 | 5 |
| **Share biodiesel (%)** | 6,2 | 6,9 | 5,3 | 13 |

Table ifeu. Source: Edwards et al. 2014 and CIVITAS[17]

Therefore, ifeu recommends allowing users to give countries' own share of biofuels parallel to default European values (if European default values can be defined – this must be carefully studied).

A possible method would be to have a module for biofuels organised in 4 parts:
- Biodiesel (blended both with FAME and HVO)
- Ethanol (blended)
- Biomethane
- Pure vegetable oil or biofuels i.e. HVO 100 and B100

Taking the example of biodiesel, they are several possible blends, for example up to 7% FAME (in volume) for all vehicles, as well as higher blends for captive fleets e.g. B20 or 30 with different feedstocks. In order to integrate new emission factors for biodiesel in HBEFA, the total amount of biodiesel consumed (if necessary calculated based on the different blends) should be calculated and then multiplied with the relevant emission factors (see Table 15). The EF for diesel incl. biodiesel or alternatively only biodiesel in gCO2e/MJ should be calculated based on the total emissions and the total amount of fuel as shown in Table 16. The same exercise can be carried out for petrol and its share of ethanol, as well as for CNG and biomethane.

As example the share of the different feedstocks used in fuel blend are shown below, first for ethanol (Table 16) and second for biodiesel (Table 17). The past shares are extracted from different sources (Naumann et al. 2016; BLE 2018). The projection from 2018 on has been derived so

[17] https://civitas.eu/

that Germany reached its goals regarding the RED in 2020 and 2030, which includes the ban of biofuels with high iluc emissions such as palm oil. Moreover the amount of biofuel globally required is linked with the amount of renewable energy planned to be used for electric mobility in order to achieve the RED targets. The amount of renewable electricity used by e-vehicles (calculated with a factor 4 as specified in the current RED II proposal) is derived from TREMOD.
This gives for 2020 an EF for ethanol of 37.9 kg CO2e/TJ and 31.6 in 2030; for biodiesel 30.1 in 2020 and 37.1 kg CO2e/TJ in 2030. The latest increases due to the decrease of palm oil in the mix, replaced by available resources such as rape oil and soja oil, as the cap for UCO given by the RED II is already met.

**Table 15: GHG-emission factors for biofuels**

| Fuel | Feed Stock | EFA (gCO2eq/MJ |
|---|---|---|
| **Biogas** | waste-to-gas | 14.0 |
| **Ethanol** | maize-to-liquid | 71.5 |
| **Ethanol** | rye | 61.7 |
| **Ethanol** | wheat-by-gas | 48.2 |
| **Ethanol** | Wheat-by-waste | 34.9 |
| **Ethanol** | sugar beet | 37.2 |
| **Ethanol** | sugar cane | 22.9 |
| **Ethanol** | ligno cellulose | 31.3 |
| **Biodiesel** | FAME rapeseed oil | 49.6 |
| **Biodiesel** | FAME soya oil | 42.1 |
| **Biodiesel** | FAME palm oil | 30.1 |
| **Biodiesel** | HVO palm oil | 39.4 |
| **Biodiesel** | HVO waste | 16.2 |

Table ifeu. Source: BioEM for all EF; ifeu for ligno cellulose

**Table 16: Scenario: share of feed stocks for ethanol**

| | Maize | Rye | Wheat - Lignite as solid fuel (CHP) | FAME Wheat-CNG as fuel (conv. boiler) | Sugar beet | Sugar cane | Cellulosic biofuels (advanced) |
|---|---|---|---|---|---|---|---|
| **<=2007** | 30% | 0% | 38% | 0% | 30% | 2% | 0% |
| **2008** | 17% | 0% | 33% | 0% | 25.0% | 25.0% | 0% |
| **2009** | 13% | 0% | 26% | 0% | 24% | 37% | 0% |
| **2010** | 23% | 0% | 46% | 0% | 1% | 30% | 0% |
| **2011** | 24% | 0% | 48% | 0% | 27% | 1% | 0% |
| **2012** | 23% | 1% | 45% | 0% | 30% | 1% | 0% |
| **2013** | 23% | 3% | 46% | 0% | 28% | 1% | 0% |
| **2014** | 24% | 3% | 46% | 0% | 26% | 1% | 0% |
| **2015** | 33% | 7% | 43% | 0% | 14% | 2% | 1% |
| **2016** | 33% | 7% | 44% | 0% | 7% | 8% | 0% |
| **2017** | 48% | 8% | 38% | 0% | 3% | 4% | 0% |
| **2018** | 34% | 6% | 32% | 7% | 5% | 6% | 10% |
| **2019** | 19% | 5% | 26% | 13% | 8% | 9% | 20% |
| **2020** | 5% | 3% | 20% | 20% | 10% | 12% | 30% |
| **2021** | 5% | 3% | 18% | 21% | 10% | 12% | 32% |
| **2022** | 4% | 2% | 16% | 21% | 10% | 13% | 34% |
| **2023** | 4% | 2% | 14% | 22% | 10% | 13% | 36% |
| **2024** | 3% | 2% | 12% | 22% | 10% | 13% | 38% |
| **2025** | 3% | 2% | 10% | 23% | 10% | 14% | 40% |
| **2026** | 2% | 1% | 8% | 23% | 10% | 14% | 42% |
| **2027** | 2% | 1% | 6% | 24% | 10% | 14% | 44% |
| **2028** | 1% | 1% | 4% | 24% | 10% | 14% | 46% |
| **2029** | 1% | 0% | 2% | 25% | 10% | 15% | 48% |
| **>=2030** | 0% | 0% | 0% | 25% | 10% | 15% | 50% |

Table ifeu. Source: (Naumann et al., 2016) and BLE 2018

**Table 17: Share of feed stocks for biodiesel**

| | FAME Rapeoil | FAME Soyaoil | FAME Palmoil | HVO Palmoil | Oil from waste |
|---|---|---|---|---|---|
| **<=2007** | 80% | 1% | 5% | 0% | 14% |
| **2008** | 51% | 42% | 6% | 0% | 1% |
| **2009** | 81% | 10% | 4% | 0% | 5% |
| **2010** | 83% | 13% | 4% | 0% | 0% |
| **2011** | 82% | 0% | 13% | 0% | 5% |
| **2012** | 58% | 2% | 20% | 0% | 20% |
| **2013** | 50% | 3% | 25% | 0% | 22% |
| **2014** | 56% | 0% | 21% | 0% | 23% |
| **2015** | 60% | 0% | 6% | 9% | 25% |
| **2016** | 39% | 0% | 12% | 9% | 40% |
| **2017** | 35% | 2% | 23% | 2% | 38% |
| **2018** | 22% | 4% | 28% | 11% | 36% |
| **2019** | 26% | 5% | 25% | 9% | 36% |
| **2020** | 15% | 5% | 30% | 15% | 35% |
| **2021** | 19% | 6% | 27% | 14% | 35% |
| **2022** | 23% | 6% | 24% | 12% | 35% |
| **2023** | 27% | 7% | 21% | 11% | 35% |
| **2024** | 31% | 7% | 18% | 9% | 35% |
| **2025** | 35% | 8% | 15% | 8% | 35% |
| **2026** | 39% | 8% | 12% | 6% | 35% |
| **2027** | 43% | 9% | 9% | 5% | 35% |
| **2028** | 47% | 9% | 6% | 3% | 35% |
| **2029** | 51% | 10% | 3% | 2% | 35% |
| **>=2030** | 55% | 10% | 0% | 0% | 35% |

Table ifeu. Source: (Naumann et al., 2016) and BLE 2018

The EF for B100 (pure biodiesel) or pure vegetable oils are straightforward and are only dependant on the type of biofuel i.e. feedstock.

In Germany, almost the entire amount of biogas produced comes from waste, which enables to reach an EF of 14kg CO2e/TJ.

### 13.2.4. GHG-emission factors for conventional fuels and gases

For the conventional fuel pre-chains, data from the EUCAR-CONCAWE-JRC collaboration are used. Here the well-to-tank greenhouse gas emission for typical European transport fuels are given and validated in a stakeholder process. These factors are the basis for the renewable energy directive, as they were used to derive the typical (default) GHG savings from biofuels. In (JEC, 2014a) no emission for construction or decommissioning of fuel production and transportation facilities are included.

**Table 18: GHG-emission factors for conventional fuels**

| Fuel | Code | EFA (gCO$_{2eq}$/MJ |
|---|---|---|
| **Gasoline** | COG1 | 13.8 |
| **Diesel** | COD1 | 15.4 |
| **Compressed natural gas (CNG)** | GMCG1 | 13.0 |
| **Liquefied Petroleum Gas (LPG)** | LRLP1 | 8.0 |
| **Liquefied natural gas (LNG, road)** | GRLG1 | 19.4 |

Table ifeu. Source: JEC 2014

## 13.3. Electricity

### 13.3.1. General considerations

The new HBEFA includes electric vehicles; therefore, upstream emission factors for the generation of electricity are needed.

The following processes have been included to derive WTT emissions factors for electricity generation:

- Exploration and extraction of the primary energy carrier (coal, oil, gas, nuclear etc.) and transport to the entrance of the power plant
- Conversion within the power plant
- Energy distribution (transforming and transportation losses)

Today there are two widely used methods for carbon foot printing in the electricity sector:

- **Physical approach** (*"grid based" or "location-based"*): only physical flows of electricity are taken into account (i.e. national consumption mix).
- **Virtual approach** (*market-based*): the electricity fluxes taken into account are the ones associated with the contractual instruments, *including certificates and guarantees of origins*, independently from the physical flux. The virtual approach can only be applied, if a consumer-market for electricity exists.

For HBEFA the physical approach is the only suitable method and will therefore be used here. The physical approach has a high reliability, avoids double- counting and can easily be derived from European energy statistics.

The emission factors for the different electricity generation technologies are derived from the widely accepted LCI database ecoinvent 3.4 (cut-off system model) Weidema et al. 2013. They encompass all upstream processes including extraction, transport and transformation of the electricity produced before exiting the power plant. For transformation and transfer to the final user further losses have to be taken into account.

For electric vehicles electricity is either supplied at a low voltage level (e.g. in a home charging station) or at medium voltage (e.g. for fast- charging infrastructure). Therefore HBEFA will include values for both voltage levels.

These values can be calculated with the following formula:

$$EFA_{cons} = \frac{EFA_{pp}}{1 - CF}$$

$EFA_{cons}$: WTT emission factor of the final consumer

$EFA_{PP}$: WTT emission factor at exit power plant

CF: Conversion factor (losses) from power plant to final consumer

Average country specific values for the transport and transformation losses can be found in Eurostat 2013 and International Energy Agency 2015. They provide a starting point for the losses at different voltage levels, assuming that the sub-divisions within voltage levels (including the total losses) are the same for all countries as in Germany.

It has to be noted, however, that with this approach, the electricity distribution infrastructure is neglected and no SF6 emissions from transmission are included.

**Table 19: Electricity losses for the different countries at different voltage levels**

| | Average losses Eurostat 2013 and International Energy Agency 2015 | losses to medium voltage | losses to low voltage |
|---|---|---|---|
| **EU 28** | 6.7% | 4.2% | 8.7% |
| **DE** | 4.1% | 2.6% | 5.4% |
| **CH** | 6.6% | 4.1% | 8.6% |
| **AT** | 5.1% | 3.2% | 6.7% |
| **FR** | 6.8% | 4.2% | 8.9% |
| **SE** | 6.7% | 4.1% | 8.7% |

Table ifeu. Source: <please enter here>

### 13.3.2. EU Mix (2000 to 2050)

HBEFA will supply default data for the European electricity mix for the years 2000 to 2050 (including scenario data).

Generic greenhouse gas emission factors for different electricity generating plants were derived using data from ecoinvent 3.4. to allow for a flexible calculation of different possible future electricity mixes. Since ecoinvent is a life cycle assessment database, the electricity factors also account for plant construction. Since no infrastructure is included in the HBEFA prechain values, all the renewable electricity generation from wind, solar and water was manually set to 0. The other emission factors still included infrastructure emissions; however, the difference between the factors with and without infrastructure for conventional power plants is negligible and lies below 4 g $CO_{2eq}$/ kWh.

Electricity generation in power plants has many (regional) differences: power plants in the different countries might use a different technology, be of a different age or have different efficiencies. In addition, the feedstock varies between the different countries. Therefore, each electricity mix in ecoinvent consists of different regionalized electricity generation datasets (e.g. for Germany more than 20 different electricity generation datasets are used).
The datasets were therefore simplified and aggregated into groups to derive generic factors for the different plant types.

The different European countries have a very diverse electricity mix and therefore the carbon intensity of their electricity mix varies greatly. While Sweden supplies most of their electricity from water power plants, France uses mainly nuclear power generation and Germany has the most diverse mix including more than 40% coal. Therefore, different countries were taken to derive “typical” values for the plant types.

**Table 20: Emission factors for electricity production from ecoinvent 3.4 used in HBEFA 4.1**

| | **Emission factor in g $CO_{2eq.}$/ kWh** | **country** |
|---|---|---|
| **Coal (solids)** | 1154 | Germany |
| **Natural gas** | 654 | Germany |
| **Hydropower** | 0 | |
| **Wind** | 0 | |
| **Nuclear** | 13 | France |
| **Photovoltaic*** | 0 | |
| **Biomass** | 133 | Germany |
| **Oil** | 833 | Germany |

*photovoltaic is usually supplied at low voltage level, but will be treated here as high voltage to simplify the calculation
Table ifeu. Source: <please enter here>

These emission factors can be used to calculate electricity mixes for scenario data. It has to be noted, however, that these factors are technically only valid for today and that future electricity generation may lead to different greenhouse gas emissions.

For the European scenario, electricity mix data is integrated into HBEFA. It stems from the widely accepted European Reference scenario 2016 (Europäische Kommission, 2013). This European reference scenario proposes a trend projection assuming that all member states achieve their legally binding goals concerning renewable energy. It includes data for all EU member states as well as the whole European Union. The values given here can be seen as a very conservative estimate, since many countries have already tightened their targets for renewable energies compared to this European scenario data.

Table 21 shows the percentages of the gross electricity generation by source in the EU 28.

**Table 21: EU Mix according to the European Reference Scenario (gross electricity generation)**

| | Nuclear energy | Solids | Oil | Gas | Biomass-waste | Hydro | Wind | Solar |
|---|---|---|---|---|---|---|---|---|
| **2000** | 31.4% | 31.1% | 6.0% | 17.1% | 1.5% | 11.9% | 0.7% | 0.2% |
| **2005** | 30.3% | 29.3% | 4.3% | 21.5% | 2.7% | 9.5% | 2.1% | 0.2% |
| **2010** | 27.5% | 24.9% | 2.6% | 24.0% | 4.4% | 11.3% | 4.5% | 0.9% |
| **2015** | 26.7% | 26.0% | 1.1% | 17.4% | 5.8% | 11.1% | 8.4% | 3.4% |
| **2020** | 23.0% | 22.9% | 0.7% | 17.3% | 6.3% | 11.2% | 13.8% | 4.9% |
| **2025** | 20.9% | 19.1% | 0.6% | 19.9% | 7.3% | 10.9% | 15.4% | 5.9% |
| **2030** | 22.0% | 16.0% | 0.5% | 18.6% | 8.0% | 10.7% | 17.2% | 6.9% |
| **2035** | 21.7% | 12.2% | 0.4% | 21.9% | 8.7% | 10.6% | 17.0% | 7.4% |
| **2040** | 19.5% | 8.8% | 0.4% | 24.6% | 9.7% | 10.5% | 18.4% | 8.1% |
| **2045** | 18.8% | 5.9% | 0.3% | 24.2% | 9.8% | 10.5% | 21.1% | 9.4% |
| **2050** | 18.1% | 6.2% | 0.1% | 20.6% | 9.6% | 10.4% | 24.1% | 10.9% |

Table ifeu. Source: <please enter here>

By multiplying the emission factors with the electricity mix data an average greenhouse gas emission factor for electricity was calculated (shown in Table 22).

**Table 22: Electricity emission factor for the EU 28**

| year | GHG emissions |
|---|---|
| **2000** | 528 g CO2eq./ kWh |
| **2005** | 524 g CO2eq./ kWh |
| **2010** | 478 g CO2eq./ kWh |
| **2015** | 441 g CO2eq./ kWh |
| **2020** | 403 g CO2eq./ kWh |
| **2025** | 378 g CO2eq./ kWh |
| **2030** | 335 g CO2eq./ kWh |
| **2035** | 314 g CO2eq./ kWh |
| **2040** | 294 g CO2eq./ kWh |
| **2045** | 260 g CO2eq./ kWh |
| **2050** | 239 g CO2eq./ kWh |

Own calculations, based on ecoinvent 3.4 and the European reference scenario
Table ifeu. Source: <please enter here>

### 13.3.3. Country Specific Values

Most countries will be able to supply their own electricity mix data to HBEFA, therefore only data for the EU is included in HBEFA.

For countries with a low share of imported electricity, the national production mix may be used. However, it is recommended to use the consumer mix instead in order to include electricity imports and exports e.g. in Austria the share of imported electricity is quite high. Only the net electricity exports and imports should be used, since it is possible to have imports and exports simultaneously due to transit trade. For these net imports or exports the domestic production mix from importing or exporting countries may be used as a proxy Itten et al. 2012.

## 13.4. Implementation in HBEFA 4.1

### 13.4.1. Concept

WTT emission factors were implemented in HBEFA 4.1 based on the following conceptual considerations:

- WTT emission factors are made available for CO2 equivalents (CO2e) only (decision at HBEFA workshop in April 2018).
- A default average EU energy mix scenario is made available for all countries; countries can optionally provide own energy mix scenarios.
- WTT (well-to-tank) and TTW (tank-to-wheel) are referred to as “scopes” within the application.

### 13.4.2. Adaptations to HBEFA functionality and data structure

The following adaptations to HBEFA functionality and data structure were made to implement the concept:

- A new pollutant “CO2e” (CO2 equivalents) was defined. Its properties can be viewed in the Expert Version under Menu *Definitions > Pollutants*.
- The calculation of CO2e requires the calculation of the following input pollutants (i.e. whenever CO2e is selected by the user, these pollutants have to be calculated in the background as well):
  - FC (fuel consumption in g/km) – required as input to calculate CO2 (reported)
  - CO2 (reported)
  - FC_MJ (fuel consumption in MJ/km) – required for the WTT emissions of electricity, and as final unit of fuel consumption in the WTT emission factor calculation (since input WTT EF are expressed in g/MJ of end energy use)
  - CH4

  - HC, since $CH_4$ is derived from HC
  - $N_2O$
- A new parameter "GWP" for the 100-year global warming potential (GWP), required to calculate $CO_2$ equivalents from $CH_4$ and $N_2O$, was added to the definition table of pollutants. It was set to the following values according with IPCC 2007:
  - $CH_4$: 25
  - $N_2O$: 298
- New tables were created for:
  - Energy mix scenarios: Shares of production types per energy, country, and year
  - WTT input emission factors in g/MJ differentiated by year, energy, energy mix scenario (and pollutant, although for now, only $CO_2e$ is available)
  - Transmission losses: Power transmission losses in % of the final energy consumption, by year, country, and loss type (medium voltage vs. low voltage)
  - Definition tables for energy mix scenarios, production types
  - Relationship table defining which energy mix scenarios are available for which country

### 13.4.3. User interaction

The user can select whether to calculate WTT emission factors, or emissions, respectively, by checking new checkboxes on

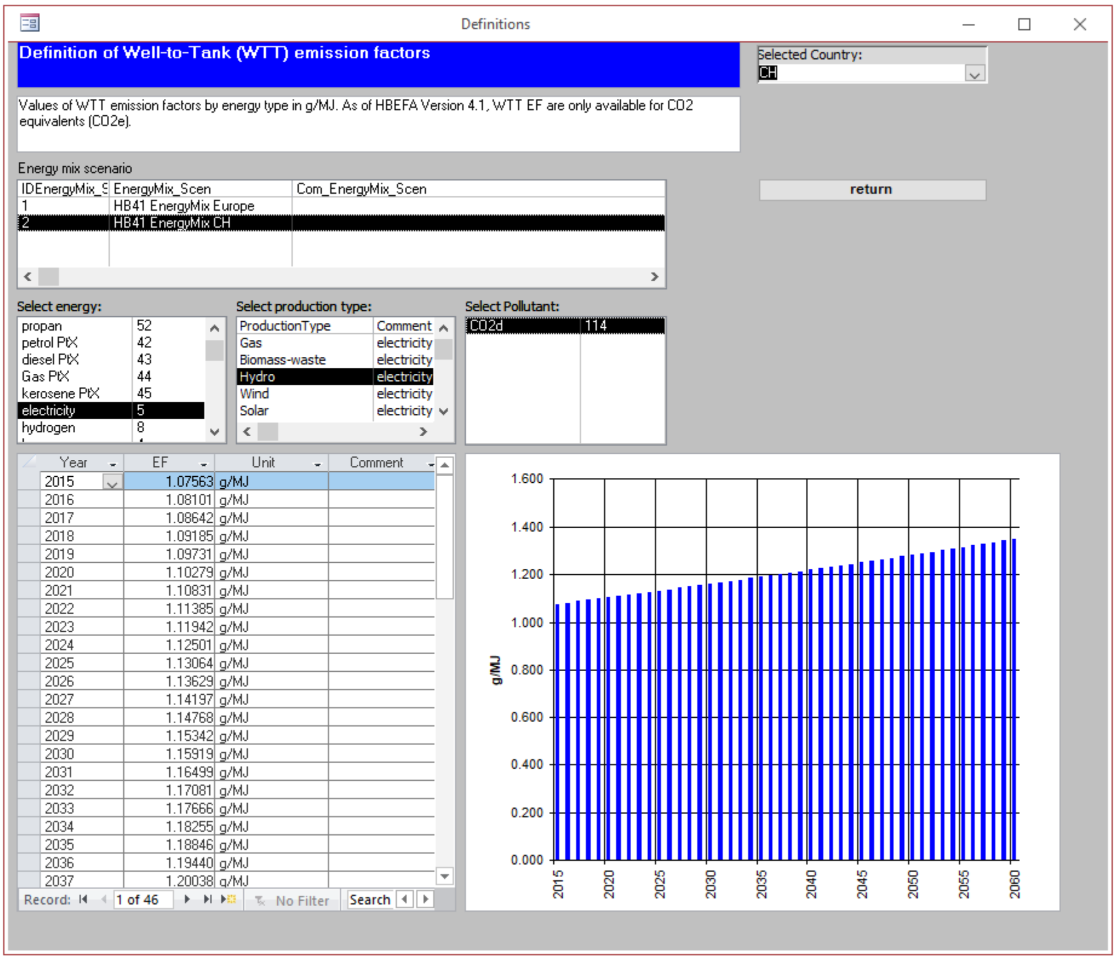
- the emission factor query form in the HBEFA Public Version (or under Menu *Emission factors* in the Expert Version)
- the emission model calculation interface in the Expert Version (Menu *Emission factors > Calculate*)

New user forms have been created for viewing (and in the Expert Version, editing) of:

- Input WTT emission factors in g/MJ (Figure 19):
  - In the Expert Version: Menu *Fuel/Energy > WTT Emission factors*
  - In the Public Version: Menu *Info > Electric vehicles > WTT emission factors*
- Energy mix scenarios (Figure 20):
  - In the Expert Version: Menu *Fuel/Energy > Energy mix*
  - In the Public Version: Menu *Info > Electric vehicles > Energy mix*
- Transmission losses:
  - In the Expert Version: Menu *Fuel/Energy > Energy losses > Transmission losses*
  - In the Public Version: Menu *Info > Electric vehicles > Transmission losses*

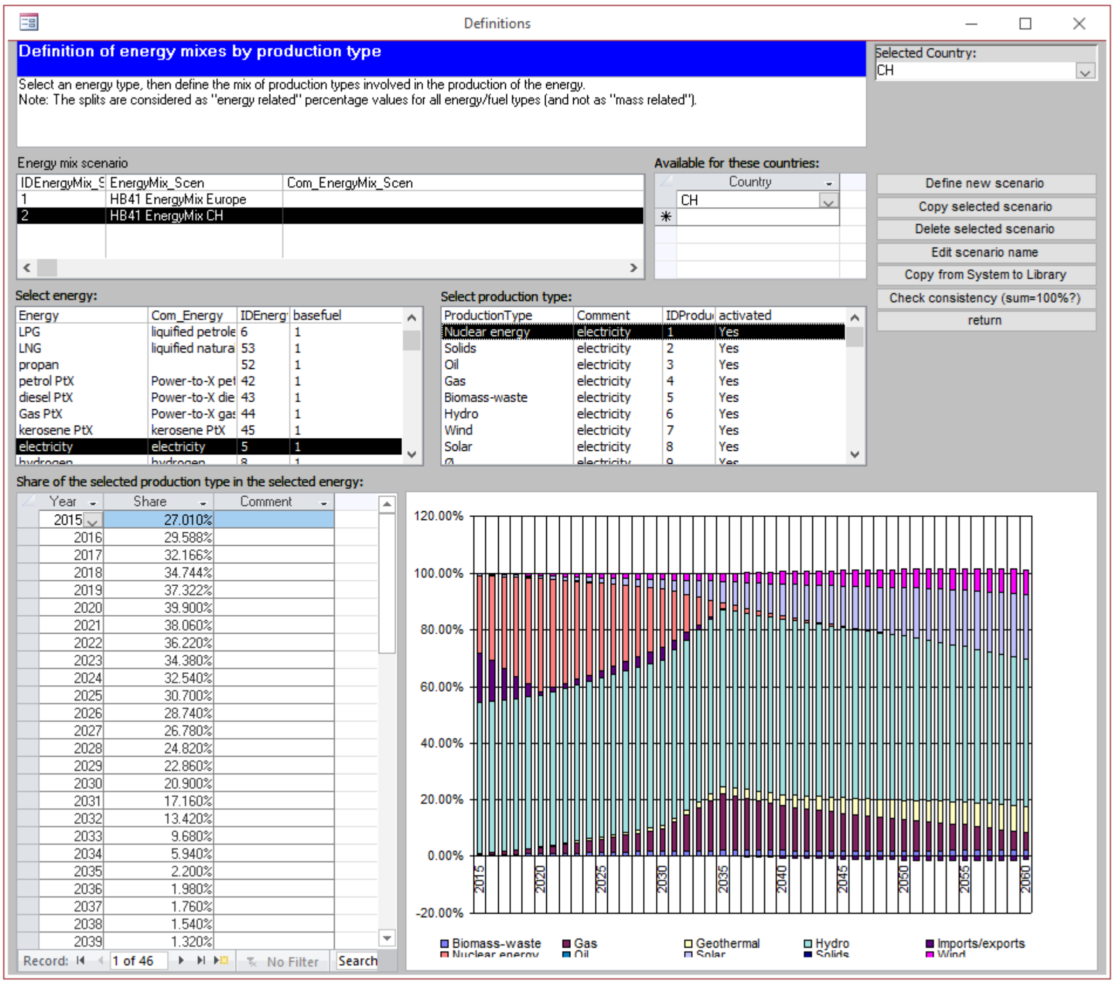
In the Expert Version, production types of energy can be added via Menu *Fuel/Energy > Production Types.* (Note that editing of existing production types has been disabled since this would affect results of other countries, possibly without the editing user being aware of the consequences).

**Figure 19: User interface for viewing/editing WTT input emission factors in g/MJ.**




Graphics INFRAS. Source: HBEFA 4.1

**Figure 20: User interface for viewing/editing energy mix scenarios (shares of production types by energy).**




Graphics INFRAS. Source: HBEFA 4.1

## 13.4.4. Outputs

The WTT emission factors in g/vehkm calculated by HBEFA are made available to the user in the following outputs:

- Emission factor query in the HBEFA Public Version (or under Menu *Emission factors* in the Expert Version): EFA_WTT and EFA_TTW (= EFA + EFA_WTT) as new output columns
- Emission model in Expert Version: TTW emissions are added as additional lines to the result table. They are differentiated from the WTT emissions by a new column “IDScope” (1 = TTW, 2 = WTT)

# 14. WP 12: “Extended version” of HBEFA

In this work package, an “Extended version” of HBEFA was planned to be made available. The idea was to provide a range of functionality somewhere between the Public and the Expert Version to a wider circle of users than the limited circle of Expert Version users. In particular, a simplified version of the Fleet Model as well as the Emission model would be part of such a version.

Against the background of additional efforts required to develop HBEFA 4.1 that were not foreseen at the time when the work programme was developed, it has been decided to postpone the implementation of an “Extended version”.

# 15. WP 13: Model implementation

## 15.1. Scope of this chapter

This chapter describes cross-cutting and general aspects of the development of the HBEFA 4.1 application. Aspects specific to the implementation of the results of particular work packages are described in the respective WP chapters.

## 15.2. Changes to vehicle classes

### 15.2.1. Simplified segmentation

In HBEFA 4.1, the segments in some vehicle categories were simplified compared to previous versions (see Table 23).

For **PC**, the three engine capacity classes from previous HBEFA versions were abolished – HBEFA 4.1 uses only one size class for PC. The reasons for this are:

- There is no “hard” information lost by this simplification. For air pollutants, the same EF were applied to all three size classes already in the previous HBEFA versions. The fuel consumption and CO2 emission factors, which were differentiated, were not measured, but calibrated – based on the same information still used in HBEFA 4.1, i.e. CO2 monitoring plus secondary information like fuel logs or fuel sales.
- There is no legal differentiation, e.g. regarding limit values, within the PC.

- The capacity classes used so far have more and more lost their meaning. With engine downsizing, engine capacity does not correlate so well with engine power anymore. On the other hand, any obvious classification that would have been well-accepted and for which data to implement it would be available in all HBEFA countries was not available. E.g. the “market segments” used in Germany are not available in the registration databases of any of the other HBEFA countries.

For **MC**, the segments were simplified as well, but not as radically:
- For 4-strokes, the two size classes <=250 cc and >250 cc are differentiated in HBEFA 4.1
- For 2-stroke motorcycles, only one size class (<=250 cc) is used in HBEFA 4.1
- The size classes of the mopeds remain unchanged.

For **HGV**, most existing segments remain unchanged. However, for **alternative fuels**, only for size classes are differentiated in HBEFA 4.1:
- 3 rigid truck size classes, i.e. <=7.5 t, 7.5 – 12 t, and >12 t (based on legal classifications)
- 1 TT/AT size class

These change in segmentation resulted in considerable effort to aggregate all other information in the HBEFA application related to segments, e.g. also age distributions, survival probabilities, age dependencies, or fuel efficiency parameters.

Nevertheless, given the memory limitation in MS Access (see next Chapter), the effort was worthwhile, since without the simplification, HBEFA would require even more memory and it is unclear whether it would still run in 32-bit office with the old segmentation plus the newly introduced segments for electric vehicles and alternative fuels.

### 15.2.2. New segments
For electric vehicles and alternative fuels, new segments have been introduced, or segments activated so far only in the Expert Version have been activated also in the Public Version. The changes are described in the respective Work Package chapters.

### 15.2.3. New emission concepts
In HBEFA 4.1, the following emission concepts are new:
- Differentiation of all Euro-6 sub-concepts, i.e. ab, c, d-temp and d, for PC and LCV. However, for some alternative drivetrain segments, only “Euro-6” is used.
- Euro-7 has been defined in all required tables, but not yet activated.

**Table 23: Changed segmentation from HBEFA 3.3 to 4.1.**

| Segment in HBEFA 3.3 | Segment in HBEFA 4.1 |
|---|---|
| PC petrol <1,4L | PC petrol |
| PC petrol 1,4-<2L | |
| PC petrol >=2L | |
| PC diesel <1,4L | PC diesel |
| PC diesel 1,4-<2L | |
| PC diesel >=2L | |
| PC CNG/petrol small | PC CNG/petrol |
| PC CNG/petrol medium | |
| PC CNG/petrol big | |
| PC FFV small | PC FFV |
| PC FFV medium | |
| PC FFV big | |
| PC BEV small | PC BEV |
| PC BEV medium | |
| PC BEV big | |
| PC PHEV petrol small | PC PHEV petrol |
| PC PHEV petrol medium | |
| PC PHEV petrol big | |
| PC PHEV diesel small | PC PHEV diesel |
| PC PHEV diesel medium | |
| PC PHEV diesel big | |
| PC LPG small | PC LPG |
| PC LPG medium | |
| PC LPG big | |
| PC FuelCell small | PC FuelCell |
| PC FuelCell medium | |
| PC FuelCell big | |
| MC 4S <=150cc | MC 4S <=250cc |
| MC 4S 151-250cc | |
| MC 4S >750cc | MC 4S >250cc |
| MC 4S 251-750cc | |
| MC 2S >150cc | MC 2S <=250cc |
| MC 2S <=150cc | |
| RigidTruck CNG >12-14t | RigidTruck CNG >12t |
| RigidTruck CNG >14-20t | |
| RigidTruck CNG >20-26t | |
| RigidTruck CNG >26-28t | |
| RigidTruck CNG >28-32t | |
| RigidTruck CNG >32t | |
| RigidTruck Electric <7,5t | RigidTruck BEV <=12t |
| RigidTruck Electric 7,5-12t | |
| RigidTruck Electric >12-14t | RigidTruck BEV >12t |
| RigidTruck Electric >14-20t | |
| RigidTruck Electric >20-26t | |
| RigidTruck Electric >26-28t | |
| RigidTruck Electric >28-32t | |
| RigidTruck Electric >32t | |

Table INFRAS. Source: HBEFA 4.1

## 15.3. Effects on emission factors accounted for by HBEFA inputs

There are two new effects in HBEFA 4.1 that imply that some emission or consumption factors depend not only on the driving behaviour within a particular traffic situation (as could be assumed in previous versions of HBEFA), but also on what happened before. These have implemented in a way that did not necessitate any structural or functional changes in HBEFA itself; instead, they are already accounted for in its inputs:

- The influence of SCR catalyst temperature and NH3 storage on NOx emissions is accounted for by simulating "conditioning cycles" in PHEM before the actual cycle for a given traffic situation. The "conditioning cycles" were provided by WP 2 (Ericsson et al. 2019) based on an analysis of which other HBEFA traffic situations typically precede HBEFA traffic situations. The modelling methodology in PHEM is described in Weller et al. (2019).
- The influence of initial SOC and the preceding trip on SOC on entry into a given traffic situation, which influences the electrical driving share of PHEV's, was simulated by the TU Graz based on typical sequences of micro-trips. Based on this, a relationship between electrical driving shares and average speed was established. In turn, typical electric driving shares by road category (motorway, rural, urban) were implemented in HBEFA (see Chapter 9.5).

## 15.4. Memory limitation in MS Access

With the new version 4.1, HBEFA reaches more and more the limits of random-access memory available to MS Access in Office 32-bit.

Already in previous versions of HBEFA, "out of memory" errors sometimes occurred. With both the number of subsegments and traffic situations increased by roughly 30% compared to HBEFA 3.3, plus new features such as WTT emission factors, such errors occur more frequently in HBEFA 4.1.

The reason is the limit of random-access memory available to MS Access in Office 32-bit. MS Access can at most use 2 GB of "virtual memory" – i.e. physical RAM plus paged memory – regardless of the RAM available in the computer on which it is running.

Figure 21 visualizes memory usage in HBEFA 4.1 in a typical use case (application start, data initialization, two emission factor queries) and thus illustrates the problem:

- Already after opening HBEFA, >700 MB of virtual memory are already used by the process, before any data have been read into memory.
- During data initialization, which is started automatically when the user opens either the form for the emission factor query or the emission model, the occupied memory increases

to roughly 1400 MB, due to reading in all required data (emission factors, country-specific data of the selected country) into RAM.

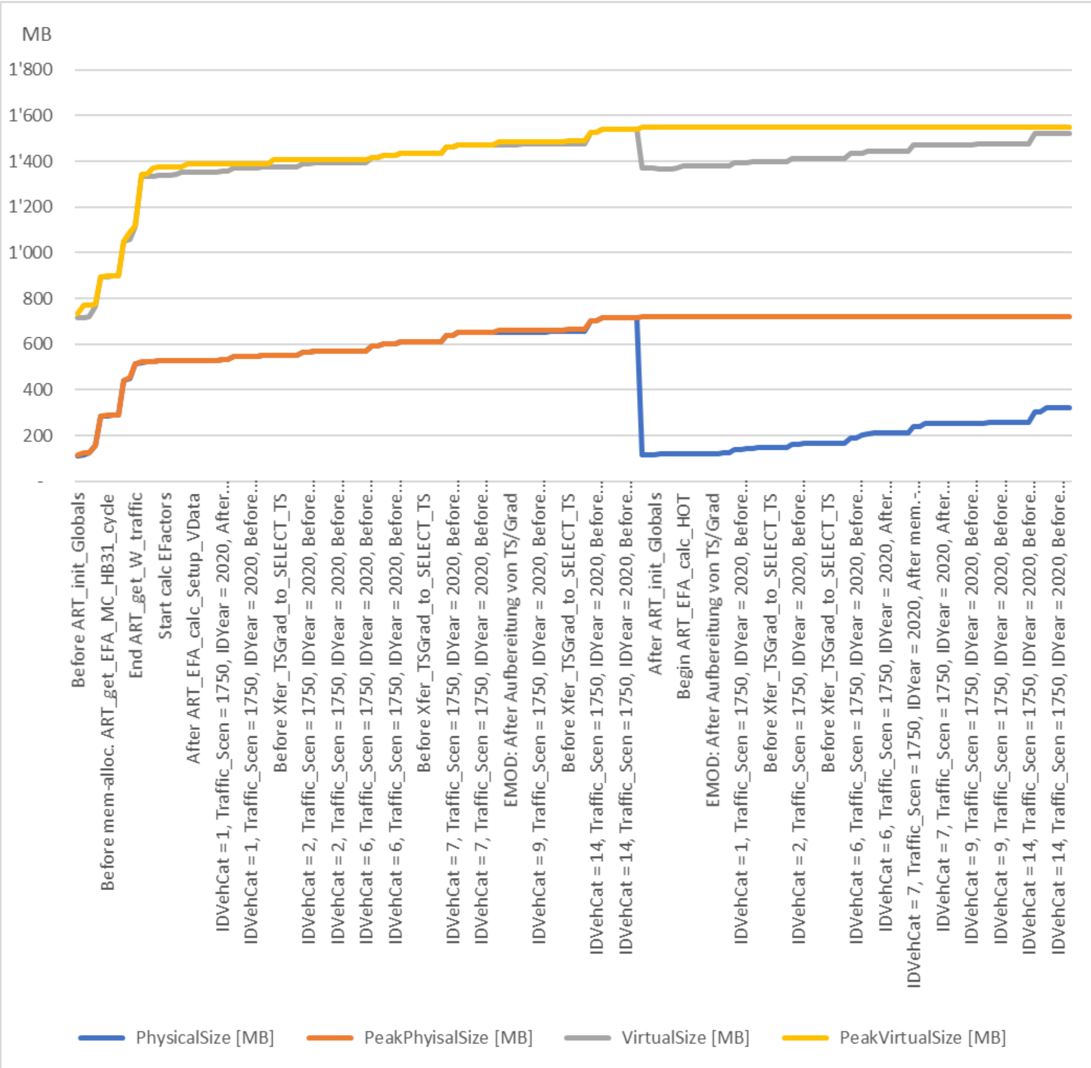
- While emission factors are calculated in a typical use case, the used memory increases depending on the number of vehicle categories, years, pollutants, number of traffic situations etc. selected.
- Typically, when occupied memory reaches around 1750 MB, HBEFA 4.1 crashes with an "out of memory" error. The 2 GB (2000 MB) are never reached either due to other processes already occupying the required memory, or due to the unavailability of contiguous address space of sufficient size for the array being allocated memory.

The following measures may serve as a work-around if "out of memory" errors occur in HBEFA 4.1:

- Close and reopen HBEFA 4.1 when an out-of-memory error occurs;
- Close other MS Office applications while running HBEFA 4.1, especially during initialization;
- Close and reopen HBEFA 4.1 frequently to free up memory blocked from opening forms, tables etc.; especially before running the menu entries that will trigger the data initialization sequence (i.e. *Emission factors > New* (or *Edit*) and *Emission model > Calculate*)
- Run HBEFA and its back-end (System, User, Library) databases on a local drive (C:), not on network drives. Based on our observations, it even makes a difference if a location on the C: drive is also mounted as a network drive (e.g. "P:") – an out-of-memory error may occur if the back-end databases are linked using the path on "P:", but not when the physically identical files are linked using the path on "C:".
  For users that have installed HBEFA and never moved the databases and never linked other back-ends, this is irrelevant since the installation is always on "C:".
- Optimizing/defragmenting the hard drive on which HBEFA is stored (via Windows 10 settings or Control Panel in older Windows versions) may also help.
- In the Expert Version:
  - Deactivate unneeded traffic scenarios under menu *FleetModel > Define/select/edit traffic scenarios*
  - Physically delete traffic scenarios from a System database (Menu *FleetModel > Merge Fleet-,TrafficActivity-, EmConcept-,FC-Scenarios*); split the System Database into multiple versions if many traffic scenarios are sometimes required.

Using HBEFA 4.1 in 64-bit instead of 32-bit MS Office should solve this problem; however, this is not a viable solution for most HBEFA users, since if an MS Office 32-bit installation is present on a computer, HBEFA 64-bit will not be compatible with it (and vice versa). Most users have MS Office on their computer, and the 32-bit version is still by far the more popular one.

**Figure 21: Memory usage in HBEFA 4.1 in a typical use case: Application start, data initialization, two emission factor queries.**




Graphics INFRAS. Source: HBEFA 4.1

## 15.5. Installer for HBEFA

HBEFA is delivered to its users in the form of an executable installer (“setup.exe” or similar), which can be double-clicked to trigger the installation process.

There are two new features regarding the installer for HBEFA 4.1:

- HBEFA 4.1 requires MS Access as a software platform to run. If this software is not available on the target computer (i.e. when no MS Access at all is installed, or an older version), the installer will install a "runtime" version instead, i.e. a version of Access with limited functionality open to the user. The previous versions of HBEFA, 3.2 and 3.3, required Access 2010 to run. HBEFA 4.1 has been upgraded to Access 2016 and is shipped with the corresponding runtime version.
- A second new feature of the 4.1 installer is that it besides the "classical" 32-bit version, also contains an HBEFA version for 64-bit MS Office (not to be confused with 64-bit Windows: most users nowadays use 64-bit Windows, but 32-bit Office). This is the main reason (besides the increased data content of the application itself) that the new HBEFA installer is more than twice as large in file size (close to 1 GB) as previous installers.

# Annex

**Table 24: List of non-regulated pollutants in HBEFA**

| Pollutant | Description |
|---|---|
| Benzene | Benzene |
| Cd (exhaust) | Cadmium (exhaust) |
| Cd (non-exhaust) | Cadmium (non-exhaust) |
| CH4 | Methane |
| Dioxin | Dioxin |
| N2O | Nitrous Oxide |
| NH3 | Ammonia |
| NMHC | Non-Methane-Hydrocarbons |
| NO2 | Nitrogen Dioxide |
| Pb | Lead |
| PM (non-exhaust) | PM 10 (non-exhaust, total) |
| SO2 | Sulfur dioxide |
| Toluene | Toluene |
| Xylene | Xylene |
| Zn (exhaust) | Zinc (exhaust) |
| Zn (non-exhaust) | Zinc (non-exhaust) |

Table ifeu

**Table 25: Test data (Average) and number of tested vehicles for N2O and NH3**

| Pollu-tant | Concept | WLTC cold | Tests (cold) | CADC Urb | CADC Rur | CADC MW | Tests (hot) |
|---|---|---|---|---|---|---|---|
| | | mg/km | number | mg/km | mg/km | mg/km | number |
| **N2O** | LDV diesel Euro-5 DPF | 8.4 | 2 | 13.6 | 4.8 | 3.2 | 19 |
| | LDV diesel Euro-6 DPF (all) | 15.4 | 34 | 15.0 | 14.9 | 6.9 | 24 |
| | LDV diesel Euro-6 DPF (with SCR) | 16.2 | 17 | 16.7 | 14.9 | 7.5 | 12 |
| | LDV petrol Euro-6 | 2.1 | 1 | 6.0 | 2.0 | 0.5 | 1 |
| **NH3** | LDV diesel Euro-5 DPF | | | 0.3 | 0.1 | 0.1 | 18 |
| | **LDV diesel Euro-6 DPF (all)** | 0.6 | 22 | 1.7 | 9.8 | 4.1 | 18 |
| | **LDV diesel Euro-6 DPF (with SCR)** | 1.1 | 7 | 2.7 | 10.8 | 8.3 | 7 |
| | **LDV petrol Euro-5** | | | 14.3 | 11.8 | 7.4 | 10 |
| | **LDV petrol Euro-6** | 30.6 | 11 | 28.3 | 12.8 | 25.1 | 7 |

Table ifeu

**Calculation of electricity losses**

To arrive at the losses for different voltage levels, the losses for the average consumer are used to calculate the total losses. These total losses are then divided between the different voltage levels. According to Bundesnetzagentur 2014 in Germany in 2013 36,6% of the total losses occured at (very) high voltage (> 72,5 kV), 26,3% at medium voltage (> 1 kV and ≤7,.5 kV) and 37,0% at low voltage (< 1kV), with average losses of 4,1%.

The electricity usage in Germany in 2013 according to (BDEW, 2015) and the division between different users as well as an assessment of the voltage level of the supplied electricity is given in Table 26.

**Table 26: Net electricity usage in Germany 2013 BDEW 2015**

| Net electricity usage 2014 | | voltage level (own assumptions) |
|---|---|---|
| Households | 25,6% | *Low* |
| Trade and business | 14,7% | *Low* |
| Industry | 45,8% | *Medium* |
| Mobility | 2,2% (2,0% for trains) | *Medium (rest)*<br>*High (for trains)* |
| Public buildings | 9,9% | *Low* |
| Agriculture | 1,8% | *Low* |

Table ifeu

As a result, we estimate that 2% of the electricity in Germany is supplied at high voltage, 46% at medium voltage and 52% at low voltage.

We assume that the division between the electricity supplied at the different voltage levels and the division of the total electricity losses are the same as in Germany for each other country. With these assumptions the average losses for each voltage level are determined. The sum of all losses can be derived by multiplying the average losses for the country with the electricity usage in this country. By dividing the total losses occurring at each voltage level with the electricity at the voltage level, losses are calculated.

Since the electricity supplied at medium or low voltage undergoes the higher voltage levels, too, these losses than have to be cumulated to arrive at the losses for the supplied electricity at each voltage level.

**Table 27: Losses per grid level in Germany**

| Grid level | Losses |
|---|---|
| High voltage | 1,5% |
| Medium voltage | 2,6% |
| Low voltage | 5,4% |
| Average | 4,1% |

Table ifeu

# Glossary

| | |
|---|---|
| **BC** | Black carbon |
| **BEV** | Battery-electric vehicle |
| **CNG** | Compressed natural gas |
| **DPF** | Diesel particle filter |
| **EFA, EF** | Emission factor |
| **EGR** | Exhaust gas recirculation |
| **FCEV** | Fuel-cell electric vehicle |
| **FFV** | Flex-fuel vehicle |
| **GHG** | Greenhouse gas |
| **GWP** | Global warming potential |
| **HEV** | Hybrid-electric vehicle |
| **HGV** | Heavy goods vehicle |
| **LCV** | Light commercial vehicle |
| **LNG** | Liquefied natural gas |
| **MC** | Motorcycle |
| **PC** | Passenger car |
| **PHEM** | Passenger car and Heavy duty Emission Model (detailed emission model at individual vehicle level, TU Graz) |
| **PM** | Particulate matter |
| **TTW** | Tank-to-wheel, i.e. direct emissions or consumption |
| **SCR** | Selective catalytic reduction |
| **UBA** | Umweltbundesamt (Germany, Austria) |
| **UBus** | Urban bus |
| **Vehkm** | Vehicle kilometre(s) |
| **WTT** | Well-to-tank, i.e. indirect or upstream emissions or consumption from the production of fuels |
| **WTW** | Well-to-wheel, i.e. WTT +TTW emissions or consumption |

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