Effects of the HBEFA 5.1 version update on emission estimates in European countries

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Introduction

The Handbook of Emission Factors for Road Transport (HBEFA) has been a standard data source of emission factors since its inception in the mid-1990s. Its country coverage started with Germany, Switzerland, and Austria, and has been extended to include also France, Sweden, and Norway (as of Version 3.1, published in 2010); the Handbook is also applied outside these countries, e.g. by serving as input to emission calculation tools such as COPERT, EcoTransIT, or LCA tools such as EcoInvent.

In order to always reflect the current state of knowledge and measurements of road transport emissions, HBEFA has been updated in 3 to 5-year intervals based on the latest available data and state of knowledge. The newest version 5.1 will be published in October 2025. For this major update (with the main version number changing from 4 to 5), all contents have been reviewed and updated.

The updates with Version 5.1 are shown in Table 1. Most of the new features focus on aspects that gain importance as hot exhaust emissions decrease – i.e. cold start excess emissions (which are now also available for heavy-duty vehicles and battery-electric vehicles), non-exhaust emissions (differentiated by processes, detailed vehicle types, and traffic situations), SCR tampering and malfunctions, and energy consumption of electric vehicles. Euro-7 emission factors have been included based on the current state of knowledge. Furthermore, all country-specific fleets have been modelled based on the current state of in-force and expected regulations, covering a time series from 1990 up to 2050 or 2060. Several other papers presented at the 2025 TaP conference cover the elaboration of inputs to HBEFA 5.1 in detail, e.g. Dippold und Hausberger (2025), Opetnik et al. (2025), or Hausberger et al. (2025).

All in all, the 5.1 update represents a substantial extension of contents compared to previous HBEFA versions. The number of "components" (pollutants, energy consumption, positive engine work) has increased from 27 to 44; the number of subsegments (vehicle types at the finest level of detail) has increased from 833 to 1375; and the number of hot base emission factors has increased from about 20 to almost 100 million. Furthermore, the HBEFA application has been migrated from Microsoft Access to a Python-based client-server solution: the addition of contents would have technically not been possible in the previous development environment; plus, the new application is more user-friendly and allows higher efficiency in use.

In this paper, we estimate greenhouse gas (GHG) and air pollutant emissions from road transport for the countries and time-series covered in HBEFA 5.1, and quantify the impact of the methodological changes and of fleet development, the Euro-7 standard, and SCR tampering between the new version HBEFA 5.1 and the last version 4.2 (published in 2022).

Table 1: Overview of content updates with HBEFA version 5.1

Update	Description
Hot emission factors (EF) update	General update of all hot base emission factors based on latest available measurement data (lab, PEMS, remote sensing)
Non-exhaust EF	Non-exhaust emission factors based on new model (Hausberger et al. 2025), differentiated by processes (tire/brake/road wear, resuspension) and subsegments
Non-regulated EF	Additional non-regulated pollutants: CH_3CHO (Acetaldehyde), HNCO (Isocyanic acid), HNO_2 (Nitrous acid), HCHO (Formaldehyde). N_2O and NH_3 from Euro-6de/VI DE based on PHEM model at traffic situation resolution.
Cold start EF	Cold start excess emission factors based on new model (Opetnik et al. 2025),available also for heavy-duty vehicles (HDV) and battery-electric vehicles (BEV)
Evaporation EF	Gasoline evaporation emission factors based on latest COPERT methodology (Mellios et al. 2024)
Euro-7 EF	Euro-7 emission factors based on known regulations/test conditions and PHEM simulation
Mileage correction factors	Updated functions for mileage correction: Additive instead of multiplicative factors allow for more realistic correction across all traffic situations
SCR tampering and malfunctions	Emission factors for tampered or malfunctioning SCR included; high emitters included in fleet scenarios.
New HGV size classes	HGV size classes for alternative drivetrains at same detail as for Diesel; size classes up to 90 t.
New L-cat. vehicle types	New segments/subsegments in the vehicle category "motorcycles" (which contains all L-category vehicles): 4-stroke mopeds, ATVs, minicars
Conditioning cycle updates	Conditioning cycles ("trip history", relevant for SCR temperature and hybrid vehicle battery SOC) updated based on driving behaviour data from Horizon Europe project "uCARe"
Country data	Update of all country-specific data (fleet data, fuel properties etc.) with time-series covering at least the period 1990-2050

Overview of the HBEFA methodology

HBEFA is a database application that provides emission factors (EF) for road transport at the required level of detail. This ranges from fine-grained emission factors by “subsegment” (the most detailed vehicle classification level in HBEFA, differentiating vehicle category, drivetrain technology, size class, and emission standard) and “traffic situation” (HBEFA differentiates 365 traffic situations defined by road type, area type, speed limit, and level of service) up to aggregated, average emission factors by vehicle category, country, and year.

HBEFA covers hot emissions, cold start extra emissions, and evaporative emissions. The hot and cold start base EF are derived from lab and PEMS measurements using the PHEM model developed at the Technical University of Graz (Hausberger und Rexeis 2018); the evaporative emissions (HC and HC components from petrol vehicles) are calculated by implementing the Tier 3 methodology in the EMEP/EEA Emission Inventory Guidebook (Mellios et al. 2024). Non-exhaust emissions, i.e. abrasion from tyres, brakes, road, and resuspension, are treated as “hot” emissions in HBEFA because they are also expressed in grams or particle number per vehicle kilometre; as of HBEFA Version 5.1, the input base emission factors for non-exhaust components originate from PHEM (Hausberger et al. 2025).

The hot base EF (valid for new reference vehicles at 20°C ambient temperature) are available by subsegment, driving cycle, gradient, and load class. Each traffic situation is assigned a representative, real-world driving cycle for every vehicle category. PHEM uses these cycles to model the base EF.

Depending on the desired output, HBEFA performs the following calculations (among others):

- Fleet aggregation: As an output of the HBEFA fleet model, relative shares of mileage and stock are available per subsegment, road category, and year. These are used to calculate average weighted emission factors at the desired fleet aggregation level. As of HBEFA 5.1, eight fleet aggregation levels are available that can be combined flexibly.

- Traffic situation aggregation: For each country, at least four traffic situation distributions are available containing the mileage shares of each traffic situation and gradient combination per vehicle category. These are used to calculate average weighted emission factors by road category, or averages over all road categories.

- Mileage correction: To account for catalyst ageing, HBEFA applies correction factors based on average cumulative mileage by subsegment and year. The cumulative mileage is tracked by the fleet model. While in earlier versions of HBEFA, multiplicative correction factors were used, the correction values in HBEFA 5.1 are additive, which is more appropriate given the low absolute base EF of newer vehicles in most traffic situations.

- Ambient temperature correction: To account for the optimization of NOx aftertreatment to the type approval temperature of around 20°C, HBEFA corrects NOx EF of Euro-5 and -6 diesel light-duty vehicles for ambient temperature.

- Energy efficiency correction: To account for improvements in energy efficiency – mainly due to the CO2 fleet limits in the EU – the input energy consumption factors are adjusted by the fleet model to the annual type approval averages published by the EEA CO2 monitoring (EEA 2020), plus a “real-world” addition that takes into account actual loads, traffic situations, and driving behaviour (see Tietge et al. 2020).

For cold start and evaporative emissions, fleet aggregation is performed the same way as for hot emissions. Climate (temperature distributions) and driving behaviour patterns such as distributions of trip length, parking times, and traffic volume are considered. In previous versions of HBEFA, these emission categories were only calculated for light-duty vehicles and motorcycles – therefore, average patterns for all these vehicles per country were sufficient. In HBEFA 5.1, where cold start is also calculated for heavy-duty vehicles with very different usage patterns, these patterns can be differentiated by vehicle category, technology, and size class.

Fleet development up to 2050

All countries covered by HBEFA are affected by regulations at EU level, namely the ban of internal combustion engines by 2035 or the Euro-7 emission standard. National regulations and different expectations how regulations will be implemented, however, lead to different fleet developments in the countries covered.

All analysed countries foresee significantly higher shares electric mileage by 2050 in HBEFA 5.1 than they did for HBEFA 4.2 (Table 2). For passenger cars and light commercial vehicles (LCV), the electric mileage shares are currently projected at around 90% by 2050, while for HBEFA 4.2 they still varied between roughly 30% and 95%.

The steepest increase is observed for Heavy Goods Vehicles (HGV), for which all countries estimated the electric mileage share to be between 0% and 10% for HBEFA 4.2, while the current estimates range from 56% to 91%. The differences are due to partly official national reference scenarios: While Germany foresees Diesel trucks to be replaced almost exclusively by BEV trucks, Austria assumes about 20% of the HGV mileage to be driven by hydrogen ICE vehicles (arguing some ICE mileage is likely to remain up to 2050); Sweden foresees about 5% of truck mileage to be driven by LNG trucks, and Switzerland foresees an about 10% share of fuel cell (FCEV) truck mileage.

For motorcycles, the expectations regarding electrification also vary between countries: While Switzerland and Sweden expect quickly progressing electrification despite the lack of a regulation affecting motorcycles, Germany and Austria are more cautious in their projections and expect only 43% and 20%, respectively, of two-wheeler mileage to be electric by 2050.

Table 2: Share of electric mileage by vehicle category in 2050 in selected countries, according to reference scenarios for HBEFA 4.2 (grey letters) and 5.1 (black letters)

Vehicle category	Pass. cars		LCV		HGV		Urban buses		MC	
HBEFA version	4.2	5.1	4.2	5.1	4.2	5.1	4.2	5.1	4.2	5.1
Switzerland	70%	91%	62%	90%	2%	83%	59%	90%	70%	85%
Austria	46%	86%	31%	89%	2%	56%	68%	94%	34%	20%
Germany	60%	92%	61%	90%	8%	91%	77%	92%	11%	43%
Sweden	95%	94%	96%	96%	0%	77%	100%	99%	70%	93%

Overall emission development

The current section focuses on the case of Switzerland, for which we have simulated scenarios with identical activity (mileages, starts/stops, and stock) with HBEFA 5.1 and 4.2. Most effects observed are valid for all countries covered in HBEFA, however.

Compared to HBEFA 4.2, in Version 5.1 the emissions of almost all pollutants decrease faster and are consequently lower in the projected period 2030-2050 (Figure 1). This is due to the higher share of electric vehicles in the fleet, the Euro-7 regulation (compare Chapter on Euro-7 effects below), and the lower base emission factors of Euro-6de/VI DE vehicles compared to HBEFA 4.2.

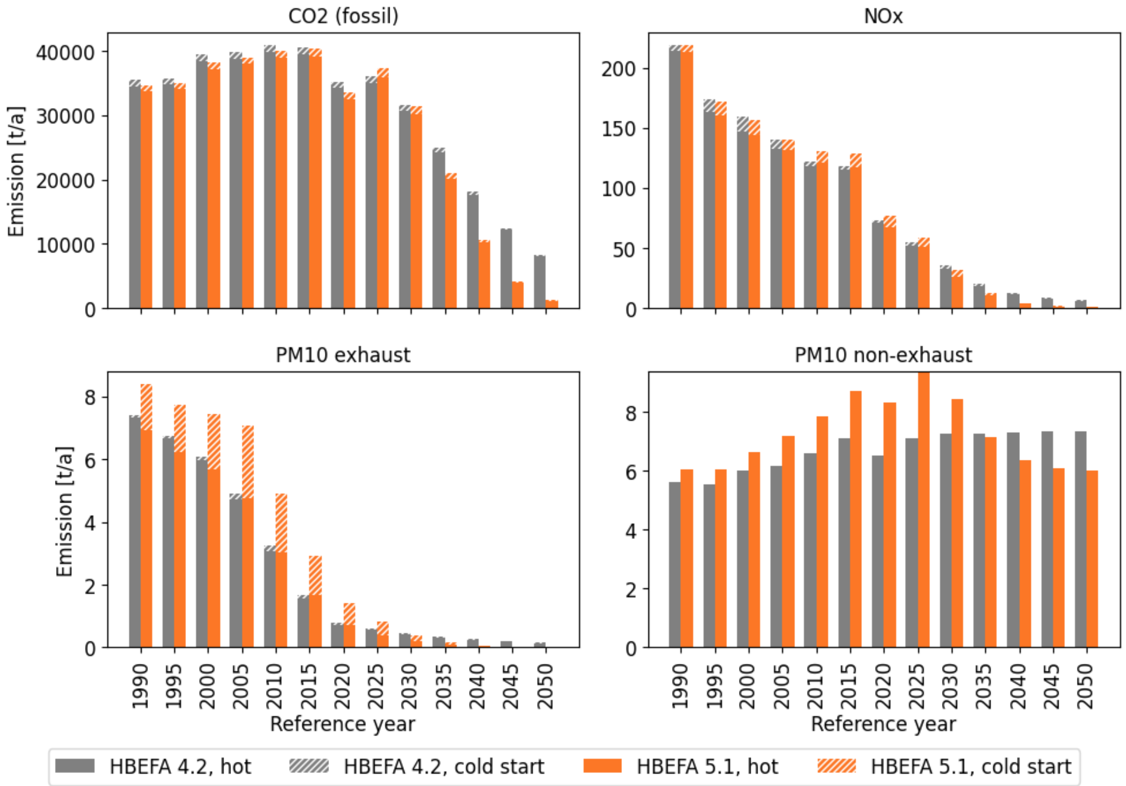

Figure 1: Comparison of road transport emissions 1990-2050 in Switzerland between HBEFA 5.1 and 4.2, differentiating hot and cold start extra emissions.

In the period up to 2025, whether emissions are higher in HBEFA 5.1 or 4.2 varies by pollutant and year. CO2 and NOx emissions are generally slightly lower in HBEFA 5.1, while PM (both exhaust and non-exhaust), CO or HC are generally higher. While the base emission factors of reference vehicles older than Euro 6de/VI DE have mostly not changed between the two HBEFA versions, CO, HC and NOx are affected by the updated mileage correction functions; for NOx, SCR malfunctions and tampering add to higher emissions between 2010 and 2025 (see dedicated chapter below). Cold start excess emissions, considered for HDV for the first time in HBEFA 5.1, most visibly add to PM10 emissions (which is however uncertain, due to lacking measurements from older vehicles), and to all pollutant emissions in the later years, when hot exhaust emissions are lower (see also dedicated chapter below).

Fossil CO2 is slightly lower in Switzerland due to an updated fleet composition: On one hand, previously used external inputs on mileage ratios between petrol and diesel PC, which artificially kept too high mileages of a technology that decreases in fleet share (in this case, petrol vehicles up to about 2015), have been omitted, which led to slightly higher Diesel PC mileage shares. On the other hand, newer data on the heavy-duty levy in Switzerland (LSVA), which are used to calibrate fleet shares for trucks, differentiate rigid trucks from truck/trailer and articulated trucks, which led to a higher rigid truck (RT) share.

Finally, PM10 non-exhaust is based on a new model in HBEFA 5.1 (Hausberger et al. 2025). It generally increases with vehicle weight (and thus with newer ICE vehicles) but is lower for BEV due to their higher share of motor braking, which reduces brake wear.

Cold start impacts on emissions and energy consumption

The share of cold start extra emissions (CSEE) increases in tendency with HBEFA 5.1 compared to HBEFA 4.2, since HBEFA 5.1 considers cold start also for Heavy-duty vehicles (HDV) and battery-electric vehicles (BEV), which was not the case in HBEFA up to Version 4.2 (Table 2). The extent to which this is the case differs per country, however.

The share of CSEE in total emissions or energy consumption depends to a large extent on trip length and parking time distributions. While for light-duty vehicles, the respective data have been available and validated for many years, empirical data for HDV are still scarce; therefore, activity data inputs for HDV cold start extra emissions are an issue that should be revisited in the future (see also chapter on Open issues below). For BEV, the share of cold start extra energy consumption (due to heating of the battery and the driver compartment) amounts to 7-15% of total energy consumption, depending on country and year.

Table 3: Share of cold start excess emissions/energy consumption in the year 2025 in Switzerland for the entire fleet, HDV and BEV, in HBEFA 4.2 (grey letters) and 5.1 (black letters).

Fleet subset	Entire fleet		HDV		BEV	
HBEFA version	4.2	5.1	4.2	5.1	4.2	5.1
Energy consumption	3%	4%	0%	3%	0%	11%
HC	45%	65%	0%	20%	n/a	n/a
NOx	5%	14%	0%	31%	n/a	n/a
PM10 (exhaust)	7%	52%	0%	47%	n/a	n/a

Impacts of SCR tampering and malfunctions on NOx emissions

Tampering and malfunctions of SCR catalyst leads to very high emissions in HDV. The shares of “high emitters” – which include SCR tampering as well as defects – in truck fleets are estimated based on plume-chasing studies and police inspections from various European countries (Pöhler et al. 2025). Depending on the country, about 22% to 31% of truck mileage is assumed to be driven by “high emitters” for Euro-V, and about 3% to 7% for Euro-VI. For Euro-7, we estimated the “high emitter” share to be half that of Euro-VI.

As a result, total road transport NOx emissions in HBEFA 5.1 are about 3% to 9% higher than they would be without considering SCT tampering and malfunctions, depending on country and year – with the highest absolute difference around the year 2015, but the relative impacts increasing towards 2050.

Effects of the Euro-7 regulation

The maximum relative impact of the Euro-7 regulation is seen around 2045, when Euro-7 vehicles will form a significant part of the fleet, but electrification has not progressed as much as in 2050. The impact varies with the country and the tampering shares; NOx and PM10 exhaust emissions in Switzerland, for example, would be about 34% higher in 2045 without Euro-7. For PM10 non-exhaust, HBEFA currently models a difference of 11% in 2035, but here only the effect on LDV brakes is considered – likely Euro-7 will also have impacts on tyres and on HDV.

Open issues

Regarding some of the new features in HBEFA 5.1, further research is needed, e.g. regarding cold start activity data for HDV (trip length, parking time distributions), non-exhaust emissions (impact of curves is only considered on average so far; generally, more measurements are needed), or SCR tampering (e.g. age dependency of high emitters). We will address these issues in future updates of HBEFA.

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