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Assessment of transport emissions in Luxembourg based on emission factors from HBEFA1.2 and HBEFA3.2

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Assessment of transport emissions in Luxembourg based on emission factors from HBEFA1.2 and HBEFA3.2

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Content

Abbreviations

CADC..........Common ARTEMIS Driving Cycle (Urban, Rural, MW = Motorway)

CO ....Carbon monoxide

DOC...........Diesel Oxidation Catalyst

DPF............Diesel Particle Filter

EGR ....Exhaust Gas Recirculation

ERMES ....European Research group on Mobile Emission Sources

FC ....Fuel consumption

HBEFA ....Handbook Emission Factors for Road Transport

HC..............Hydrocarbons

HDV ....Heavy Duty Vehicle

JRC............Joint Research Centre

LCV............Light Commercial Vehicle (N I-1, N I-II, N I-III)

NEC ....National Emission Ceilings

NH_3 ....Ammonia

NO_x ....Nitrogen oxides

RD..............Real Driving

RDE ....Real Driving Emissions

PC..............Passenger Car

PEMS..........Portable Emission Measurement System

PHEM..........Passenger car and Heavy duty Emission Model

PM ....Particle mass emissions

SO_2 ....Sulphur dioxide

TUG ....University of Technology Graz

TWC...........Three Way Catalyst

VOC ....Volatile organic compounds

Executive Summary

Directive 2001/81/EC of the European Parliament and the Council on National Emission Ceilings for certain pollutants ("NEC Directive") sets upper limits for each Member State for the total emissions from 2010 on for the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution (sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC) and ammonia (NH_3)). The limits set for Luxembourg are 11 kt for NO_x, 9 kt for VOC, 4 kt for SO_2 and 7 kt for NH_3.

Background of the definition of the NEC targets were model calculations with the RAINS model of the International Institute for Applied Systems Analysis in Laxenburg, which were based on the state of knowledge at the end of the 1990ies. Concerning trend of vehicle specific emissions it was assumed that the emission levels will be reduced by the same ratio as the emission limits in the vehicle type approval. However, in the meantime it was found that the reductions in vehicle specific NO_x emissions in real world driving are much smaller than it was expected at the time when the targets were established. This has been shown especially for diesel passenger cars (PC) and light commercial vehicles (LCV) certified according to the emission standards EURO 2 to EURO 6 as well as for heavy duty vehicles (HDV) certified from EURO II to EURO V.

This study determines the amount of additional emissions, which is caused by these higher emission factors compared to the data which the NEC limits are based on. For this exercise emission factors have been taken from two different versions of the "Handbook emission factors for road transport" (HBEFA):

1. HBEFA version 1.2 (released in January 1999) which was the basis for the definition of the NEC limits, and
2. HBEFA version 3.2 (released in July 2014) which is the latest reference database including all available in-use emission tests and recent forecasts for upcoming vehicle technology.

The calculations were done with up-to-date data on vehicle mileage and fleet composition for Luxembourg. For the reference year 2010 the following NO_x emissions have been determined:

	HBEFA 3.2	HBEFA 1.2	Difference (3.2-1.2)
Total transport incl. ~~Austrian~~ fuel used in foreign countries	29.5 kt	20.2 kt	+ 9.3 kt
Inland transport incl. non-road machinery	7.1 kt	4.4 kt	+ 2.7 kt

The calculated additional emissions can be directly attributed to the European emission legislation and its test procedures, which cover vehicle operation in real world conditions very weakly. These emissions were not foreseeable at the time of definition of NEC targets and could not be influenced by any national measures in Luxembourg.

Zusammenfassung

Die EU-Richtlinie 2001/81/EG vom 23. Oktober 2001 über nationale Emissionshöchstmengen für bestimmte Luftschadstoffe (National Emission Ceilings, NEC) legt für Luxemburg Emissionshöchstmengen u. a. für NO_x (11 kt/Jahr), VOC (9 kt/Jahr), SO_2 (4 kt/Jahr) und NH_3 (7 kt/Jahr) fest, die ab 2010 einzuhalten sind. Grundlage der Festlegung waren Modellrechnungen mit dem RAINS-Modell des Internationalen Instituts für Angewandte Systemanalyse in Laxenburg, die auf dem Stand des Wissens zum Ende der 1990er-Jahre beruhten. Bezüglich der Emissionsentwicklung bei Kraftfahrzeugen war angenommen worden, dass die spezifischen Emissionen etwa in jenem Verhältnis zurückgehen würden, das sich aus der Verringerung der Emissionsgrenzwerte für die Typprüfung ergibt.

Seit Festlegung dieser „NEC Ziele" wurde festgestellt, dass die Reduktionen der spezifischen NO_x-Emissionen der dieselbetriebenen Kfz im realen Verkehr wesentlich geringer als ursprünglich erwartet ausgefallen sind. Dies gilt vor allem für PKW und Leichte Nutzfahrzeuge zugelassen nach EURO 2 bis EURO 6 und für Schwere Nutzfahrzeuge zertifiziert gemäß EURO II bis EURO V.

In dieser Studie wird dargestellt, welche Auswirkung der Unterschied zwischen den ursprünglich angenommenen und den aus neuen Messungen resultierenden Emissionsfaktoren auf die luxemburgischen Luftschadstoffemissionen hat. Dazu wurden Berechnungen für die luxemburgische Luftschadstoffinventur mit Emissionsfaktoren aus zwei verschiedenen Versionen für das Handbuch Emissionsfaktoren des Straßenverkehrs (HBEFA) durchgeführt:

1. HBEFA 1.2 (herausgegeben im Januar 1999) welches die Basis für die Definition der NEC Grenzwerte darstellt, und
2. HBEFA 3.2 (herausgegeben im Juli 2014) welches den aktuellen Kenntnisstand zum Emissionsverhalten der europäischen Fahrzeug-Flotte darstellt.

Die Berechnungen wurden in beiden Varianten mit den aktuellen Daten zu Verkehrsmengengerüst für Luxemburg durchgeführt. Für das Referenzjahr 2010 wurden folgende NO_x-Emissionsmengen ermittelt:

	HBEFA 3.2	HBEFA 1.2	Differenz (3.2-1.2)
Verkehr gesamt (inkl. Tanktourismus)	29.5 kt	20.2 kt	+ 9.3 kt
Inlandsverkehr inkl. mobile Maschinen	7.1 kt	4.4 kt	+ 2.7 kt

Diese Mehremissionen gegenüber der ursprünglichen Hochrechnung sind direkt auf die Europäische Abgasgesetzgebung und deren Testverfahren zurückzuführen und konnten durch nationale Maßnahmen nicht beeinflusst werden.

1. Scope of work

Directive 2001/81/EC of the European Parliament and the Council on National Emission Ceilings for certain pollutants ("NEC Directive") sets upper limits for each Member State for the total emissions from 2010 on for the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution (sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC) and ammonia (NH_3)). The limits set for Luxembourg are 11 kt for NO_x, 9 kt for VOC, 4 kt for SO_2 and 7 kt for NH_3.

Background of the definition of the NEC targets were model calculations with the RAINS model of the International Institute for Applied Systems Analysis in Laxenburg, which were based on the state of knowledge at the end of the 1990ies. Concerning trend of vehicle specific emissions it was assumed that the emission levels will be reduced by the same ratio as the emission limits in the vehicle type approval. However, in the meantime it was found that the reductions in vehicle specific NO_x emissions in real world driving are much smaller than it was expected at the time when the targets were established, e.g. [1], [2], [3]. This has been shown especially for diesel passenger cars (PC) and light commercial vehicles (LCV) certified according to the emission standards EURO 1 to EURO 6 as well as for heavy duty vehicles (HDV) certified from EURO I to EURO V. If the current and significantly higher NO_x emission factors are used in the emission inventories accordingly much higher emission levels are calculated.

This study determines the amount of additional emissions, which is caused by these higher emission factors compared to the data which the NEC limits are based on. The calculations were done with up-to-date data on vehicle mileage and fleet composition for Luxembourg. The calculated additional emissions can be directly attributed to the European emission legislation and its test procedures, which cover vehicle operation in real world conditions very weakly. These emissions were not foreseeable at the time of definition of NEC targets and could not be influenced by any national measures in Luxembourg.

2. Methodology

Starting point of the comparison is traffic and fleet data from the latest version of the Luxembourgian national emission inventory 1990-2013 [14] and data from the forecast scenario "BAU" [15] until the year 2030. The here used "BAU" scenario is a combination of the existing BAU scenario based on statistic data until 2012 [14] and a partly actualization due to the update for 2013 [15]. A complete revision of the BAU scenario with latest data was not part of the project.

For the comparison the Luxembourgian national transport emissions have been calculated for each year in the time period from 1990 to 2030 based on data from two different versions of the "Handbook emission factors for road transport" (HBEFA)[1]:

3. HBEFA version 1.2 (released in January 1999) which was the basis for the definition of the NEC limits, and

[1] The HBEFA [4] is the main data source for emission factors from road transport in Europe. Most other common used emission models (e.g. COPERT) are also based on HBEFA data.

4. HBEFA version 3.2 (released in July 2014) which is the latest reference database including all available in-use emission tests and up-to-date forecasts for upcoming vehicle technology.

For both considered HBEFA versions the emission factors have been imported into the model NEMO, which is the standard model used for modelling of road transport emissions in the Luxemburg national emission inventory.

The section below gives a short description of the model NEMO.

2.1. The model NEMO

The model NEMO (Network Emission Model) was developed at the Institute for Internal Combustion Engines and Thermodynamics (IVT) at the Graz University of Technology (TUG) as tool for the simulation of traffic related emissions in road networks. Typical applications reach from emission inventories for cities, regions and countries to complex measures like environmental zones or promotion of alternative propulsion systems. An interface to macro scale traffic models, such as VISUM and to air quality modelling is available.

NEMO combines both detailed calculation of the vehicle fleet composition and simulation of emission factors on a vehicle level. NEMO calculates the percentages of different vehicle layers on the overall traffic volume as a function of year and considered road type based on data on vehicle stock, composition of new registrations and vehicle usage. The simulation of the emissions of the different vehicle layers is based on the correlation of the specific engine emission behaviour (emissions in grams per kilowatt-hour engine work) with the cycle average engine power in a normalised format. The calculation of the required engine power is based on average speed and additional kinematic parameters for the description of the cycle dynamics for a given road section. Compared to more detailed instantaneous emission models - which are usually based on simulation in 1Hz time resolution – this simplified approach gives no disadvantage for the modelling of emissions on large street networks as in most of the cases 1Hz data for vehicle operation are not available. An additional benefit of the NEMO simulation approach is the short computing time.

The parameterisation of NEMO is based on data from European in-use measurements which are also used for the Handbook Emission Factors of Road Transport [4]. NEMO is updated regularly according to recent data on emission behaviour and vehicle technologies. All on-road vehicle categories are covered; a tool for the transport sectors rail and inland waterway shipping is also available. NEMO is equipped with a Graphical User Interface which allows for efficient data editing, scenario handling and display of model results.

A crucial point in emission modelling is the characterisation of driving behaviour on the single road sections. For NEMO a method was developed, which allows for automatized derivation of driving behaviour based on a link with common traffic models. These models use the peak hour driving time between knots of the street work as resistance parameter for allocation of traffic volumes to the single road sections. NEMO imports this data together with the parameters of the capacity-restraint functions and calculates the daily average velocity for each road section. Based on functions derived from the driving cycles used in the HBEFA then the kinematic parameters needed for emission simulation (vehicle stop time and average brake deceleration) are assessed.

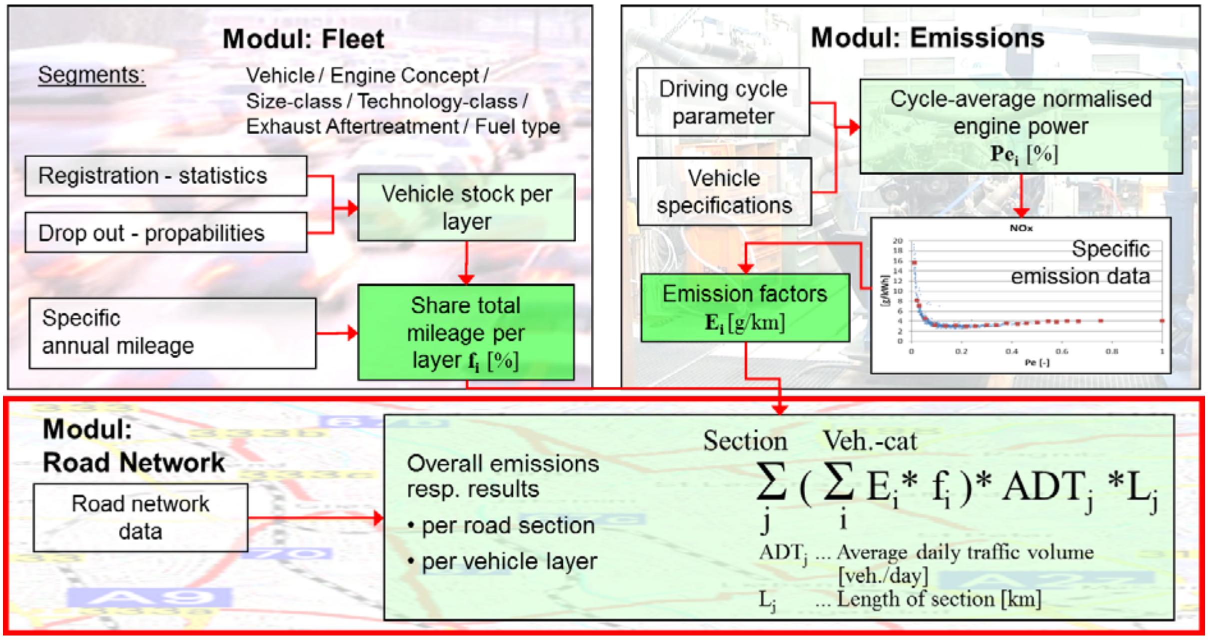

Figure 1: Schematic picture of the model NEMO

NEMO calculates the emissions for all regulated pollutants (NO_x, THC, CO, PM exhaust) for hot vehicle operation. Fuel consumption is simulated based on a slightly extended method which also considers the energy content of the applied fuel type. The emissions of CO_2 and SO_2 are simulated based on fuel consumption and fuel specifications. The non-regulated pollutants N_2O, NH_3 CH_4, NMHC and C_6H_6 are calculated with an approach similar to the HBEFA 3.2 based on fixed emission factors for certain vehicle categories and driving situations.

Additional influencing mechanisms on the emission output of road traffic implemented in NEMO are:

- Cold start effects for each vehicle class (data and approach compatible to the HBE-FA 3.2)
- Influence of mileage and maintenance on the emissions of gasoline vehicles [11]
- Calibration of fuel consumption based on statistics of g/km CO_2 of new registered vehicles in the NEDC type approval and literature on the discrepancies between NEDC and real world CO_2 reduction rates [13]
- Evaporation from gasoline emissions (data and approach compatible to the HBE-FA 3.2)

Particle emissions due to vehicle induced abrasion and re-suspension processes (“PM non-exhaust”) are taken into account by NEMO in addition to the PM-exhaust emissions. The calculation of the PM non-exhaust emissions based on the values published in [12].

Furthermore the model GEORG, e.g. [5] - which is also part of the methodology for the Luxembourg transport emission inventory - has been applied in the current study for calculation of energy consumption and the emissions of the non-road machinery.

In both scenarios considered in this study (“HBEFA 1.2” and “HBEFA 3.2”) the emissions from non-road machinery were calculated according to the latest emission inventory (i.e. similar numbers for non-road emissions are used in both scenarios).

3. Emission factors

This section gives a comparison of emission factors of the HBEFA versions 1.2 and 3.2 and describes how the model NEMO was parameterised to represent these two datasets.

3.1. Passenger cars

Table 1 gives an overview on the passenger car emission standards covered in the two HBEFA versions and the associated introduction dates for new registrations. HBEFA 1.2 includes emission measurements until EURO 1 (both for Otto and Diesel cars) and gives a prognosis for emission levels of passenger cars until EURO 4. HBEFA version 3.2 additionally includes measurements on cars certified from EURO 2 to EURO 6 (however only a limited sample for EURO 6 technology) as well as a prognosis for a more stringent stage "EURO 6c" which is drafted to come into force at the end of this decade.

Table 1: Passenger car emission data in HBEFA 1.2 and HBEFA 3.2

emission standard	HBEFA1.2			HBEFA3.2		
	emission data	new registrations		emission data	new registrations	
		from	until		from	until
pre EURO 1	**meas.**	until	1993	**meas.**	until	1993
EURO 1	**meas.**	1994	1995	**meas.**	1994	1995
EURO 2	progn.	1996	1999	**meas.**	1996	1999
EURO 3	progn.	2000	2004	**meas.**	2000	2004
EURO 4	progn.	2005	and after	**meas.**	2005	2008
EURO 5	n.a.			**meas.**	2009	2014
EURO 6	n.a.			meas.+progn.	2015	2018
EURO 6c	n.a.			progn.	2019	and after

Besides the additional available emission tests also the methods of generation of emission factors have changed significantly over the different HBEFA versions (used models, underlying driving cycles). The main findings related to the updates of passenger cars emission factors from HBEFA 1.2 to 3.2 are documented in [6] (EURO 3 and EURO 4) and in [7] (EURO 5 and EURO 6).

3.1.1. Diesel cars

In the HBEFA 1.2 the emission factors for a certain driving condition are differentiated by the emission standard (the "EURO class") as well as the engine capacity class. Figure 2 shows the HBEFA 1.2 values for Diesel cars and the emission component NO_x for the average "urban", "rural" and "motorway" driving situation. About two out of three Diesel cars in Luxembourg fall within the capacity class from 1.5 to 2.0 litres.[2]

[2] In later HBEFA versions the differentiation of passenger car emission factors by capacity classes was neglected as no clear dependency of emission levels by engine size have been found in the emission test data.

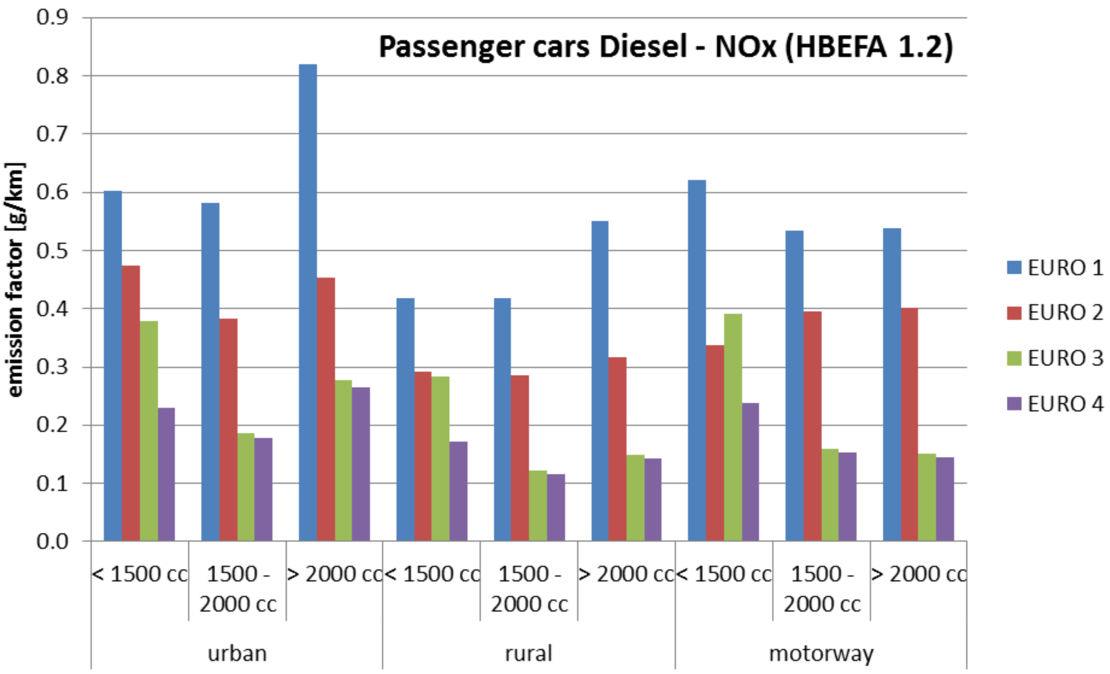

Figure 2: HBEFA 1.2 NOx emission factors for Diesel passenger cars by vehicle segment

In the following pictures weighted emission factors according to the Austrian fleet activity in 2010 are shown.[3]

Figure 3 gives a comparison of NO_x emission factors for diesel passenger cars. For EURO 1 vehicles (for which emission measurements were already available in the HBEFA 1.2) HBEFA 3.2 calculates about 20% higher NO_x levels. This difference can be attributed to additional emission data and to the change of methods in the prediction of real world emission levels. For emissions standards EURO 2 to EURO 4 HBEFA 1.2 predicts a stepwise NO_x reduction compared to EURO 1 which is related to the relative decrease of emission limits in the type approval. This - from today's point of knowledge very optimistic assumption - resulted in a prediction of real world NO_x levels which are by far lower than the related emission limit in the type approval (EURO 2: 0.7 g/km; EURO 3: 0.5 g/km, EURO 4: 0.25 g/km).

However, real world emission data for EURO 2 to EURO 5 diesel cars did not show any significant decrease of NO_x output compared to EURO 1 levels. The updated emission factors for EURO 2 exceed the HBEFA1.2 prognosis by more than 100%, for EURO 3 and EURO 4 the HBEFA3.2 value exceeds the prediction by about 300%. Main reasons for the high real world NO_x levels are shortcomings in the emission type approval, which – since the introduction of electronic engine control systems with EURO 2 technology - allow for different optimisations in the type approval cycle (low NO_x levels in the NEDC on the chassis dyno) and in real world driving (low fuel consumption, better drivability etc.).

For vehicles certified to EURO 6 the HBEFA3.2 predicts a significant improvement in NO_x levels compared to the earlier EURO standards, however the extend of this evidence is uncertain yet.

[3] For other reference years or other countries the weighted emission factors can vary. The comparison shown here is based on Austrian numbers as Luxembourg fleet data is not included in the HBEFA software. Section 3.5 gives a description how the information on vehicle specific emission behavior transferred from the HEBFA into NEMO to reflect Luxembourg conditions.

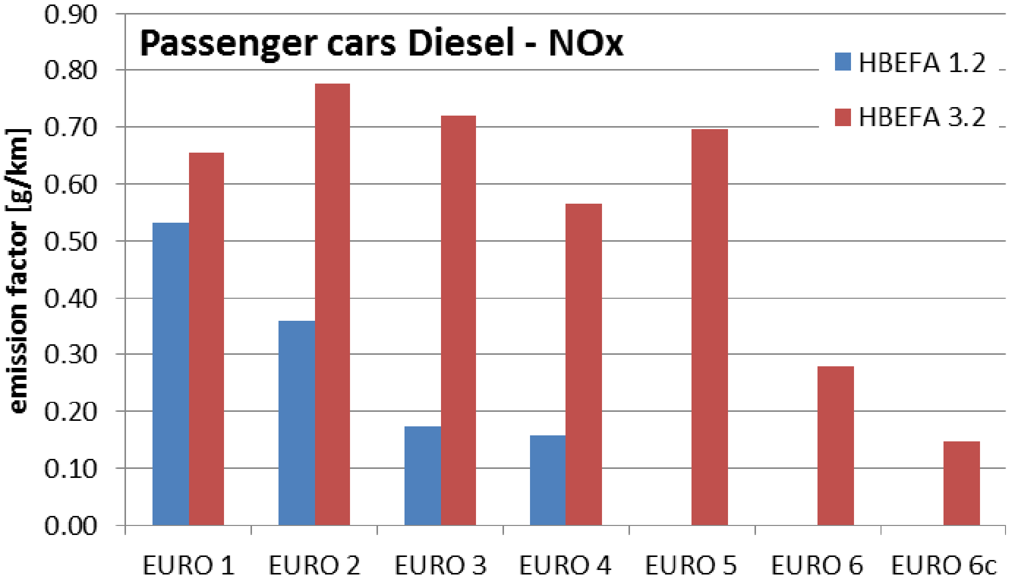

Figure 3: Average NO_x emission factors passenger cars Diesel

Table 2 compares the average emission factors for Diesel cars for all regulated pollutants. Contrary to NO_x, the emission factors for HC and CO have been overestimated in the HBEFA1.2 compared to the latest status of knowledge. Particle mass emissions (PM) have been underestimated in the HBEFA1.2 by about 50% to 100%.

Table 2: Average emission factors passenger cars Diesel

	HBEFA 1.2				HBEFA 3.2				ratio HBEFA3.2/HBEFA1.2			
PC Diesel [g/km]	NOx	HC	CO	PM	NOx	HC	CO	PM	NOx	HC	CO	PM
EURO 1	0.53	0.03	0.17	0.05	0.66	0.03	0.25	0.099	123%	98%	144%	216%
EURO 2	0.36	0.03	0.28	0.05	0.78	0.03	0.15	0.073	216%	96%	51%	156%
EURO 3	0.17	0.02	0.23	0.03	0.72	0.01	0.08	0.036	416%	77%	36%	143%
EURO 4	0.16	0.01	0.19	0.01	0.57	0.01	0.07	0.019	357%	65%	34%	223%
EURO 5	n.a.	n.a.	n.a.	n.a.	0.70	0.01	0.06	0.002	---	---	---	---
EURO 6	n.a.	n.a.	n.a.	n.a.	0.28	0.01	0.05	0.002	---	---	---	---
EURO 6c	n.a.	n.a.	n.a.	n.a.	0.15	0.01	0.05	0.002	---	---	---	---

3.1.2. Otto cars

Figure 4 shows the average NO_x emission factors for Otto cars. In the recent HBEFA version lower emission levels are specified than in version 1.2.[4] For Otto propulsion the de-

[4] The shown factors only consider only emission output in "hot" operation conditions. Especially for Otto engines with Three-way catalyst also extra emissions in cold start conditions contribute to the overall emission amount. Cold start emissions are considered in the emission modelling separately (both in the HBEFA and NEMO). In this study only the standard settings for cold start emissions in NEMO have been used. This does not significantly influence the comparison of emissions calculated for the two HBEFA versions as the update of cold start emissions from HBEFA1.2 to HBEFA3.2 did not significantly change the levels.

velopment in engine and aftertreatment technology obviously was better than assumed at the end of the 1990ies.

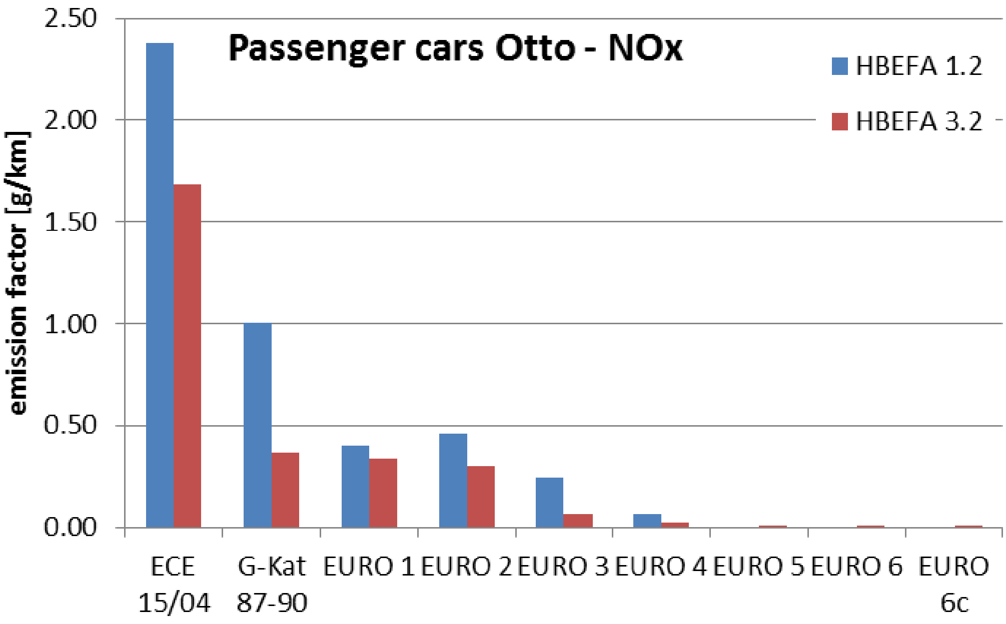

Figure 4: Average NO_x emission factors passenger cars Otto

Table 3 shows the average emission factors for Otto cars for all regulated pollutants. Except from HC and CO emissions from Otto cars coming into the fleet in the late 80ies all other emission factors are lower in the up-to-date HBEFA version.

Table 3: Average emission factors passenger cars Otto

	HBEFA1.2				HBEFA3.2				ratio HBEFA3.2/HBEFA1.2			
PC Otto [g/km]	NOx	HC	CO	PM	NOx	HC	CO	PM	NOx	HC	CO	PM
ECE 15/04	2.38	1.33	12.01	n.a.	1.68	0.97	11.58	0.003	71%	73%	96%	---
G-Kat 87-90	1.01	0.13	2.24	n.a.	0.37	0.56	6.49	0.003	37%	417%	290%	---
EURO 1	0.40	0.10	2.06	n.a.	0.34	0.14	1.39	0.003	84%	141%	68%	---
EURO 2	0.46	0.11	2.21	n.a.	0.30	0.05	1.42	0.004	65%	47%	64%	---
EURO 3	0.25	0.06	1.56	n.a.	0.07	0.02	1.55	0.003	29%	32%	99%	---
EURO 4	0.06	0.03	0.92	n.a.	0.03	0.02	0.38	0.002	39%	62%	41%	---
EURO 5	n.a.	n.a.	n.a.	n.a.	0.01	0.01	0.31	0.002	---	---	---	---
EURO 6	n.a.	n.a.	n.a.	n.a.	0.01	0.01	0.31	0.002	---	---	---	---
EURO 6c	n.a.	n.a.	n.a.	n.a.	0.01	0.01	0.31	0.002	---	---	---	---

3.2. Light duty vehicles

Table 4 compares the average emission factors for Diesel driven light commercial vehicles (LCV). Similar to the findings for passenger cars also the predictions for NO_x emissions made in the HBEFA 1.2 were found to be too optimistic. Emission factors for LCVs from the HBEFA3.2 still have to be considered uncertain as they are based on a very small sample of measured vehicles.

Table 4: Average emission factors light commercial vehicles Diesel

LCV Diesel [g/km]	HBEFA 1.2				HBEFA 3.2				ratio HBEFA3.2/HBEFA1.2			
	NOx	HC	CO	PM	NOx	HC	CO	PM	NOx	HC	CO	PM
EURO 1	0.83	0.07	0.74	0.08	1.12	0.07	0.48	0.134	135%	94%	64%	169%
EURO 2	0.71	0.05	0.29	0.07	1.01	0.05	0.22	0.109	142%	108%	75%	159%
EURO 3	0.53	0.03	0.16	0.03	0.85	0.03	0.13	0.052	160%	116%	80%	170%
EURO 4	0.30	0.02	0.15	0.02	0.70	0.03	0.11	0.026	235%	106%	73%	146%
EURO 5	n.a.	n.a.	n.a.	n.a.	0.65	0.00	0.01	0.001	---	---	---	---
EURO 6	n.a.	n.a.	n.a.	n.a.	0.23	0.00	0.01	0.001	---	---	---	---
EURO 6c	n.a.	n.a.	n.a.	n.a.	0.12	0.00	0.01	0.001	---	---	---	---

Table 5 shows the emission factors for LCVs with Otto engines. The emission factors are even more uncertain, however Otto driven LCVs have only very minor influence on the fleet emissions as about 95% of the LCV fleet are equipped with Diesel engines.

Table 5: Average emission factors light commercial vehicles Otto

LCV Otto [g/km]	HBEFA1.2				HBEFA3.2				ratio HBEFA3.2/HBEFA1.2			
	NOx	HC	CO	PM	NOx	HC	CO	PM	NOx	HC	CO	PM
Konv >81	2.77	1.28	16.94	n.a.	2.87	2.04	29.72	0.005	104%	159%	175%	---
G-Kat 87-90	1.12	0.13	4.57	n.a.	2.87	1.85	24.76	0.005	257%	1389%	542%	---
EURO 1	n.a.	n.a.	n.a.	n.a.	1.28	0.33	10.32	0.005	---	---	---	---
EURO 2	0.67	0.08	3.97	n.a.	0.85	0.15	5.43	0.005	127%	181%	137%	---
EURO 3	0.33	0.06	3.11	n.a.	0.39	0.10	4.16	0.005	117%	168%	134%	---
EURO 4	0.17	0.04	2.41	n.a.	0.20	0.07	3.17	0.005	122%	156%	132%	---
EURO 5	n.a.	n.a.	n.a.	n.a.	0.02	0.02	1.95	0.005	---	---	---	---
EURO 6	n.a.	n.a.	n.a.	n.a.	0.02	0.02	2.01	0.005	---	---	---	---
EURO 6c	n.a.	n.a.	n.a.	n.a.	0.02	0.02	2.01	0.005	---	---	---	---

3.3. Heavy duty vehicles

In the HBEFA1.2 the emission factors for heavy duty vehicles (HDV) have been based on measurements on engines certified to EURO I and earlier standards. A prognosis has been given for emission standards until EURO V based on the reductions in the type approval (Table 6). The recent HBEFA version 3.2 includes emission tests on engines and HDV of all emission standards including the latest stage EURO VI. In the last 15 years also the methods of derivation of emission factors for the different HDV classes based on the available emission test data (which are to a large extend data from the engine dynamometer) have been improved significantly.

Table 6: Heavy duty vehicle emission data in HBEFA1.2 and HBEFA3.2

emission standard	HBEFA1.2			HBEFA3.2		
	emission data	new registrations		emission data	new registrations	
		from	until		from	until
pre EURO	**meas.**	until	1993	**meas.**	until	1993
EURO I	**meas.**	1994	1995	**meas.**	1994	1995
EURO II	progn.	1996	2000	**meas.**	1996	2000
EURO III	progn.	2001	2005	**meas.**	2001	2005
EURO IV	progn.	2006	2008	**meas.**	2006	2008
EURO V	progn.	2009	and after	**meas.**	2009	2013
EURO VI	n.a.			**meas.**	2014	and after

Below the comparison of HDV emission levels from the two HBEFA versions is done on a fuel specific basis (in “gram emissions per kilogram fuel”). This allows for a straight forward comparison which is not biased by the fact that the data on HDV fleet mix has changed over the different HBEFA versions significantly.[5] Figure 5 gives a comparison of fuel specific NO_x levels. For pre EURO and EURO I the data on both HBEFA versions give nearly similar numbers. From EURO II on the data on NO_x output from the HBEFA3.2 are significantly higher than the HBEFA 1.2 forecast. The reasons are similar to the findings for Diesel passenger cars, i.e. the combination of type approval tests which are not representative for real world conditions and the possibilities of modern engine control systems.[6] With the coming into force of EURO VI the type approval procedures have been significantly improved which – according to test results on new EURO VI vehicles and engines - resulted in real world NO_x emissions, which are close to or even lower than the type approval limits.

[5] Recent data show a higher share of heavier HDV classes as well as higher average vehicle weights. In this study this up-to-date fleet data has been used in the calculations in both scenarios (“HBEFA1.2“ and “HBEFA3.2”).

[6] The updates of the HDV emission factors in the HBEFA are documented in [9] (EURO II), [8] (EURO III), [6] (EURO IV and V) and [7] (EURO V and VI).

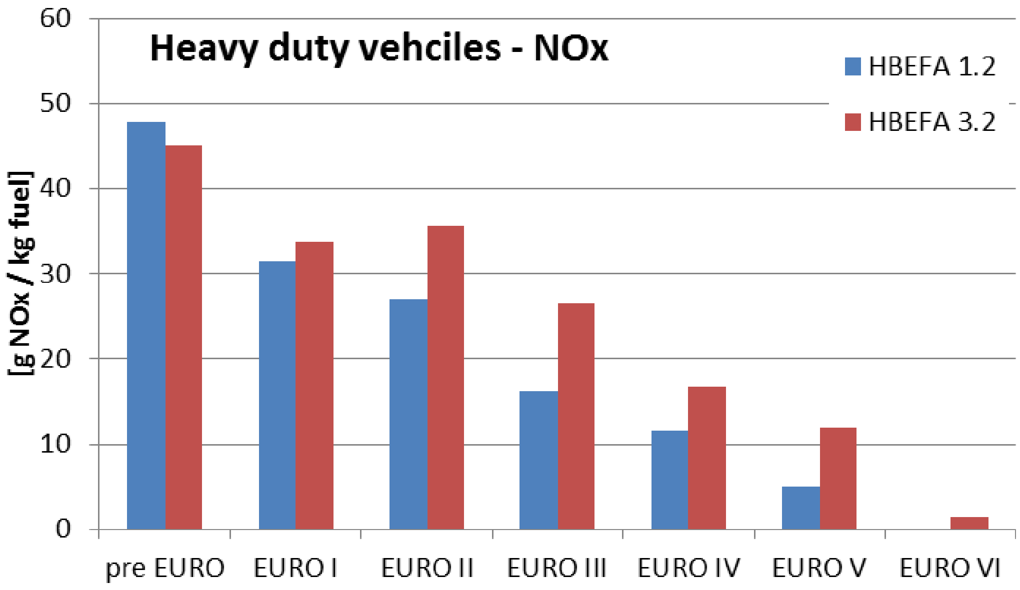

Figure 5: Average NO_x emissions per fuel consumption for HDV

Table 7 gives the comparison of the fuel specific emission levels for all regulated pollutants. For CO and PM the HBEFA1.2 generally predicts lower emission output. The reason can be found in shortcomings in the former methods to model the influence of transient engine load conditions on the emission behaviour.

Table 7: Average fuel specific emission levels for HDV

HDV Diesel [g Em/ kg Fuel]	HBEFA1.2				HBEFA3.2				ratio HBEFA3.2/HBEFA1.2			
	NOx	HC	CO	PM	NOx	HC	CO	PM	NOx	HC	CO	PM
pre EURO	47.89	4.36	12.05	1.45	45.14	4.17	10.59	1.84	94%	96%	88%	127%
EURO I	31.57	2.81	4.35	0.94	33.76	2.31	6.66	1.40	107%	82%	153%	149%
EURO II	26.98	1.72	1.98	0.35	35.64	1.47	5.47	0.66	132%	86%	276%	187%
EURO III	16.17	1.25	1.43	0.23	26.51	1.25	6.01	0.60	164%	100%	419%	265%
EURO IV	11.59	1.05	1.02	0.06	16.79	0.12	5.30	0.15	145%	11%	520%	229%
EURO V	5.02	1.03	1.00	0.06	11.85	0.16	4.72	0.15	236%	16%	471%	238%
EURO VI	n.a.	n.a.	n.a.	n.a.	1.40	0.00	0.46	0.01	---	---	---	---

3.4. Two Wheelers

For two-wheelers the HBEFA1.2 includes emission factors for the emission standards “pre EURO” and EURO 1, in the HBEFA3.2 additionally the stages EURO 2 and EURO 3 are specified. The emission factors for “pre EURO” and EURO 1 have not been modified significantly in the updates from version 1.2 to 3.2. In general in the HBEFA the data on two-wheeler emissions on are based on measurements in the type approval cycle only, so the representativeness for real world emissions is uncertain. However, due to the very small share on overall mileage two-wheeler this uncertainty does not significantly influence the Luxembourg emission inventory.

3.5. Parametrisation of NEMO to represent emission factors from HBEFA 3.2 and HBEFA 1.2

Since HBEFA version 3.1 (published in 2010) a standard method is available how the emission behaviour of the different vehicle segments is parameterised in NEMO to be fully compatible with the HBEFA data. This is done based on a two-stage approach:

1.) Compilation of characteristic curves for specific emission behaviour as a function of cycle average engine power

2.) Application of an overall calibration factor in a way that the weighted overall emission factor for a certain mix of traffic situations (e.g. the Austrian mix) of NEMO and the HBEFA match.

For step 1.) the underlying data for all single traffic situations as specified in the HBEFA are used.[7] Based on the resulting characteristic curves NEMO is able to predict the emission behaviour in any kind of driving situation. Step 2.) then establishes full compatibility in terms of country specific emission results as applicable in an national emission inventory.

3.5.1. Dataset "HBEFA 3.2"

The parameterisation of NEMO referring to the recent 3.2 version of the HBEFA already was the baseline for the Luxembourgian national emission inventory 1990-2013 as published in [14]. As no Luxembourgian data on distribution of traffic situations is available in the HBEFA tool, the final parameterisation of NEMO has been performed by comparison of NEMO and HBEFA results for the Austrian mix of traffic situations. The Luxembourgian national emission inventory then has been simulated in NEMO based on the Luxembourgian fleet and Luxembourgian street net data.

The recent NEMO version as used in [14] furthermore considers cold start emissions from HDV [16], which are not covered in the HBEFA 3.2. As the method used in the recent Luxembourgian national emission inventory is the reference in this study for the comparison with the old HBEFA1.2 data, in this study the calculations specified with "HBEFA 3.2" also include HDV cold start emissions.

3.5.2. Dataset "HBEFA 1.2"

The structure of HBEFA version 1.2 differs significantly from the latest 3.2 version. Emission factors have been determined from baseline in-use emission test data by rather simple functions but not by a complex simulation model. Also much fewer traffic situations are specified in the HBEFA 1.2 (approx. 20 compared to 276 in HBEFA 3.2). As a consequence step 1.) of the NEMO parametrisation was not applicable based on the HBEFA 1.2 data. Instead for each vehicle segment the characteristic curves for specific emission behaviour have been taken over from the comparable dataset from the HBEFA 3.2 parameterisation. The final calibration then has been performed based on the comparison

[7] Since version 3.1 the emission factors in the HBEFA are based on simulation results of the model "PHEM". For step 1.) the underlying PHEM results including information on average engine power are required.

of HBEFA1.2 emission factors for the Austrian average traffic situation with the according NEMO result. Several plausibility checks have been performed to verify compatibility of the resulting NEMO model behaviour with the original HBEFA 1.2 data.

Then the Luxembourgian national emission inventory has been simulated in NEMO also with the HBEFA 1.2 parameters and based on the Luxembourgian fleet and Luxembourgian street net data.

4. Results for transport emissions

This chapter summarises the results for the Luxembourgian national transport emission inventory based on the emission factors of the two HBEFA versions. Detailed results for the main pollutants are also given in table form in the Annex. The full set of results is available as MS Excel files in the standard inventory format. This report especially focuses on NO_x emissions and the years 2010 to 2013 as well as the projections for 2020 and 2030.

4.1. NO_x

Figure 6 shows the time series from 1990 to 2030 for NO_x emissions of the main relevant vehicle categories passenger cars (PC) and heavy duty vehicles (HDV) calculated with the two sets of HBEFA emission factors. Figure 7 plots the differences between the two scenarios over the years for each vehicle category. Only emissions from inland mileage are shown (i.e. the numbers do not include emissions related to fuel export). According to the recent HBEFA version 3.2 emissions from Otto cars are clearly lower than predicted in the HBEFA 1.2, especially until the end of the last decade. For the year 2010 the "3.2" calculation gives about 0.21 kt less NO_x from Otto cars than the "1.2" results. According to recent data NO_x emissions from Otto engines will even more be on a very low level in the future.

The situation for Diesel cars is completely different: The scenario based on the HBEFA 1.2 forecast shows an amount of yearly NO_x of about 0.6 kt around the year 2000 with an increasing tendency to a quantity of 0.8 kt in the year 2013. Based on the measured emission factors for modern Diesel cars in the HBEFA 3.2 yearly NO_x emissions rise up to about 2.6 kt in the year 2010 and reach a peak value of 3.0 kt in 2014. For the year 2010 the NO_x difference between the "3.2" and the "1.2" calculation is at 1.97 kt, i.e. the recent data show more than three times higher NO_x output than "1.2". An analogue situation to Diesel cars can be found for HDV. Since the coming into the fleet of EURO II vehicles in the mid of the 1990ies more NO_x was emitted by HDV than predicted by the HBEFA 1.2. For the year 2010 0.59 kt extra NO_x are calculated in the "3.2" calculations. However, due the effectiveness of the EURO VI regulations for HDV the situation for NO_x from HDV is predicted to improve significantly from 2014 on. For the end of the decade lower NO_x from HDV are predicted based on the recent HBEFA 3.2 than calculated with the HBEFA 1.2 factors.

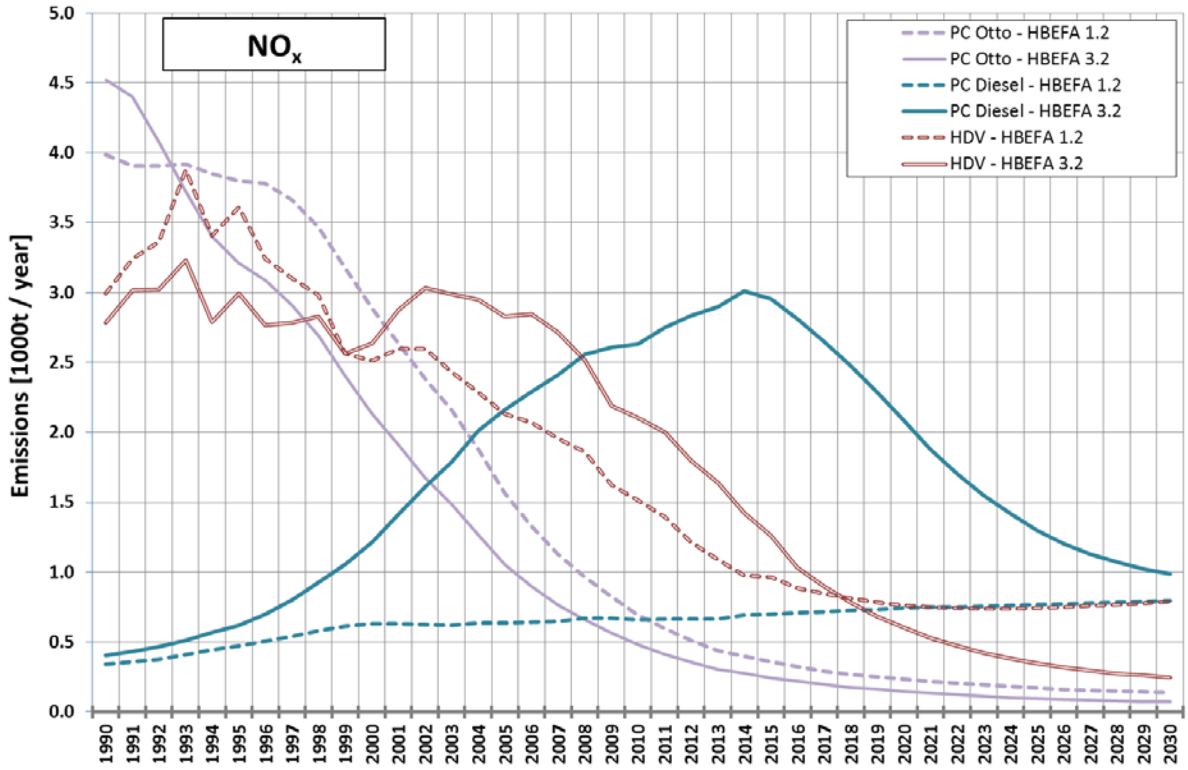

Figure 6: NO_x emissions per vehicle category (inland mileage)

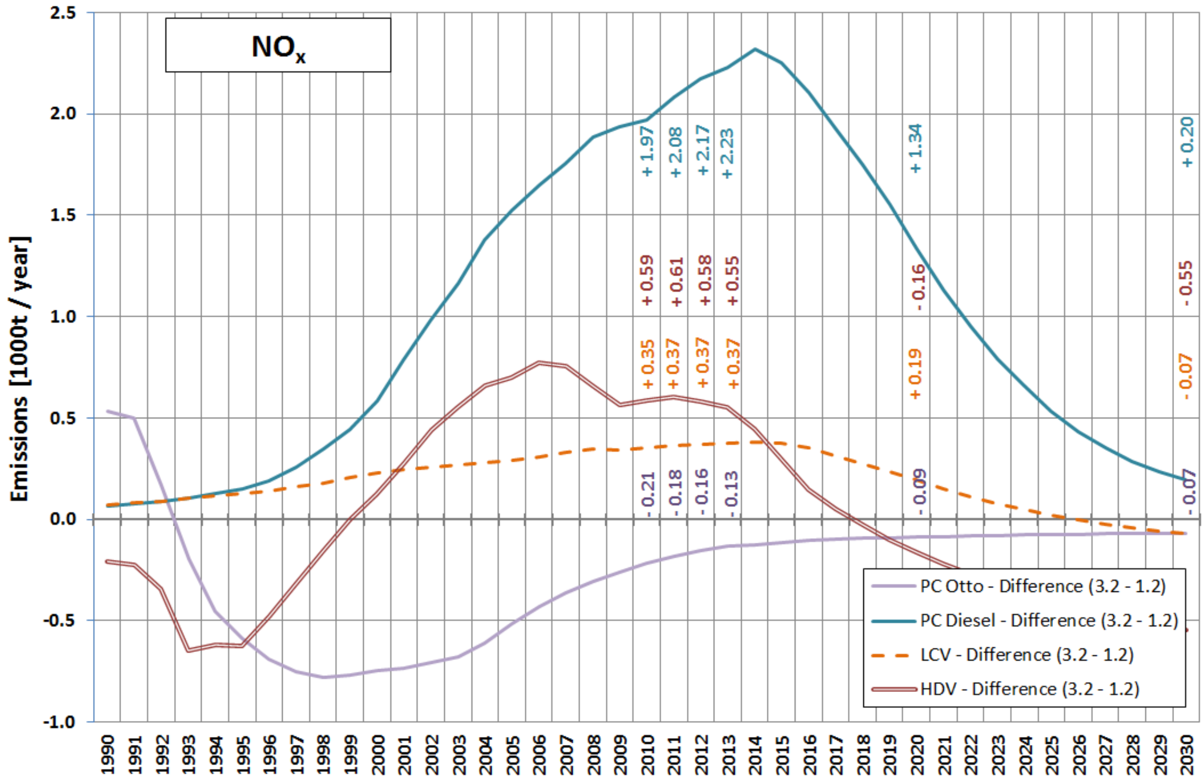

Figure 7: Differences for NO_x emissions per vehicle category (inland mileage) between HBEFA 3.2 and 1.2

Figure 8 compares the time series for total inland NO_x from Luxembourgian transport including non-road machinery. Based on HBEFA 3.2 the yearly NO_x emissions have been at a constant level of about 8 to 9 kt from 1990 until the end of the last decade. For the year 2010 2.70 kt higher NO_x emissions are determined in the HBEF 3.2 scenario compared to the “1.2” calculation. For the years after 2002 also the HBEFA 3.2 scenario gives a decreasing NO_x trend, showing in 2020 still 1.28 kt more NO_x than the HBEFA 1.2. In the following decade then the “3.2” NO_x prediction falls below the “1.2” forecast.

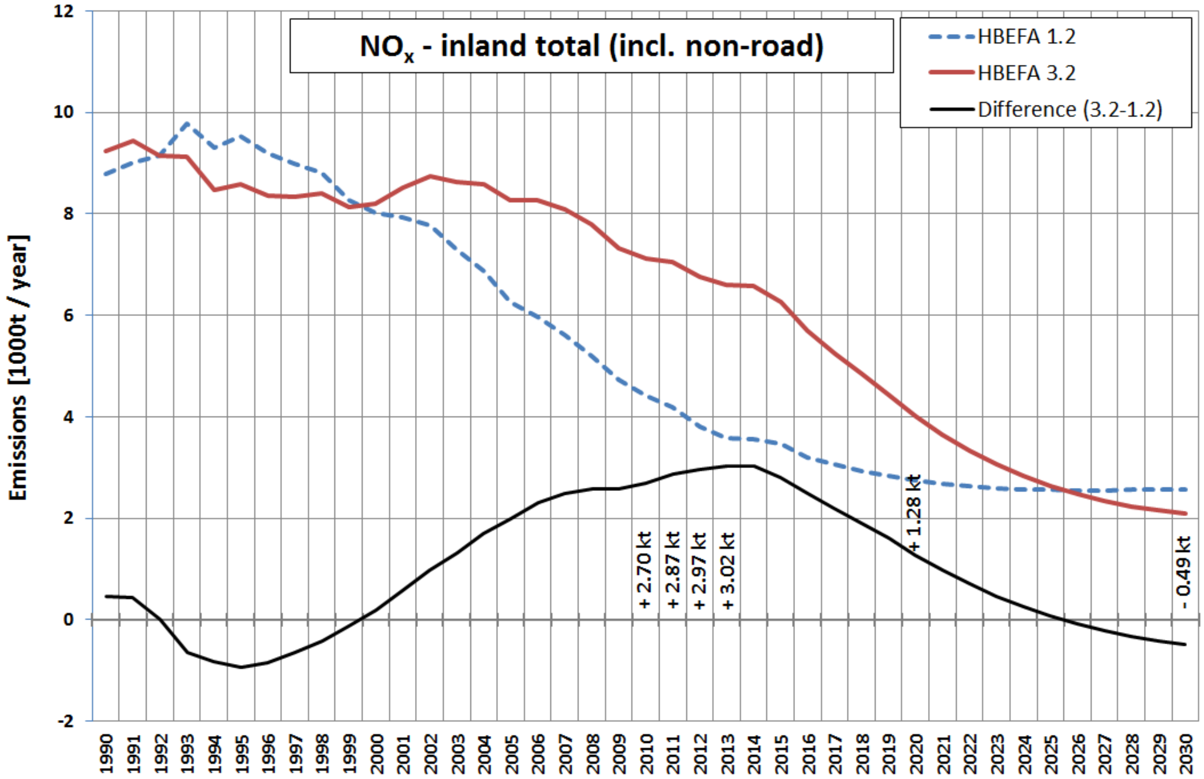

Figure 8: NO_x emissions of the total inland transport including non-road machinery

The results for total NO_x emissions from Luxemburg transport including the emissions associated to the fuel sold in Luxemburg but used abroad are shown in Figure 9. For the year 2010 a value of 29.5 kt is calculated with the HBEFA 3.2 emission factors which gives 9.3 kt more NO_x compared to the value of 20.2 kt from the HBEFA 1.2. For the upcoming years the calculations with the recent set of emission factors predict a continuous decrease of NO_x emissions with 10.3 kt in the year 2020 and 6.0 kt in the year 2030. Besides the uncertainties in the development of transport demand and fuel prices this up-to-date forecast of course again contains some uncertainties regarding the real world emission factors of EURO 6 / VI and especially EURO 6c vehicles.

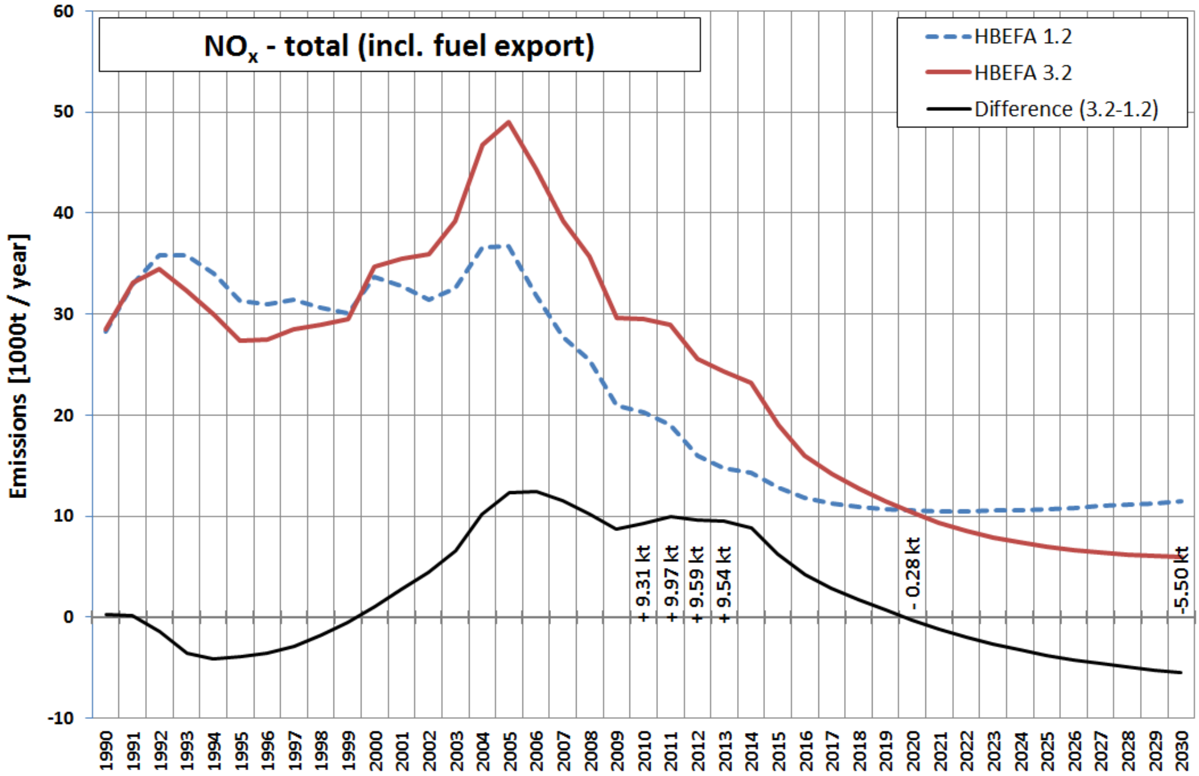

Figure 9: NO_x emissions of the total transport sector with fuel sold in Luxembourg

4.2. HC

HC emissions from on-road transport are mostly determined by the data on emission behaviour of Otto cars. For hot operation conditions the HBEFA 3.2 specifies higher emission factors from 1990ies cars and somewhat lower HC emissions for recent Otto vehicle generations than the HBEFA 1.2: HC levels are also influenced by cold start behaviour. Here the model data has not been varied in this study in the two HBEFA scenarios (see footnote 4 on page 12). Anyway, since the last decade the overall HC emissions from transport are on a low absolute level and are dominated by the contribution of the non-road machinery with still increasing shares. Figure 10 and Figure 11 show the results for total HC emitted from Luxembourgian transport. The quantities do not differ significantly between the two calculation variants.

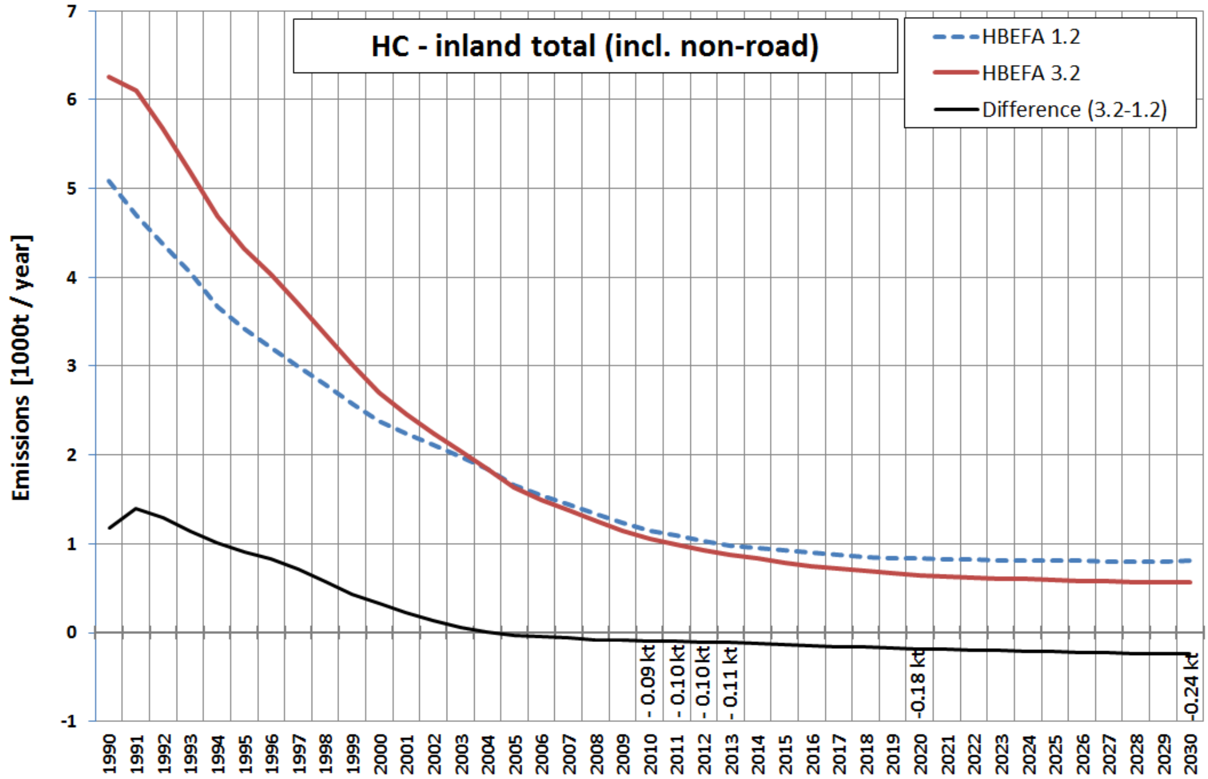

Figure 10: HC emissions of the total inland transport including non-road machinery

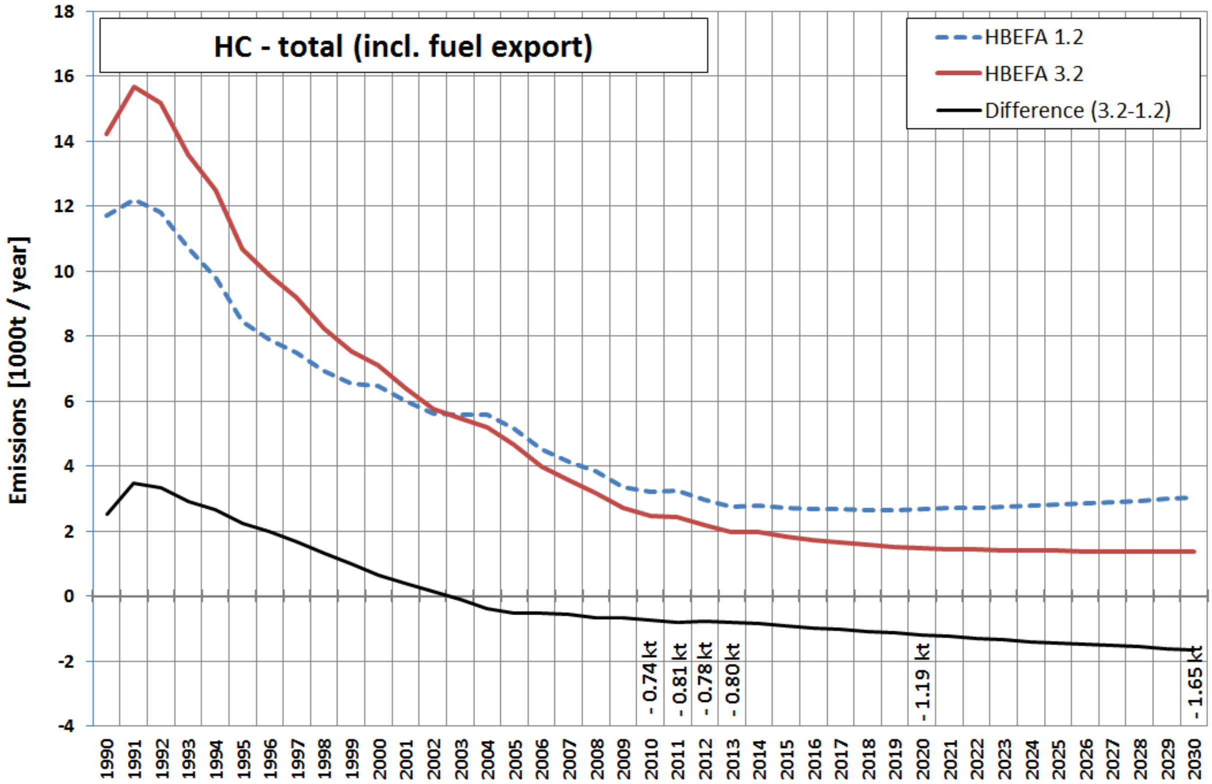

Figure 11: HC emissions of the total transport sector with fuel sold in Luxembourg

4.3. PM exhaust

In Figure 12 the calculations for PM exhaust emissions (inland transport) are shown. For the year 2010 the HBEFA 3.2 calculation results in 0.09 kt higher PM emissions than based on the HBEFA 1.2. For the subsequent years the HBEFA3.2 predicts more reduction in PM exhaust emissions than the HBEFA 1.2 due to the introduction of EURO5/6 and EURO VI vehicles equipped with DPF which were not foreseen in the HBEFA 1.2.

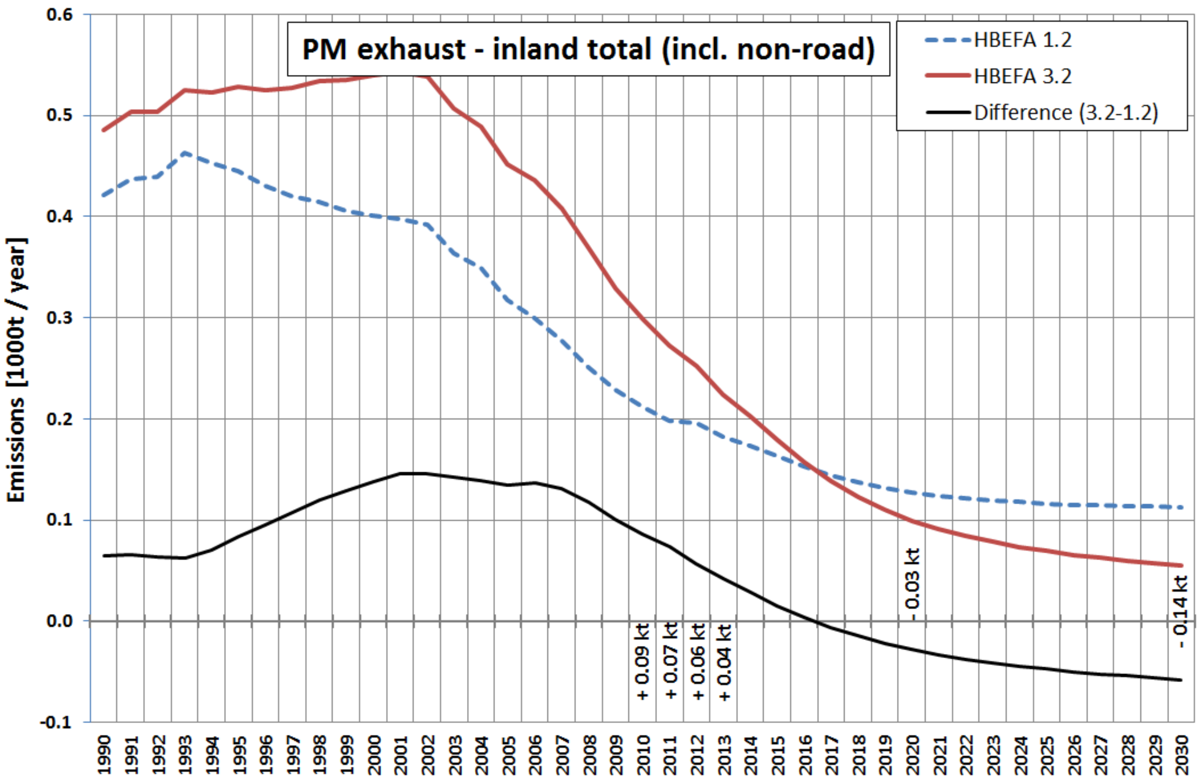

Figure 12: PM exhaust emissions of the total inland transport including non-road machinery

Figure 13 shows the trends for PM exhaust if the total fuel in Luxembourg is considered. For the year 2010 the "3.2" calculation shows 0.29 kt more PM exhaust than the values based on the old HBEFA.

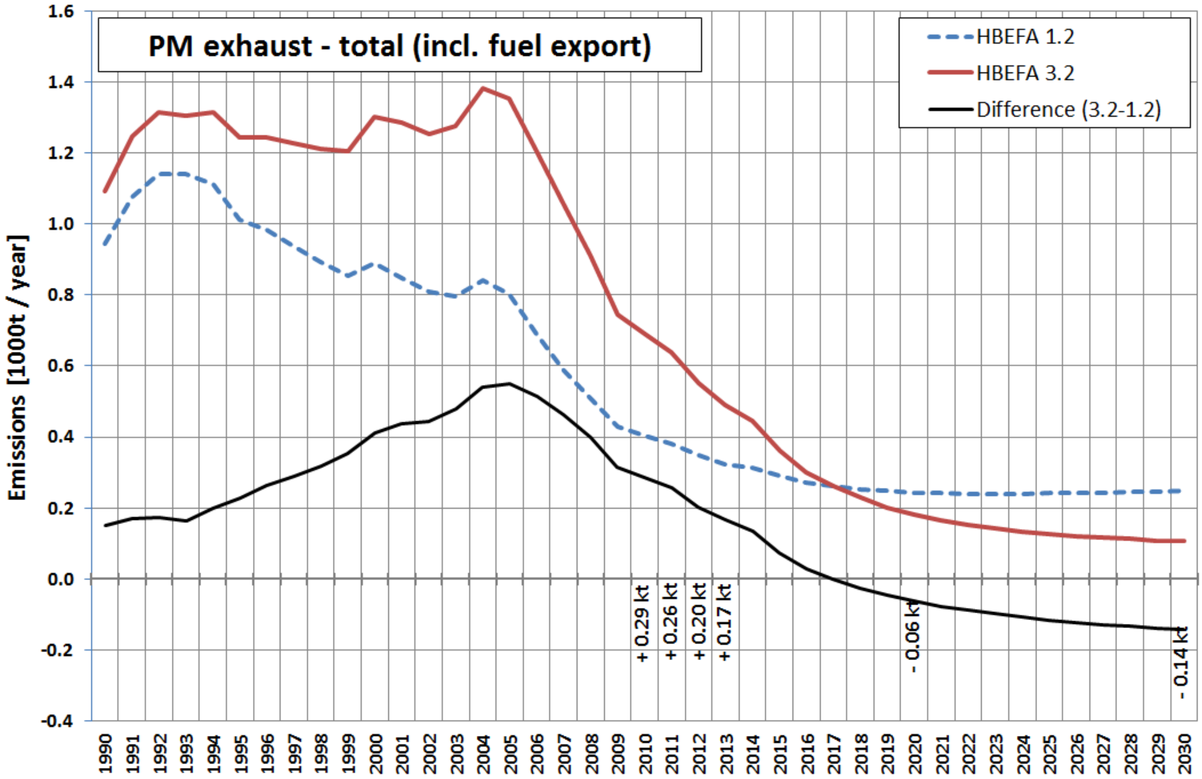

Figure 13: PM exhaust emissions of the total transport sector with fuel sold in Luxembourg

4.4. CO

The results for CO emissions are given in Figure 14 and Figure 15. Similar to HC the total CO amount is mainly determined by the emission factors of Otto cars (incl. cold start behaviour) and by the non-road machinery. The HBEFA 3.2 calculations result in less CO emissions for inland transport (0.45 kt) slightly higher emissions (+2.00 kt) for total transport including fuel export compared to the HBEFA 1.2 scenario.

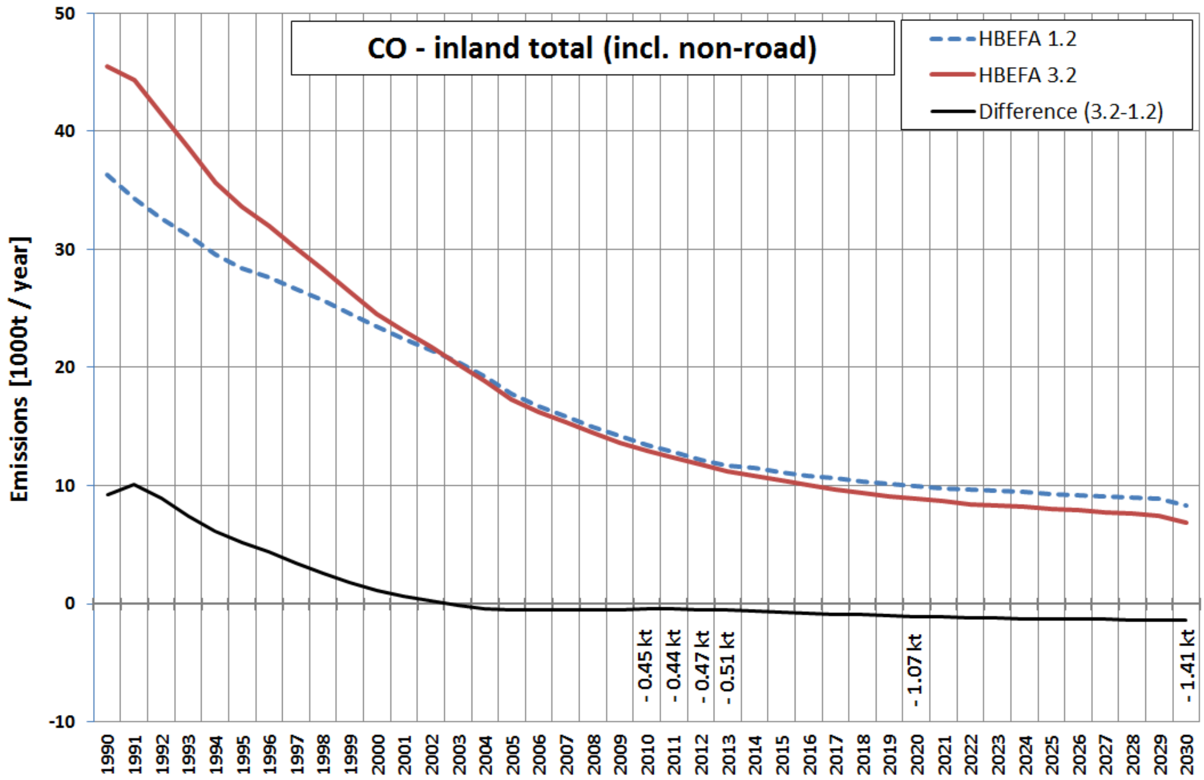

Figure 14: CO emissions of the total inland transport including non-road machinery

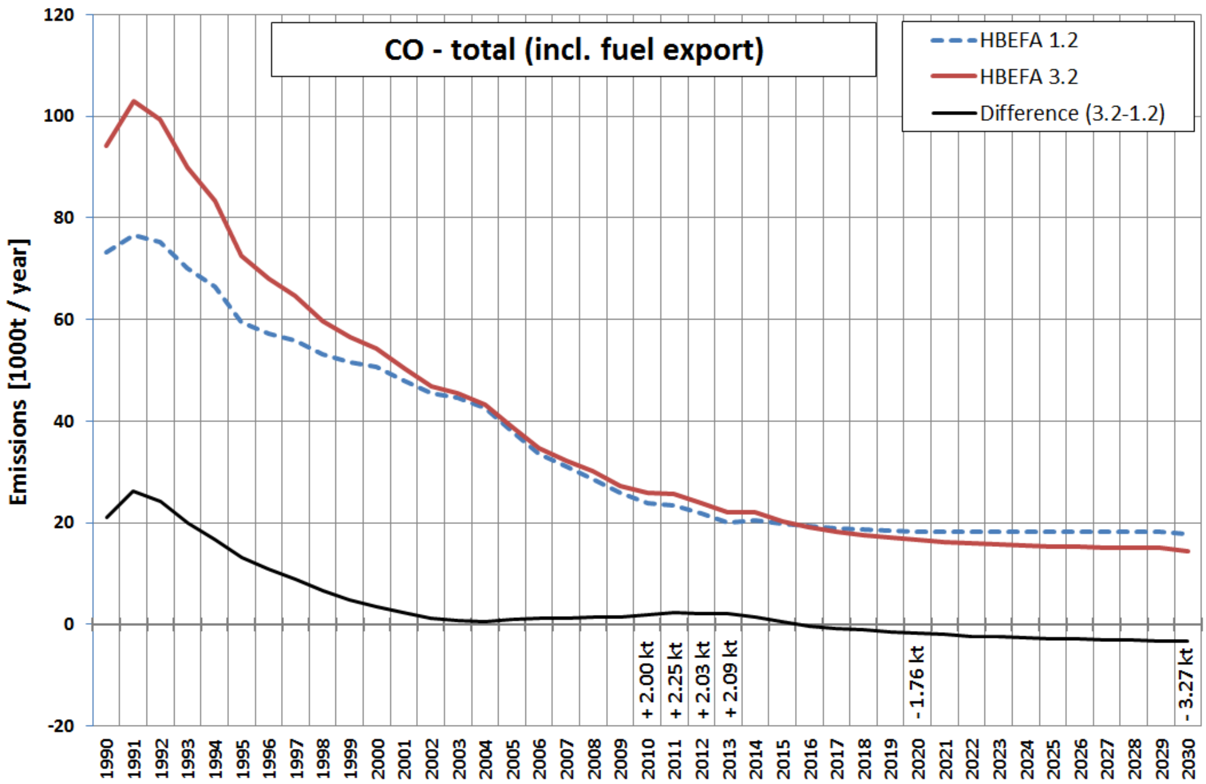

Figure 15: CO emissions of the total transport sector with fuel sold in Luxembourg

4.5. SO_2

For SO_2 in both scenarios similar emission quantities are calculated as the total consumed fuel and the sulphur content is identical (Figure 16).

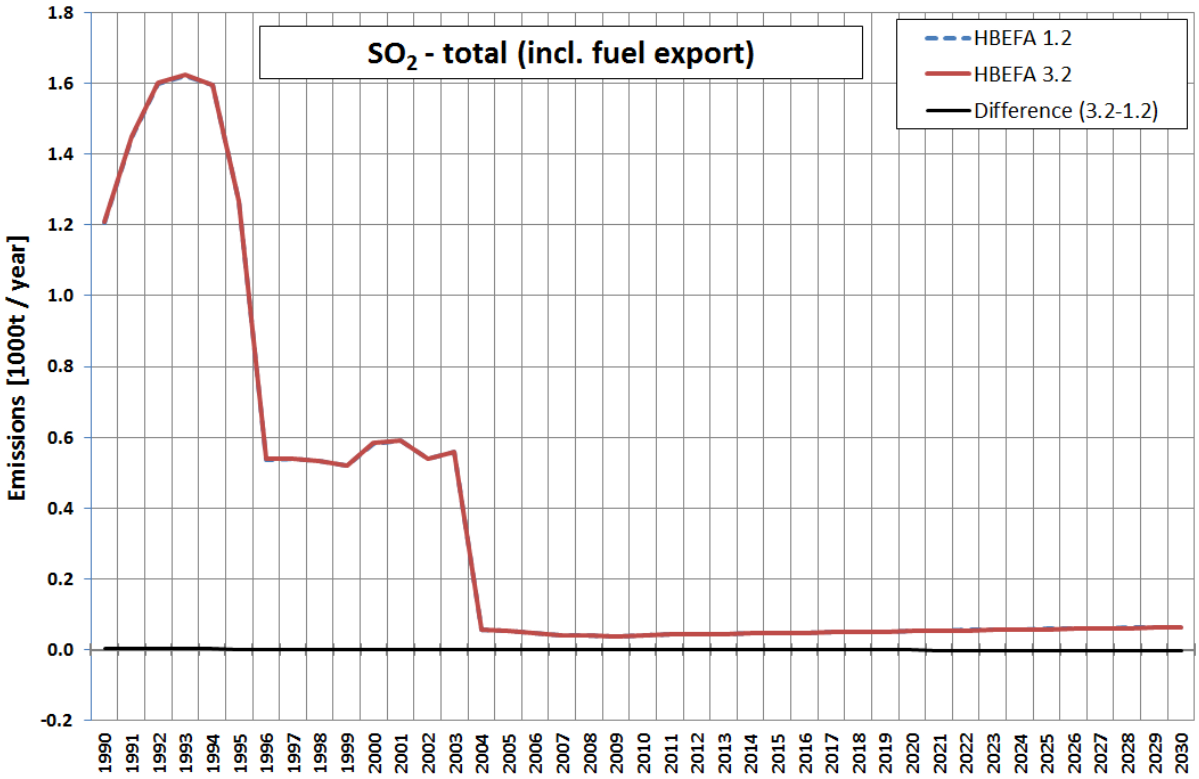

Figure 16: SO_2 emissions of the total transport sector with fuel sold in Luxembourg

5. References

[1] Weiss M. et al: Analyzing on-road Emissions of Light-duty Vehicles with Portable Emission Measurement Systems (PEMS). Publications Office of the European Union (2011). JRC Publication N°: JRC62639. ISBN: 978-92-79-19072-8 http://publications.jrc.ec.europa.eu/repository/handle/111111111/15725

[2] Bach C., Lienin S.: Emissionsvergleich verschiedener Antriebsarten in aktuellen Personenwagen. EMPA Materials Science and Technology. Dübendorf, 1. November 2007

[3] Lambrecht U. et al: Ursachen und zukünftige Entwicklung der NO_2-Belastung. Herausforderung NO2-Immissionen Gesetzgebung, Luftbelastung, Lösungen Fachtagung am 03. und 04. März 2010 in Heidelberg

[4] Handbook emission factors for road transport (HBEFA) http://www.hbefa.net/

[5] Schwingshackl M., Hausberger S.: Berechnungen der Emissionen Mobiler-Maschinen in Wien, im Auftrag der Wiener Umweltschutzabteilung - MA 22, Bericht Nr.: I-20/12/Haus Em zu Projekt Em 15/2012-679 vom 30.11.2012

[6] Hausberger S., Rexeis M., Zallinger M., Luz R.: Emission Factors from the Model PHEM for the HBEFA Version 3. Report Nr. I-20/2009 Haus-Em 33/08/679 from 07.12.2009

[7] Rexeis M., Hausberger S., Kühlwein J., Luz R.: Update of Emission Factors for EURO 5 and EURO 6 vehicles for the HBEFA Version 3.2. Final report No. I-31/2013/ Rex EM-I 2011/20/679 from 06.12.2013.

[8] Hausberger S.: Update der Emissionsfaktoren für schwere Nutzfahrzeuge nach EURO III. Erstellt im Auftrag von INFRAS Schweiz. Bericht Nr. FVT-45/03/ Haus Em 6790-30 vom 22.12.2003

[9] Hausberger S. et al: Update of the Emission Functions for Heavy Duty Vehicles in the Handbook Emission Factors for Road Traffic. Bericht Nr.: Pi-55/01 Haus 00/5/683 vom 30.4.2002

[10] Umweltbundesamt Berlin: Handbuch Emissionsfaktoren des Strassenverkehrs Version 1.2 / Januar 1999. Dokumentation zur Version Deutschland erarbeitet durch INFRAS in Zusammenarbeit mit IFEU Heidelberg

[11] Samaras, Z. (2004). Artemis Subtask 3123: Investigation of the emission degradation of gasoline vehicles, Aristotle University of Thessaloniki - Lab of Applied Thermodynamics

[12] Schmidt W., Düring I., Lohmeyer A., (2011) Einbindung des HBEFA 3.1 in das FIS Umwelt und Verkehr sowie Neufassung der Emissionsfaktoren für Aufwirbelung und Abrieb des Straßenverkehrs

[13] Mock P., German J., Bandivadekar A., Riemersma I. (2012), ICCT working paper 2012-02: Discrepancies between type-approval and „real-world" fuel-consumption and CO2 values.

[14] Molitor R., Hausberger S., Obermayer C., Rexeis M., Schwingshackl M. 2015: Aktualisierung der Zeitreihen zum Kraftstoffexport und der Emissionen von klimarelevanten Gasen und Luftschadstoffen des Verkehrssektors in Luxemburg von 1990 – 2013, Erstellt im Auftrag von: Le Gouvernement du Grand-Duché de Luxembourg Ministère du Développement durable et Infrastructures, Jänner 2015

[15] Molitor R., Hausberger S., Obermayer C., Schwingshackl M. 2014: BAU-Prognose zum Kraftstoffexport und der zugehörigen Emissionen von klimarelevanten Gasen und Luftschadstoffen des Verkehrssektors in Luxemburg von 2015 - 2030 und Ausblick bis 2050, Erstellt im Auftrag von: Le Gouvernement du Grand-Duché de Luxembourg Ministère du Développement durable et Infrastructures, Dezember 2014

[16] Rexeis M., Schwingshackl M., Dippold M., Hausberger S.: Emissionen aus Kalt- und Kühlstarts sowie aus AdBlue-Verwendung in SCR-Katalysatoren von LKW, LNF, 2-Rädern sowie von mobilen Maschinen. Erstellt im Auftrag des Umweltbundesamtes GmbH. Bericht Nr.: I-24/201313/Rex Em 11/2013-679 vom 16.9.2013

APPENDIX

Table 8: Comparison of NOx emissions from Luxembourgian transport according to HBEFA 1.2 and 3.2

NOx in 1000t per year

	HBEFA 1.2						HBEFA 3.2						Difference					
year	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)
1990	3.99	0.34	0.21	2.99	8.78	28.22	4.52	0.40	0.28	2.78	9.24	28.50	0.53	0.06	0.07	-0.21	0.46	0.27
1991	3.90	0.36	0.22	3.24	9.00	32.98	4.40	0.43	0.30	3.01	9.43	33.14	0.50	0.08	0.08	-0.23	0.43	0.16
1992	3.91	0.38	0.22	3.36	9.14	35.81	4.07	0.46	0.31	3.02	9.14	34.44	0.16	0.09	0.09	-0.34	0.00	-1.37
1993	3.92	0.41	0.23	3.88	9.77	35.85	3.72	0.51	0.33	3.23	9.13	32.33	-0.19	0.10	0.10	-0.65	-0.63	-3.53
1994	3.85	0.44	0.23	3.41	9.31	34.04	3.40	0.57	0.35	2.79	8.48	29.91	-0.45	0.13	0.12	-0.62	-0.83	-4.13
1995	3.79	0.47	0.24	3.61	9.52	31.26	3.21	0.62	0.37	2.99	8.59	27.39	-0.59	0.15	0.13	-0.62	-0.93	-3.87
1996	3.78	0.51	0.24	3.24	9.19	31.00	3.09	0.70	0.38	2.77	8.35	27.43	-0.69	0.19	0.14	-0.48	-0.84	-3.56
1997	3.66	0.54	0.24	3.10	8.99	31.37	2.91	0.80	0.40	2.78	8.34	28.52	-0.75	0.26	0.16	-0.32	-0.65	-2.85
1998	3.47	0.58	0.24	2.98	8.80	30.68	2.69	0.92	0.42	2.83	8.39	28.96	-0.78	0.35	0.18	-0.16	-0.41	-1.72
1999	3.18	0.61	0.26	2.56	8.26	30.08	2.41	1.05	0.47	2.56	8.14	29.56	-0.77	0.44	0.21	0.00	-0.12	-0.52
2000	2.88	0.63	0.28	2.51	8.01	33.65	2.14	1.21	0.51	2.64	8.20	34.71	-0.75	0.58	0.23	0.13	0.19	1.06
2001	2.64	0.63	0.28	2.59	7.93	32.73	1.91	1.41	0.52	2.87	8.51	35.50	-0.73	0.78	0.24	0.28	0.57	2.77
2002	2.38	0.62	0.28	2.60	7.77	31.46	1.68	1.61	0.54	3.03	8.75	35.90	-0.71	0.99	0.26	0.44	0.98	4.45
2003	2.16	0.62	0.28	2.43	7.31	32.55	1.48	1.79	0.55	2.99	8.62	39.19	-0.68	1.17	0.27	0.56	1.31	6.64
2004	1.88	0.64	0.28	2.29	6.87	36.59	1.27	2.02	0.56	2.95	8.58	46.77	-0.61	1.38	0.28	0.66	1.71	10.19
2005	1.57	0.64	0.29	2.13	6.26	36.68	1.05	2.16	0.58	2.83	8.26	48.99	-0.51	1.52	0.29	0.70	2.00	12.32
2006	1.33	0.64	0.29	2.07	5.97	31.92	0.90	2.29	0.59	2.84	8.26	44.37	-0.43	1.65	0.31	0.77	2.30	12.46
2007	1.13	0.65	0.28	1.96	5.61	27.68	0.77	2.41	0.61	2.71	8.09	39.24	-0.36	1.76	0.33	0.76	2.48	11.56
2008	0.97	0.67	0.27	1.86	5.21	25.49	0.66	2.55	0.61	2.52	7.79	35.71	-0.31	1.88	0.34	0.66	2.58	10.22
2009	0.82	0.67	0.25	1.62	4.72	20.95	0.56	2.61	0.59	2.19	7.31	29.62	-0.26	1.94	0.34	0.57	2.59	8.67
2010	**0.69**	**0.66**	**0.24**	**1.51**	**4.42**	20.21	**0.48**	**2.63**	**0.59**	**2.10**	**7.11**	29.52	**-0.21**	**1.97**	**0.35**	**0.59**	**2.70**	**9.31**
2011	**0.60**	**0.67**	**0.24**	**1.40**	**4.18**	19.00	**0.41**	**2.75**	**0.60**	**2.00**	**7.06**	28.97	**-0.18**	**2.08**	**0.37**	**0.61**	**2.87**	**9.97**
2012	**0.51**	**0.67**	**0.23**	**1.21**	**3.80**	16.01	**0.36**	**2.84**	**0.60**	**1.80**	**6.76**	25.60	**-0.16**	**2.17**	**0.37**	**0.58**	**2.97**	**9.59**
2013	**0.44**	**0.67**	**0.23**	**1.09**	**3.58**	14.80	**0.30**	**2.90**	**0.60**	**1.64**	**6.60**	24.34	**-0.13**	**2.23**	**0.37**	**0.55**	**3.02**	**9.54**
2014	0.40	0.69	0.23	0.98	3.56	14.33	0.27	3.01	0.61	1.42	6.58	23.18	-0.12	2.32	0.38	0.45	3.02	8.85
2015	0.36	0.70	0.23	0.97	3.46	12.84	0.24	2.95	0.60	1.26	6.27	19.05	-0.11	2.25	0.37	0.29	2.81	6.20
2016	0.32	0.71	0.23	0.89	3.19	11.79	0.22	2.81	0.58	1.03	5.69	15.97	-0.10	2.10	0.35	0.15	2.50	4.17
2017	0.29	0.72	0.23	0.84	3.06	11.31	0.20	2.65	0.54	0.90	5.25	14.18	-0.10	1.93	0.31	0.05	2.20	2.87
2018	0.27	0.73	0.23	0.81	2.94	10.97	0.18	2.48	0.50	0.78	4.84	12.73	-0.09	1.75	0.27	-0.03	1.90	1.76
2019	0.25	0.73	0.23	0.78	2.83	10.73	0.16	2.29	0.47	0.68	4.43	11.44	-0.09	1.55	0.23	-0.10	1.60	0.71
2020	**0.23**	**0.74**	**0.23**	**0.76**	**2.74**	10.58	**0.15**	**2.08**	**0.43**	**0.60**	**4.02**	10.30	**-0.09**	**1.34**	**0.19**	**-0.16**	**1.28**	**-0.28**
2021	0.22	0.75	0.24	0.75	2.67	10.51	0.13	1.88	0.38	0.53	3.65	9.35	-0.08	1.13	0.15	-0.22	0.98	-1.16
2022	0.20	0.75	0.24	0.74	2.63	10.51	0.12	1.70	0.35	0.47	3.33	8.57	-0.08	0.95	0.11	-0.27	0.71	-1.94
2023	0.19	0.76	0.24	0.74	2.59	10.54	0.11	1.55	0.32	0.42	3.06	7.92	-0.08	0.79	0.08	-0.32	0.47	-2.62
2024	0.18	0.76	0.24	0.74	2.57	10.62	0.10	1.42	0.29	0.38	2.83	7.40	-0.08	0.65	0.05	-0.36	0.26	-3.22
2025	0.17	0.77	0.25	0.74	2.56	10.72	0.10	1.30	0.26	0.35	2.64	6.98	-0.08	0.54	0.02	-0.40	0.08	-3.74
2026	0.16	0.77	0.25	0.75	2.55	10.84	0.09	1.21	0.25	0.32	2.47	6.64	-0.07	0.43	0.00	-0.43	-0.08	-4.20
2027	0.16	0.78	0.25	0.76	2.55	10.98	0.08	1.13	0.23	0.29	2.34	6.39	-0.07	0.35	-0.02	-0.46	-0.21	-4.59
2028	0.15	0.78	0.26	0.77	2.56	11.14	0.08	1.07	0.21	0.28	2.24	6.20	-0.07	0.29	-0.04	-0.49	-0.32	-4.93
2029	0.14	0.79	0.26	0.78	2.56	11.30	0.07	1.02	0.20	0.26	2.15	6.07	-0.07	0.24	-0.06	-0.52	-0.41	-5.23
2030	**0.14**	**0.79**	**0.27**	**0.79**	**2.58**	11.47	**0.07**	**0.99**	**0.19**	**0.25**	**2.09**	5.97	**-0.07**	**0.20**	**-0.07**	**-0.55**	**-0.49**	**-5.50**

Table 9: Comparison of HC emissions from Luxembourgian transport according to HBEFA 1.2 and 3.2

HC in 1000t per year

	HBEFA 1.2						HBEFA 3.2						Difference					
year	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)
1990	3.91	0.09	0.09	0.31	5.08	11.70	5.23	0.11	0.14	0.11	6.26	14.22	1.32	0.01	0.04	-0.19	1.18	2.52
1991	3.50	0.09	0.09	0.33	4.70	12.19	5.05	0.11	0.13	0.12	6.10	15.66	1.55	0.01	0.04	-0.21	1.40	3.47
1992	3.16	0.09	0.08	0.34	4.37	11.83	4.63	0.11	0.12	0.13	5.67	15.18	1.46	0.01	0.04	-0.22	1.30	3.35
1993	2.82	0.09	0.07	0.36	4.06	10.71	4.13	0.11	0.11	0.13	5.19	13.60	1.32	0.01	0.04	-0.23	1.14	2.90
1994	2.48	0.09	0.07	0.33	3.68	9.80	3.64	0.11	0.10	0.13	4.68	12.47	1.16	0.01	0.04	-0.20	1.01	2.67
1995	2.25	0.09	0.06	0.34	3.42	8.44	3.31	0.10	0.09	0.14	4.33	10.66	1.06	0.01	0.03	-0.20	0.90	2.22
1996	2.08	0.09	0.06	0.30	3.21	7.88	3.04	0.11	0.09	0.13	4.03	9.85	0.96	0.02	0.03	-0.18	0.83	1.98
1997	1.91	0.09	0.05	0.28	3.00	7.51	2.74	0.11	0.08	0.12	3.71	9.19	0.82	0.02	0.03	-0.16	0.71	1.69
1998	1.73	0.09	0.04	0.27	2.79	6.92	2.40	0.11	0.07	0.12	3.36	8.23	0.67	0.02	0.03	-0.15	0.57	1.31
1999	1.55	0.10	0.04	0.23	2.57	6.54	2.06	0.11	0.07	0.11	3.01	7.54	0.51	0.02	0.03	-0.12	0.44	1.00
2000	1.38	0.10	0.04	0.22	2.38	6.46	1.77	0.11	0.07	0.11	2.70	7.11	0.39	0.02	0.03	-0.11	0.33	0.66
2001	1.24	0.10	0.04	0.21	2.24	6.02	1.53	0.12	0.06	0.11	2.47	6.41	0.29	0.02	0.02	-0.10	0.22	0.39
2002	1.12	0.10	0.03	0.21	2.11	5.63	1.31	0.12	0.05	0.11	2.24	5.77	0.19	0.01	0.02	-0.10	0.13	0.14
2003	1.03	0.10	0.03	0.19	1.98	5.58	1.14	0.11	0.05	0.11	2.04	5.48	0.12	0.01	0.02	-0.08	0.06	-0.10
2004	0.91	0.11	0.03	0.18	1.84	5.58	0.97	0.12	0.04	0.11	1.84	5.21	0.06	0.01	0.01	-0.07	0.00	-0.37
2005	0.79	0.11	0.03	0.17	1.66	5.17	0.81	0.11	0.04	0.10	1.63	4.65	0.02	0.00	0.01	-0.07	-0.03	-0.52
2006	0.70	0.11	0.03	0.16	1.54	4.53	0.71	0.11	0.03	0.10	1.49	4.00	0.01	0.00	0.01	-0.07	-0.05	-0.53
2007	0.62	0.11	0.02	0.16	1.44	4.13	0.62	0.11	0.03	0.09	1.37	3.56	0.00	0.00	0.00	-0.07	-0.06	-0.57
2008	0.56	0.12	0.02	0.15	1.34	3.83	0.56	0.11	0.02	0.08	1.26	3.16	0.00	-0.01	0.00	-0.07	-0.08	-0.67
2009	0.49	0.11	0.02	0.14	1.23	3.36	0.49	0.11	0.02	0.07	1.15	2.72	0.00	-0.01	0.00	-0.07	-0.09	-0.65
2010	**0.43**	**0.11**	**0.02**	**0.14**	**1.15**	3.23	**0.43**	**0.10**	**0.02**	**0.06**	**1.06**	2.48	**0.00**	**-0.01**	**0.00**	**-0.08**	**-0.09**	**-0.74**
2011	**0.39**	**0.11**	**0.02**	**0.14**	**1.09**	3.23	**0.39**	**0.10**	**0.02**	**0.05**	**0.99**	2.42	**0.00**	**-0.02**	**0.00**	**-0.08**	**-0.10**	**-0.81**
2012	**0.34**	**0.11**	**0.02**	**0.13**	**1.03**	2.96	**0.34**	**0.09**	**0.01**	**0.05**	**0.93**	2.18	**0.00**	**-0.02**	**-0.01**	**-0.08**	**-0.10**	**-0.78**
2013	**0.31**	**0.11**	**0.02**	**0.12**	**0.98**	2.75	**0.31**	**0.09**	**0.01**	**0.04**	**0.87**	1.96	**0.00**	**-0.02**	**-0.01**	**-0.08**	**-0.11**	**-0.80**
2014	0.29	0.12	0.02	0.11	0.95	2.80	0.29	0.09	0.01	0.03	0.83	1.96	0.00	-0.03	-0.01	-0.08	-0.12	-0.84
2015	0.27	0.12	0.02	0.12	0.92	2.73	0.26	0.09	0.01	0.03	0.79	1.82	-0.01	-0.03	-0.01	-0.09	-0.14	-0.91
2016	0.25	0.12	0.02	0.12	0.90	2.69	0.24	0.09	0.01	0.03	0.75	1.72	-0.01	-0.03	-0.01	-0.10	-0.15	-0.97
2017	0.24	0.12	0.02	0.12	0.87	2.67	0.22	0.09	0.01	0.02	0.72	1.64	-0.01	-0.03	-0.01	-0.10	-0.16	-1.03
2018	0.22	0.12	0.02	0.12	0.85	2.66	0.21	0.09	0.01	0.02	0.69	1.58	-0.02	-0.03	-0.01	-0.10	-0.16	-1.08
2019	0.21	0.12	0.02	0.12	0.84	2.66	0.20	0.09	0.01	0.02	0.67	1.53	-0.02	-0.04	-0.01	-0.11	-0.17	-1.13
2020	**0.21**	**0.12**	**0.02**	**0.13**	**0.83**	2.67	**0.18**	**0.09**	**0.01**	**0.02**	**0.65**	1.49	**-0.02**	**-0.04**	**-0.02**	**-0.11**	**-0.18**	**-1.19**
2021	0.20	0.12	0.02	0.13	0.82	2.70	0.17	0.09	0.01	0.02	0.63	1.46	-0.02	-0.04	-0.02	-0.11	-0.19	-1.24
2022	0.19	0.12	0.02	0.13	0.82	2.73	0.16	0.09	0.01	0.01	0.62	1.43	-0.03	-0.04	-0.02	-0.11	-0.20	-1.29
2023	0.19	0.12	0.02	0.13	0.81	2.76	0.15	0.09	0.00	0.01	0.61	1.41	-0.03	-0.04	-0.02	-0.12	-0.20	-1.35
2024	0.18	0.13	0.02	0.13	0.81	2.79	0.15	0.09	0.00	0.01	0.60	1.40	-0.03	-0.04	-0.02	-0.12	-0.21	-1.39
2025	0.18	0.13	0.02	0.14	0.81	2.83	0.14	0.09	0.00	0.01	0.59	1.39	-0.03	-0.04	-0.02	-0.12	-0.22	-1.44
2026	0.17	0.13	0.02	0.14	0.81	2.86	0.14	0.09	0.00	0.01	0.58	1.38	-0.03	-0.04	-0.02	-0.13	-0.22	-1.48
2027	0.17	0.13	0.02	0.14	0.80	2.90	0.13	0.09	0.00	0.01	0.58	1.38	-0.04	-0.04	-0.02	-0.13	-0.23	-1.53
2028	0.16	0.13	0.02	0.14	0.80	2.94	0.13	0.09	0.00	0.01	0.57	1.37	-0.04	-0.04	-0.02	-0.13	-0.23	-1.57
2029	0.16	0.13	0.02	0.15	0.80	2.98	0.12	0.09	0.00	0.01	0.57	1.37	-0.04	-0.04	-0.02	-0.14	-0.24	-1.61
2030	**0.16**	**0.13**	**0.03**	**0.15**	**0.81**	3.03	**0.12**	**0.09**	**0.00**	**0.01**	**0.56**	1.38	**-0.04**	**-0.04**	**-0.02**	**-0.14**	**-0.24**	**-1.65**

Table 10: Comparison of PM exhaust emissions from Luxembourgian transport according to HBEFA 1.2 and 3.2

PM exhaust in 1000t per year

	HBEFA 1.2						HBEFA 3.2						Difference					
year	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)
1990	0.00	0.08	0.01	0.09	0.42	0.94	0.02	0.09	0.03	0.09	0.49	1.09	0.02	0.02	0.02	0.01	0.06	0.15
1991	0.00	0.08	0.01	0.10	0.44	1.08	0.02	0.10	0.03	0.10	0.50	1.25	0.02	0.02	0.02	0.01	0.07	0.17
1992	0.00	0.08	0.01	0.10	0.44	1.14	0.02	0.10	0.03	0.10	0.50	1.31	0.02	0.02	0.02	0.00	0.06	0.17
1993	0.00	0.09	0.01	0.11	0.46	1.14	0.02	0.11	0.04	0.11	0.53	1.31	0.02	0.02	0.02	0.00	0.06	0.16
1994	0.00	0.09	0.01	0.10	0.45	1.11	0.02	0.11	0.04	0.10	0.52	1.31	0.02	0.03	0.02	0.00	0.07	0.20
1995	0.00	0.09	0.02	0.10	0.44	1.01	0.02	0.12	0.04	0.11	0.53	1.24	0.02	0.04	0.02	0.00	0.08	0.23
1996	0.00	0.09	0.02	0.09	0.43	0.98	0.02	0.13	0.04	0.10	0.53	1.24	0.02	0.04	0.02	0.01	0.10	0.26
1997	0.00	0.09	0.02	0.08	0.42	0.94	0.02	0.14	0.04	0.09	0.53	1.23	0.02	0.05	0.03	0.01	0.11	0.29
1998	0.00	0.09	0.02	0.08	0.41	0.89	0.02	0.15	0.05	0.09	0.53	1.21	0.02	0.06	0.03	0.01	0.12	0.32
1999	0.00	0.09	0.02	0.06	0.41	0.85	0.02	0.16	0.05	0.07	0.53	1.21	0.02	0.07	0.03	0.01	0.13	0.35
2000	0.00	0.10	0.02	0.05	0.40	0.89	0.02	0.17	0.05	0.07	0.54	1.30	0.02	0.08	0.03	0.01	0.14	0.41
2001	0.00	0.10	0.02	0.05	0.40	0.85	0.02	0.18	0.05	0.07	0.54	1.29	0.02	0.08	0.03	0.02	0.15	0.44
2002	0.00	0.10	0.02	0.05	0.39	0.81	0.02	0.18	0.05	0.07	0.54	1.25	0.02	0.08	0.03	0.02	0.15	0.44
2003	0.00	0.10	0.02	0.04	0.36	0.80	0.02	0.18	0.05	0.07	0.51	1.28	0.02	0.08	0.02	0.02	0.14	0.48
2004	0.00	0.10	0.02	0.04	0.35	0.84	0.02	0.18	0.05	0.06	0.49	1.38	0.02	0.08	0.02	0.02	0.14	0.54
2005	0.00	0.10	0.02	0.04	0.32	0.80	0.01	0.17	0.04	0.06	0.45	1.35	0.01	0.08	0.02	0.02	0.13	0.55
2006	0.00	0.09	0.02	0.03	0.30	0.69	0.01	0.17	0.04	0.06	0.44	1.21	0.01	0.08	0.02	0.02	0.14	0.51
2007	0.00	0.09	0.02	0.03	0.28	0.59	0.01	0.16	0.04	0.05	0.41	1.05	0.01	0.08	0.02	0.02	0.13	0.46
2008	0.00	0.08	0.02	0.03	0.25	0.51	0.01	0.15	0.04	0.05	0.37	0.91	0.01	0.07	0.02	0.02	0.12	0.40
2009	0.00	0.08	0.02	0.02	0.23	0.43	0.01	0.13	0.04	0.04	0.33	0.75	0.01	0.05	0.02	0.02	0.10	0.32
2010	**0.00**	**0.07**	**0.02**	**0.02**	**0.21**	0.40	**0.01**	**0.11**	**0.04**	**0.04**	**0.30**	0.69	**0.01**	**0.04**	**0.02**	**0.02**	**0.09**	**0.29**
2011	**0.00**	**0.07**	**0.02**	**0.02**	**0.20**	0.38	**0.01**	**0.10**	**0.04**	**0.03**	**0.27**	0.64	**0.01**	**0.03**	**0.02**	**0.02**	**0.07**	**0.26**
2012	**0.00**	**0.06**	**0.02**	**0.02**	**0.20**	0.35	**0.01**	**0.08**	**0.03**	**0.03**	**0.25**	0.55	**0.01**	**0.02**	**0.02**	**0.01**	**0.06**	**0.20**
2013	**0.00**	**0.06**	**0.02**	**0.01**	**0.18**	0.32	**0.00**	**0.07**	**0.03**	**0.03**	**0.22**	0.49	**0.00**	**0.01**	**0.01**	**0.01**	**0.04**	**0.17**
2014	0.00	0.06	0.02	0.01	0.17	0.31	0.00	0.06	0.03	0.02	0.20	0.45	0.00	0.00	0.01	0.01	0.03	0.13
2015	0.00	0.06	0.02	0.01	0.16	0.29	0.00	0.06	0.02	0.02	0.18	0.36	0.00	0.00	0.01	0.01	0.02	0.07
2016	0.00	0.06	0.02	0.01	0.15	0.27	0.00	0.05	0.02	0.02	0.16	0.30	0.00	-0.01	0.00	0.00	0.00	0.03
2017	0.00	0.05	0.02	0.01	0.14	0.26	0.00	0.04	0.02	0.01	0.14	0.26	0.00	-0.01	0.00	0.00	-0.01	0.00
2018	0.00	0.05	0.02	0.01	0.14	0.25	0.00	0.04	0.01	0.01	0.12	0.23	0.00	-0.02	0.00	0.00	-0.01	-0.03
2019	0.00	0.05	0.02	0.01	0.13	0.25	0.00	0.03	0.01	0.01	0.11	0.20	0.00	-0.02	0.00	0.00	-0.02	-0.05
2020	**0.00**	**0.05**	**0.02**	**0.01**	**0.13**	0.24	**0.00**	**0.03**	**0.01**	**0.01**	**0.10**	0.18	**0.00**	**-0.02**	**-0.01**	**0.00**	**-0.03**	**-0.06**
2021	0.00	0.05	0.02	0.01	0.12	0.24	0.00	0.03	0.01	0.01	0.09	0.17	0.00	-0.03	-0.01	0.00	-0.03	-0.08
2022	0.00	0.05	0.02	0.01	0.12	0.24	0.00	0.03	0.01	0.01	0.08	0.15	0.00	-0.03	-0.01	0.00	-0.04	-0.09
2023	0.00	0.05	0.02	0.01	0.12	0.24	0.00	0.02	0.01	0.01	0.08	0.14	0.00	-0.03	-0.01	0.00	-0.04	-0.10
2024	0.00	0.05	0.02	0.01	0.12	0.24	0.00	0.02	0.01	0.00	0.07	0.13	0.00	-0.03	-0.01	0.00	-0.04	-0.11
2025	0.00	0.05	0.02	0.01	0.12	0.24	0.00	0.02	0.00	0.00	0.07	0.13	0.00	-0.03	-0.01	-0.01	-0.05	-0.11
2026	0.00	0.05	0.02	0.01	0.12	0.24	0.00	0.02	0.00	0.00	0.07	0.12	0.00	-0.03	-0.01	-0.01	-0.05	-0.12
2027	0.00	0.05	0.02	0.01	0.11	0.24	0.00	0.02	0.00	0.00	0.06	0.12	0.00	-0.03	-0.01	-0.01	-0.05	-0.13
2028	0.00	0.05	0.02	0.01	0.11	0.25	0.00	0.02	0.00	0.00	0.06	0.11	0.00	-0.03	-0.02	-0.01	-0.05	-0.13
2029	0.00	0.05	0.02	0.01	0.11	0.25	0.00	0.02	0.00	0.00	0.06	0.11	0.00	-0.04	-0.02	-0.01	-0.06	-0.14
2030	**0.00**	**0.05**	**0.02**	**0.01**	**0.11**	0.25	**0.00**	**0.02**	**0.00**	**0.00**	**0.06**	0.11	**0.00**	**-0.04**	**-0.02**	**-0.01**	**-0.06**	**-0.14**

Table 11: Comparison of CO emissions from Luxembourgian transport according to HBEFA 1.2 and 3.2

CO in 1000t per year

	HBEFA 1.2						HBEFA 3.2						Difference					
year	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)	PC Otto	PC Diesel	LCV	HDV	inland total (incl. non-road)	total (incl. export)
1990	23.78	0.42	0.75	0.72	36.28	73.24	32.87	0.46	1.18	0.37	45.49	94.26	9.09	0.04	0.43	-0.34	9.21	21.03
1991	21.73	0.43	0.72	0.77	34.31	76.57	31.70	0.47	1.15	0.40	44.38	102.90	9.97	0.04	0.43	-0.37	10.07	26.34
1992	20.11	0.44	0.66	0.80	32.66	75.16	28.96	0.48	1.07	0.41	41.58	99.39	8.85	0.05	0.41	-0.39	8.91	24.23
1993	18.58	0.46	0.62	0.87	31.22	69.98	26.02	0.50	1.02	0.44	38.66	89.84	7.44	0.04	0.39	-0.43	7.44	19.86
1994	17.06	0.46	0.59	0.77	29.52	66.53	23.15	0.51	0.96	0.40	35.67	83.38	6.10	0.04	0.37	-0.36	6.15	16.85
1995	16.14	0.45	0.56	0.78	28.41	59.49	21.24	0.52	0.91	0.44	33.58	72.61	5.10	0.06	0.35	-0.34	5.17	13.12
1996	15.55	0.47	0.51	0.68	27.59	57.21	19.80	0.54	0.84	0.41	31.95	68.09	4.24	0.07	0.33	-0.27	4.36	10.88
1997	14.82	0.50	0.46	0.61	26.66	55.83	18.16	0.55	0.75	0.40	30.13	64.68	3.34	0.05	0.29	-0.21	3.47	8.84
1998	14.04	0.54	0.40	0.55	25.72	53.11	16.50	0.56	0.66	0.40	28.32	59.76	2.46	0.02	0.26	-0.14	2.60	6.65
1999	13.00	0.59	0.39	0.44	24.57	51.62	14.64	0.56	0.62	0.37	26.35	56.45	1.64	-0.03	0.24	-0.07	1.78	4.83
2000	12.02	0.63	0.36	0.39	23.45	50.73	13.03	0.56	0.56	0.37	24.58	54.20	1.02	-0.07	0.20	-0.02	1.13	3.48
2001	11.21	0.68	0.33	0.37	22.43	48.08	11.76	0.55	0.50	0.40	23.07	50.39	0.55	-0.13	0.17	0.04	0.64	2.31
2002	10.36	0.73	0.30	0.34	21.47	45.53	10.53	0.54	0.44	0.43	21.69	46.85	0.17	-0.19	0.14	0.10	0.22	1.32
2003	9.63	0.77	0.27	0.30	20.46	44.69	9.51	0.52	0.38	0.44	20.33	45.39	-0.12	-0.25	0.11	0.14	-0.13	0.69
2004	8.65	0.85	0.23	0.27	19.26	42.56	8.33	0.52	0.31	0.44	18.87	43.22	-0.31	-0.33	0.08	0.18	-0.39	0.66
2005	7.50	0.90	0.22	0.24	17.81	38.04	7.14	0.50	0.27	0.44	17.31	38.99	-0.36	-0.40	0.06	0.20	-0.51	0.95
2006	6.62	0.94	0.20	0.22	16.76	33.50	6.29	0.48	0.24	0.46	16.25	34.62	-0.32	-0.46	0.04	0.24	-0.51	1.13
2007	5.84	0.99	0.19	0.20	15.83	31.00	5.56	0.47	0.21	0.48	15.32	32.19	-0.28	-0.52	0.02	0.27	-0.51	1.20
2008	5.21	1.05	0.18	0.19	14.99	28.57	4.97	0.46	0.18	0.50	14.49	30.10	-0.24	-0.59	0.00	0.31	-0.51	1.53
2009	4.57	1.07	0.16	0.16	14.17	25.79	4.38	0.45	0.15	0.49	13.67	27.19	-0.19	-0.62	-0.01	0.32	-0.50	1.40
2010	**3.98**	**1.06**	**0.15**	**0.16**	**13.40**	23.83	**3.84**	**0.42**	**0.13**	**0.51**	**12.95**	25.84	**-0.14**	**-0.64**	**-0.02**	**0.35**	**-0.45**	**2.00**
2011	**3.54**	**1.09**	**0.15**	**0.15**	**12.85**	23.52	**3.43**	**0.41**	**0.12**	**0.53**	**12.40**	25.77	**-0.11**	**-0.68**	**-0.03**	**0.38**	**-0.44**	**2.25**
2012	**3.14**	**1.10**	**0.15**	**0.13**	**12.23**	21.94	**3.05**	**0.39**	**0.10**	**0.51**	**11.75**	23.98	**-0.09**	**-0.71**	**-0.05**	**0.37**	**-0.47**	**2.03**
2013	**2.80**	**1.11**	**0.14**	**0.12**	**11.72**	20.06	**2.71**	**0.38**	**0.09**	**0.49**	**11.20**	22.15	**-0.09**	**-0.73**	**-0.06**	**0.36**	**-0.51**	**2.09**
2014	2.64	1.16	0.14	0.12	11.46	20.47	2.53	0.38	0.08	0.43	10.83	22.02	-0.10	-0.77	-0.06	0.32	-0.62	1.55
2015	2.44	1.17	0.14	0.12	11.14	19.89	2.33	0.38	0.07	0.39	10.43	20.35	-0.12	-0.79	-0.07	0.27	-0.71	0.46
2016	2.28	1.19	0.14	0.12	10.84	19.40	2.15	0.38	0.06	0.33	10.04	19.10	-0.13	-0.81	-0.08	0.21	-0.81	-0.30
2017	2.15	1.21	0.14	0.12	10.59	19.02	2.01	0.38	0.06	0.29	9.70	18.26	-0.14	-0.83	-0.08	0.17	-0.88	-0.75
2018	2.05	1.22	0.14	0.12	10.35	18.71	1.90	0.37	0.05	0.26	9.40	17.58	-0.15	-0.85	-0.09	0.14	-0.95	-1.13
2019	1.96	1.24	0.14	0.12	10.12	18.46	1.80	0.37	0.05	0.23	9.11	17.00	-0.17	-0.87	-0.10	0.11	-1.01	-1.46
2020	**1.89**	**1.26**	**0.15**	**0.12**	**9.94**	18.31	**1.72**	**0.37**	**0.05**	**0.20**	**8.86**	16.54	**-0.18**	**-0.88**	**-0.10**	**0.08**	**-1.07**	**-1.76**
2021	1.83	1.27	0.15	0.12	9.80	18.25	1.64	0.37	0.04	0.18	8.68	16.21	-0.19	-0.89	-0.10	0.06	-1.13	-2.04
2022	1.77	1.28	0.15	0.12	9.63	18.16	1.57	0.37	0.04	0.16	8.45	15.88	-0.20	-0.90	-0.11	0.04	-1.18	-2.28
2023	1.72	1.29	0.15	0.12	9.53	18.17	1.51	0.37	0.04	0.14	8.31	15.67	-0.21	-0.91	-0.11	0.02	-1.22	-2.49
2024	1.68	1.30	0.15	0.12	9.43	18.17	1.46	0.37	0.04	0.13	8.18	15.53	-0.22	-0.92	-0.11	0.00	-1.25	-2.65
2025	1.64	1.31	0.16	0.13	9.33	18.18	1.41	0.37	0.04	0.12	8.04	15.40	-0.22	-0.93	-0.12	-0.01	-1.28	-2.78
2026	1.60	1.32	0.16	0.13	9.21	18.18	1.37	0.37	0.04	0.10	7.90	15.28	-0.22	-0.94	-0.12	-0.02	-1.31	-2.90
2027	1.57	1.33	0.16	0.13	9.07	18.17	1.34	0.37	0.04	0.10	7.74	15.16	-0.23	-0.95	-0.12	-0.03	-1.34	-3.01
2028	1.54	1.34	0.16	0.13	8.96	18.19	1.31	0.37	0.04	0.09	7.60	15.09	-0.23	-0.96	-0.12	-0.04	-1.36	-3.10
2029	1.52	1.35	0.16	0.14	8.86	18.23	1.28	0.37	0.04	0.08	7.48	15.04	-0.23	-0.97	-0.13	-0.05	-1.38	-3.19
2030	**1.49**	**1.36**	**0.17**	**0.14**	**8.27**	17.77	**1.26**	**0.37**	**0.04**	**0.08**	**6.86**	14.50	**-0.24**	**-0.98**	**-0.13**	**-0.06**	**-1.41**	**-3.27**