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Teil 1

Comparison of the Calculated Dry Deposition Fluxes for 2005 and 2020

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Genfer Luftreinhaltekonvention der UNECE:

Erstellung einer methodenkonsistenten Zeitreihe von Stoffeinträgen und Ihren Wirkungen in Deutschland.
Teil 1

Comparison of the calculated dry deposition fluxes for 2005 and 2020

von

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16. Zusammenfassung

Aufbauend auf die im MAPESI Projekt (FKZ 3710 64 200) berechnete Zeitreihe der atmosphärischen Stickstoff- und Schwefeldeposition (2004-2007) wurde in diesem Projekt eine Prognose der Deposition im Jahr 2020 erstellt. Das LOTOS-EUROS Modell wurde zur Berechnung des trockenen Depostitionsflusses verwendet. Die Emissionsprognose für das Jahr 2020 wurde aus dem PAREST-Projekt (FKZ 206 43 200/01) übernommen. Die Wirkung bereits beschlossener Maßnahmen wurden berücksichtigt (Current Legislation Szenario). Die für das Jahr 2020 berechneten Depositionsflüsse wurden mit denen für das Jahr 2005 verglichen.

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16. Abstract

The LOTOS-EUROS model is used to determine the dry deposition flux. A comparison is made between the calculated dry deposition using the projected emissions in 2020 for Germany, accounting for the reductions under the current legislation, and the calculated dry deposition fluxes using the PAREST 2005 emission database.

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Comparison of the calculated dry deposition fluxes for 2005 and 2020

Roy Wichink Kruit, Gerbrand Boersen, Martijn Schaap, Peter Builtjes,
TNO-Utrecht, 20 January 2011

Introduction

Within the MAPESI project (FKZ 3707 64 200) deposition flux maps are determined for Germany based on a combination of observations and model results. Wet deposition is based on an interpolation scheme of observed fluxes. For the determination of dry deposition, however, we have to rely on a chemistry transport model which includes a dry deposition module. The dry deposition flux can not be monitored directly, because flux measurements are very expensive and the variability in space and time of the deposition fluxes is generally high for most of the atmospheric substances.
In the current project, the LOTOS-EUROS model is used to determine the dry deposition flux. In this note, a comparison is made between the calculated dry deposition using the projected emissions in 2020 for Germany, accounting for the reductions under the current legislation, and the calculated dry deposition fluxes using the PAREST 2005 emission database. For a detailed description of the method used to calculate the dry deposition and a discussion of the 2005 results, see Builtjes et al, 2010.

Methodology in MAPESI

Within the MAPESI project the dry deposition is calculated on an hour-by-hour basis using the LOTOS-EUROS model at a spatial resolution of about 7 by 7 km (0.0625 x 0.125 degrees lat-lon) over Germany. An updated description of the aerodynamic resistance per land use category, Ra, was used instead of one average value per grid cell. The quasi-laminar boundary-layer resistance, Rb, and the surface resistance, Rc, are calculated with the DEPAC module in the LOTOS-EUROS model. We used the ECMWF meteorology of 2005 for both the model run with the 2005 emissions and the model run with the 2020 emissions. The PAREST 2005 emission database contains the officially reported country totals for Europe and an improved spatial allocation of the emissions based on ZSE for Germany. The 2020 emission database contains the projected emissions for 2020 under current legislation-CLE, in Germany. Note that the emission reductions are restricted to Germany. For more information concerning the emission data bases, see Jörß, 2010, Denier van der Gon, 2010.

Emission reductions

In this section we provide an overview of the modelled dry deposition fluxes for SOx, NOy and NHx for the years 2005 and 2020. We will first mention the differences between the German emissions in the emission databases of 2020 and 2005 for the different tracer components, see also Wichink Kruit, Dec. 2010, and Table 1, which summarizes this inventory (based on a previous note on the emission changes between 2005 and 2020 included in Annex 1).

Table 1 Change in the emissions for the reference year 2020 compared to the reference year 2005, Germany (see also Annex 1)

Germany Emission Change 2005-2020 kt/year	**NO_X**	**%**	**NMVOC**	**%**	**SO_X**	**%**	**NH_3**	**%**	**PM_{25}**	**%**	**PM_{10}**	**%**
Energy transformation	-0.8	-0.3%	0.1	1.2%	-32.9	-11.3%	-0.2	-6.7%	-0.9	-9.0%	-1	-8.8%
Small combustion sources	-8.4	-8.2%	10.4	12.3%	-41.7	-53.7%	0.2	7.4%	2.9	10.6%	3.2	10.9%
Industrial combustion	-6.3	-8.8%	0.2	5.1%	-2.2	-3.4%	-0.3	-21.4%	-1.2	-13.6%	-3.1	-15.9%
Industrial process emissions	-23.3	-25.7%	-8.6	-10.0%	-26.5	-22.5%	0.1	1.0%	-4.4	-26.8%	-9.7	-18.5%
Extraction of fossil fuels	0	0.0%	-13	-51.8%	-2	-25.3%	0	0.0%	-0.1	-11.1%	-0.2	-4.5%
Solvent and product use	0	0.0%	57.4	7.7%	0	0.0%	0	0.0%	-0.2	-2.2%	-0.2	-2.2%
Road transport gasoline	-88.3	-78.7%	-65.5	-71.3%	-0.2	-50.0%	-3.3	-33.0%	0	0.0%	0	0.0%
Road transport diesel	-431	-75.4%	6.7	17.5%	0.2	50.0%	0.3	60.0%	-19	-90.0%	-19	-90.0%
Road transport lpg	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Brake and tyrewear	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1.3	12.3%	2.4	12.2%
Volatilisation losses	0	0.0%	-12.5	-53.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Traffic resuspension	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0.4	8.2%	4.6	9.4%
Non road transport	-83.2	-35.7%	-31.6	-40.4%	-1.9	-61.3%	0	0.0%	-13.6	-64.5%	-13.6	-64.5%
Waste handling and disposal	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Agriculture	1.5	1.9%	0	0.0%	0	0.0%	5.6	1.0%	0	0.0%	2.1	8.2%
SUM OVER ALL SECTORS	-639.8	-41.4%	-56.5	-3.9%	-107	-19.1%	2.5	0.4%	-34.3	-25.3%	-34.3	-13.1%

The emission reduction of SO_2 between 2005 and 2020 is calculated to be 19.1% or 107 kt and is mainly obtained by "energy transformation", "small combustion sources" and "industrial process emissions" (roughly 30% each).

The huge reduction in the emission of NO_x of 41.4% or 640 kt is mainly obtained by the reduction of the emissions in the sector “road transport diesel”, which accounts for 2/3 of this emission reduction.

The emissions of NH_3 are projected to *increase* between 2005 and 2020 with about 0.4% or 2.5 kt. This increase mainly is the net result of a projected increase in the emission of ammonia of 5.6 kt in the agricultural sector and a reduction of 3.3 kt by "road transport gasoline".

Modelled dry deposition fluxes

In Figure 1a and 1b, we present the annual total dry deposition distributions for oxidized sulphur (upper panels), oxidized nitrogen (middle panels) and reduced nitrogen (lower panels). The dry deposition fluxes that are calculated with the PAREST 2005 emission database are presented in the left side of Figure 1a. The right side of Figure 1a represents the calculated distribution of the dry deposition fluxes in 2020. The left side of Figure 1b shows the absolute difference between the dry deposition fluxes in 2020 and 2005. The right side of Figure 1b shows the relative difference between the dry deposition fluxes in 2020 and 2005. The distributions show the composite values, meaning that an hectare has the average land use distribution of that grid cell. The results are summarized in Table 2.

Table 2. The average dry deposition flux (Eq ha^{-1} a^{-1}) for oxidized sulphur, oxidized nitrogen and reduced nitrogen.

Species	**2005**	**2020**	**difference 2020-2005**	**% difference 2020-2005**
SO_x	213.6	186.9	-26.7	-12.5
NO_y	260.3	193.5	-66.8	-25.7
NH_x	511.4	523.3	11.9	2.3
total N	771.7	716.8	-54.9	-23.3

Oxidized Sulphur (SO_x-S; upper panels in Figure 1)

The deposition flux for oxidized sulfur shows maxima in the Ruhr area, along the Nord-Ost-see canal, and some locations near large power plants or industrial complexes. Only in the Ruhr area the deposition flux exceeds 600 Eq ha^{-1} a^{-1}. On average the dry deposition flux is 213.6 Eq ha^{-1} a^{-1} over Germany in 2005. The projected reduction of the SO_2 emission of 19.1% in 2020 results in a reduction of the dry SO_x deposition of 26.7 Eq ha^{-1} a^{-1} or 12.5%. The average dry deposition flux is projected to be 186.9 Eq ha^{-1} a^{-1} in 2020.

Oxidized Nitrogen (NO_y-N; middle panels in Figure 1)

The dry deposition distribution of oxidized nitrogen resembles the distribution of the HNO_3 (nitric acid) and NO_2 concentrations. Over central Germany, a large scale background deposition of about 200 Eq ha^{-1} a^{-1} is present. In the Ruhr area, the maximum deposition values exceed 600 Eq ha^{-1} a^{-1}. On average the deposition flux of NO_y-N over Germany is 260.3 Eq ha^{-1} a^{-1} in 2005 and 193.5 Eq ha^{-1} a^{-1} in 2020, a reduction of 66.8 Eq ha^{-1} a^{-1} or about 26 %.

Reduced Nitrogen (NH_x-N; lower panels in Figure 1)

The distribution of the dry deposition of NH_x-N shows that the largest dry deposition fluxes are observed in Niedersachsen and Nordrhein-Westfalen area, where the most intensive agriculture is located. The average dry deposition flux of NH_x-N is 511.4 Eq ha^{-1} a^{-1} in 2005, while an increase of 11.9 Eq ha^{-1} a^{-1} is expected between 2005 and 2020, resulting in an average dry deposition flux of 523.3 Eq ha^{-1} a^{-1} in 2020. This is a small increase of about 2.3%.

Discussion

It is shown that the emission reductions of SO_2, NO_x and NH_3 of 19.1%, 41.4% and -0.4%, respectively, do not automatically result in equal reductions of the dry deposition fluxes. This is because many non-linear chemical processes act on the dry deposition process, i.e., a changed chemical composition of the atmosphere may result in a different sensitivity of the chemical reactions (parameterized in the LOTOS-EUROS model) on equal temperature and humidity. However, the areas and sectors in which the emissions are reduced generally also show a reduction in the dry deposition. For example, the areas with heavy industry and power plants where the SO_2 emissions are reduced, also show decreased dry deposition. Likewise, the huge reduction of the NO_x emissions result in a decrease of the dry NO_y deposition around highways.

As mentioned before, the increased NH_3 emissions by the agricultural sector are only partly compensated by the reduction of NH_3 emission by "road traffic gasoline". This finally results in a rather small increase of the emissions of NH_3 of 0.4%. The agricultural areas indeed show increased dry deposition of NH_x. However, it is remarkable to see that the dry deposition of NH_x near the coast and close to the Alps decreases (see Figure 1b), which cannot be attributed to the decrease in emissions from the "road traffic gasoline". It is more likely that chemical equilibriums are changed in such a way that more ammonia reacts with other atmospheric substances, so that it is transported in the form of secondary inorganic aerosol (SIA) over much longer distances. This nicely illustrates the non-linear behavior of the dry deposition process on atmospheric conditions and chemical equilibriums.

The calculated, gridded, dry as well as wet deposition fluxes have been made available to UBA by Jan.12, 2011.

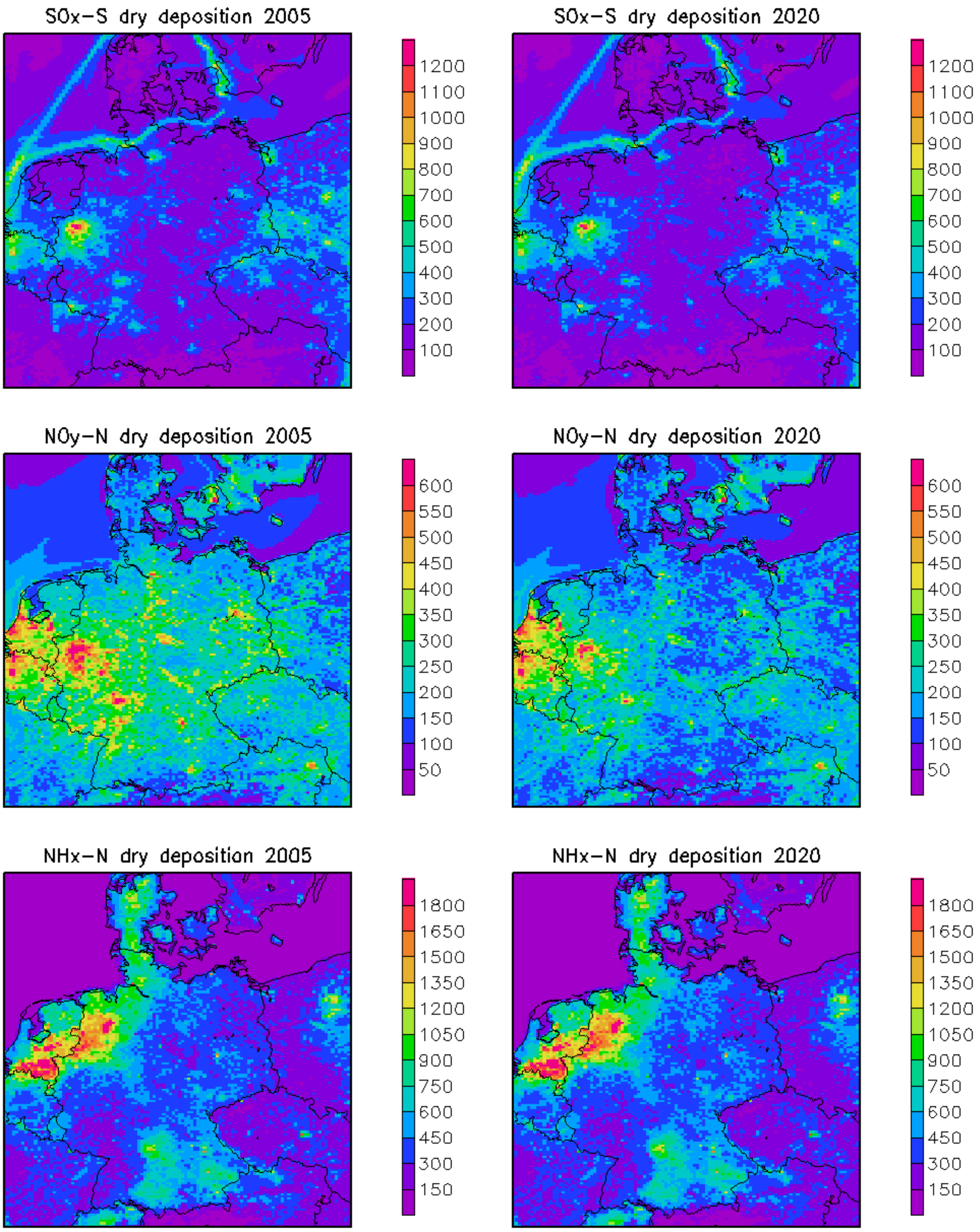

Figure 1a. Annual dry deposition distributions of oxidized sulphur, oxidized nitrogen and reduced nitrogen (upper, middle and lower panels, respectively) for 2005 and 2020 in Eq ha^{-1} a^{-1} (left and right side, respectively).

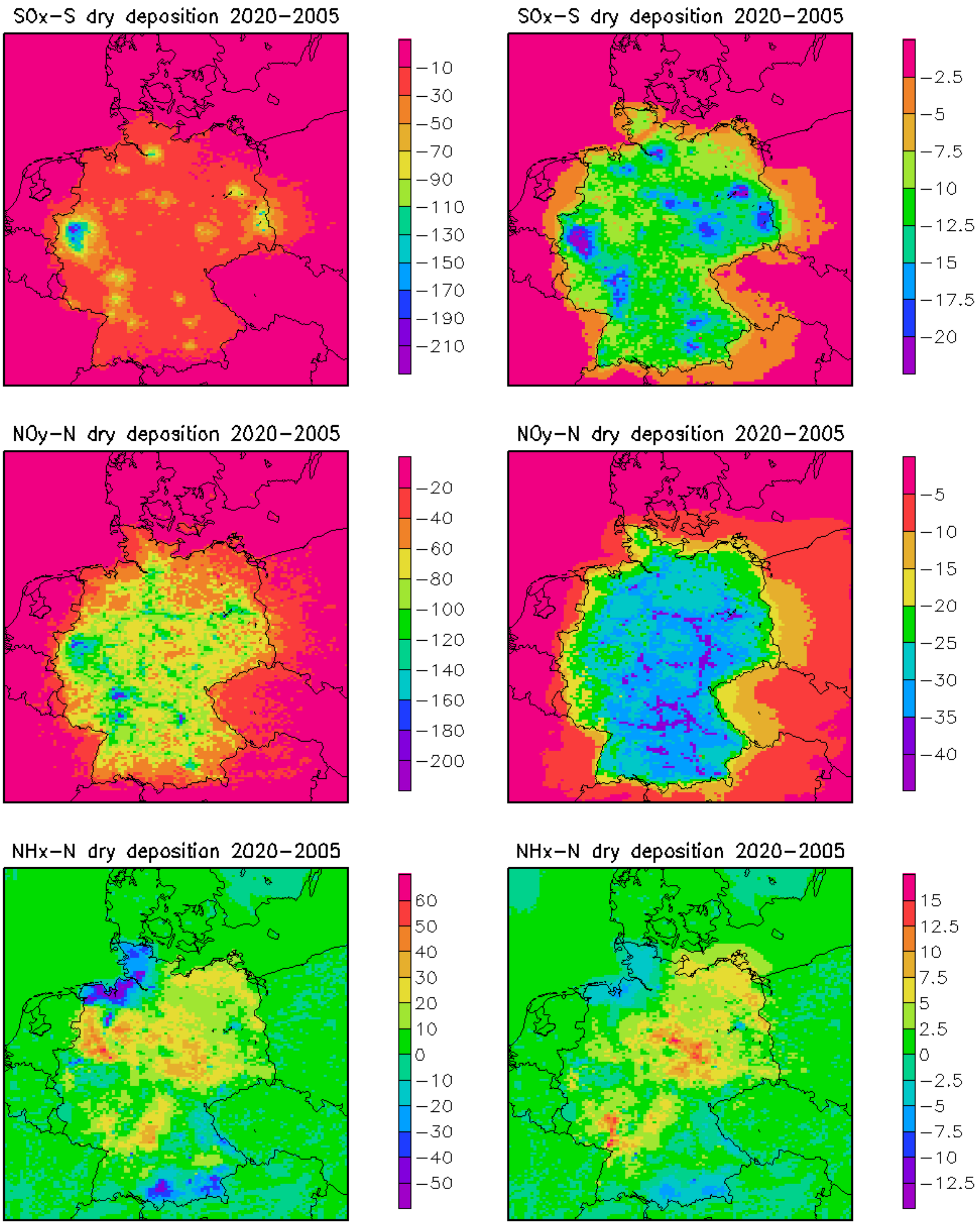

Figure 1b. The absolute and relative difference (in Eq ha^{-1} a^{-1} on the left side and in % on the right side, respectively) in the annual dry deposition distributions of oxidized sulphur, oxidized nitrogen and reduced nitrogen (upper, middle and lower panels, respectively) between 2020 and 2005.

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Denier van der Gon, H., Vischedijk, A., van der Brugh, H., Droge, R.: „A high resolution European emission data base for the year 2005“. PAREST-Bericht June 2010

Jörß, W., Kugler, U., Theloke, J.: “Emissionen im PAREST-Referenzszenario 2005-2020”. PAREST-Bericht Mai 2010.

Wichink Kruit, R.: “Statistical analysis of the changes in emissions in Germany between the reference years 2005 and 2020“. TNO-Utrecht, NL, 15 december 2010.

ANNEX 1: FKZ 35101080 Project " Genfer Luftreinhaltekonvention der UNECE: Erstellung einer methoden-konsistenten Zeitreihe von Stoffeinträgen und Ihren Wirkungen in Deutschland. Teil 1

Statistical analysis of the changes in emissions in Germany between the reference years 2005 and 2020, Roy Wichink Kruit, TNO-Utrecht, NL 15 december 2010.

In this short communication the changes in the emissions between the reference years 2005 and 2020 are discussed. These emissions are taken from the PAREST-project and are described in Stern (2010) and are based on the inventory of Jörß et al. (2010). In this emission inventory, the energy reference scenario (including the emission standards Euro 5 and Euro 6) is included for the year 2020, the so-called CLE-Current Legislation Scenario. A more detailed description of the energy reference scenario can be found in Jörß et al. (2010).

Germany Emissions 2005 kt/year	**NO_X**	**NMVOC**	**SO_X**	**NH_3**	**PM_{25}**	**PM_{10}**
Energy transformation	282.5	8.4	290	3	10	11.3
Small combustion sources	101.9	84.7	77.6	2.7	27.4	29.4
Industrial combustion	71.4	3.9	64.6	1.4	8.8	19.5
Industrial process emissions	90.6	86.2	117.6	9.6	16.4	52.5
Extraction of fossil fuels	0	25.1	7.9	0	0.9	4.4
Solvent and product use	0	742.6	0	1.7	9.1	9.1
Road transport gasoline	112.2	91.9	0.4	10	0	0
Road transport diesel	571.4	38.2	0.4	0.5	21.1	21.1
Road transport lpg	0	0	0	0	0	0
Brake and tyrewear	0	0	0	0	10.6	19.6
Volatilisation losses	0	23.4	0	0	0	0
Traffic resuspension	0	0	0	0	4.9	48.9
Non road transport	233.1	78.3	3.1	1.1	21.1	21.1
Waste handling and disposal	0.1	0	0	0	0	0
Agriculture	80.8	254.7	0	576.9	5.7	25.7
SUM OVER ALL SECTORS	1544	1437.5	561.6	606.9	135.8	262.5

Table 1 Emissions (kt/year) for the reference year 2005, Germany**.**

Germany Emissions 2020 kt/year	**NO_X**	**NMVOC**	**SO_X**	**NH_3**	**PM_{25}**	**PM_{10}**
Energy transformation	281.7	8.5	257.1	2.8	9.1	10.3
Small combustion sources	93.5	95.1	35.9	2.9	30.3	32.6
Industrial combustion	65.1	4.1	62.4	1.1	7.6	16.4
Industrial process emissions	67.3	77.6	91.1	9.7	12	42.8
Extraction of fossil fuels	0	12.1	5.9	0	0.8	4.2
Solvent and product use	0	800	0	1.7	8.9	8.9
Road transport gasoline	23.9	26.4	0.2	6.7	0	0
Road transport diesel	140.4	44.9	0.6	0.8	2.1	2.1
Road transport lpg	0	0	0	0	0	0
Brake and tyrewear	0	0	0	0	11.9	22
Volatilisation losses	0	10.9	0	0	0	0
Traffic resuspension	0	0	0	0	5.3	53.5
Non road transport	149.9	46.7	1.2	1.1	7.5	7.5
Waste handling and disposal	0.1	0	0	0	0	0
Agriculture	82.3	254.7	0	582.5	5.7	27.8
SUM OVER ALL SECTORS	904.2	1381	454.6	609.4	101.5	228.2

Table 2 Emissions (kt/year) for the reference year 2020, Germany

Germany Emission Change 2005-2020 kt/year	**NO_X**	**NMVOC**	**SO_X**	**NH_3**	**PM_{25}**	**PM_{10}**
Energy transformation	-0.8	0.1	-32.9	-0.2	-0.9	-1
Small combustion sources	-8.4	10.4	-41.7	0.2	2.9	3.2
Industrial combustion	-6.3	0.2	-2.2	-0.3	-1.2	-3.1
Industrial process emissions	-23.3	-8.6	-26.5	0.1	-4.4	-9.7
Extraction of fossil fuels	0	-13	-2	0	-0.1	-0.2
Solvent and product use	0	57.4	0	0	-0.2	-0.2
Road transport gasoline	-88.3	-65.5	-0.2	-3.3	0	0
Road transport diesel	-431	6.7	0.2	0.3	-19	-19
Road transport lpg	0	0	0	0	0	0
Brake and tyrewear	0	0	0	0	1.3	2.4
Volatilisation losses	0	-12.5	0	0	0	0
Traffic resuspension	0	0	0	0	0.4	4.6
Non road transport	-83.2	-31.6	-1.9	0	-13.6	-13.6
Waste handling and disposal	0	0	0	0	0	0
Agriculture	1.5	0	0	5.6	0	2.1
SUM OVER ALL SECTORS	-639.8	-56.5	-107	2.5	-34.3	-34.3

Table 3 Change in the emissions for the reference year 2020 compared to the reference year 2005, Germany.

Germany Emission Change 2005-2020 %	**NO_X**	**NMVOC**	**SO_X**	**NH_3**	**PM_{25}**	**PM_{10}**
Energy transformation	-0.3%	1.2%	-11.3%	-6.7%	-9.0%	-8.8%
Small combustion sources	-8.2%	12.3%	-53.7%	7.4%	10.6%	10.9%
Industrial combustion	-8.8%	5.1%	-3.4%	-21.4%	-13.6%	-15.9%
Industrial process emissions	-25.7%	-10.0%	-22.5%	1.0%	-26.8%	-18.5%
Extraction of fossil fuels	0.0%	-51.8%	-25.3%	0.0%	-11.1%	-4.5%
Solvent and product use	0.0%	7.7%	0.0%	0.0%	-2.2%	-2.2%
Road transport gasoline	-78.7%	-71.3%	-50.0%	-33.0%	0.0%	0.0%
Road transport diesel	-75.4%	17.5%	50.0%	60.0%	-90.0%	-90.0%
Road transport lpg	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brake and tyrewear	0.0%	0.0%	0.0%	0.0%	12.3%	12.2%
Volatilisation losses	0.0%	-53.4%	0.0%	0.0%	0.0%	0.0%
Traffic resuspension	0.0%	0.0%	0.0%	0.0%	8.2%	9.4%
Non road transport	-35.7%	-40.4%	-61.3%	0.0%	-64.5%	-64.5%
Waste handling and disposal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Agriculture	1.9%	0.0%	0.0%	1.0%	0.0%	8.2%
SUM OVER ALL SECTORS	-41.4%	-3.9%	-19.1%	0.4%	-25.3%	-13.1%

Table 4 Change (%) in the emissions for the reference year 2020 compared to the reference year 2005, Germany.

relative contribution to total emission change 2005-2020 %	**NO_x**	**NMVOC**	**SO_x**	**NH_3**	**PM_{25}**	**PM_{10}**
Energy transformation	0%	0%	-31%	-8%	-3%	-3%
Small combustion sources	-1%	18%	-39%	8%	8%	9%
Industrial combustion	-1%	0%	-2%	-12%	-3%	-9%
Industrial process emissions	-4%	-15%	-25%	4%	-13%	-28%
Extraction of fossil fuels	0%	-23%	-2%	0%	0%	-1%
Solvent and product use	0%	102%	0%	0%	-1%	-1%
Road transport gasoline	-14%	-116%	0%	-132%	0%	0%
Road transport diesel	-67%	12%	0%	12%	-55%	-55%
Road transport lpg	0%	0%	0%	0%	0%	0%
Brake and tyrewear	0%	0%	0%	0%	4%	7%
Volatilisation losses	0%	-22%	0%	0%	0%	0%
Traffic resuspension	0%	0%	0%	0%	1%	13%
Non road transport	-13%	-56%	-2%	0%	-40%	-40%
Waste handling and disposal	0%	0%	0%	0%	0%	0%
Agriculture	0%	0%	0%	224%	0%	6%
SUM OVER ALL SECTORS	-100%	-100%	-100%	100%	-100%	-100%

Table 5 Relative contribution of the emission reduction of each sector to the total emission reduction between the reference years 2020 and 2005, Germany.

In the following section, we will briefly discuss the emission reductions per component (in order of relative importance):

NO_x → total emission reduction 41.4% (640 kt)

The tables show that the energy reference scenario especially leads to a huge reduction of the emission of NO_x of 41.4%. This emission reduction is mainly obtained by the reduction of the emissions in the sector “road transport diesel”, which accounts for 2/3 of this emission reduction.

PM_{25} → total emission reduction 25.3% (34.3 kt)

The second largest emission reduction is obtained for the emission of PM25, i.e., 25.3%, which can also be attributed to "road transport diesel" for more than 50%. The remaining part of the reduction is obtained by "non road transport" or "other mobile sources and machinery" as it called in Jörß et al. (2010).

SO_x → total emission reduction 19.1% (107 kt)

The emission reduction of SO_2 between 2005 and 2020 is calculated to be 19.1%. The sectors that deliver the largest contribution to this emission reduction (roughly 30% each) are "energy transformation", "small combustion sources" and "industrial process emissions".

PM_{10} → total emission reduction 13.1% (34.3 kt)

The emission reduction of PM_{10} of 34.3 kt is equal to the emission reduction of PM_{25}. However, relative to its total emission, the reduction of 13.1% is smaller than the reduction for PM_{25}. Like for PM_{25}, the reduction can be attributed to "road transport diesel" for more than 50%. The remaining part of the reduction is again obtained by "non road transport".

NMVOC → total emission reduction 3.9% (56.5 kt)

The emissions of NMVOC are reduced by 3.9% or 56.5 kt. This relatively small reduction is the result of a few relatively large changes in the emissions. Especially for the sector "solvent and product use" an increase in the emissions of 57.4 kt is projected, which is an increase of 7.7% from this sector. The "road transport gasoline" sector accounts for the largest decrease in the emissions of 65.5 kt, which is a reduction of 71.3% for this sector.

NH_3 → total emission reduction -0.4% (-2.5 kt)

The emissions of NH_3 are projected to *increase* between 2005 and 2020 with about 0.4% or 2.5 kt. Agriculture is expected to emit 5.6 kt of ammonia more in 2020, but the reduction of 3.3 kt by "road transport gasoline" partly cancels this increase.

NOTE: especially for the components that show relatively large positive and negative changes in the emissions compared to the total change in the emissions, one should be careful in analyzing table 5. This table gives the percentages relative to the total change, which is 100% by definition.

Literature

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