"HTAP_v2: a mosaic of regional and global emission gridmaps for 2008 and 2010 to study hemispheric transport of air pollution" by G. Janssens-Maenhout et al., ACPD 15, C2857–C2864, 2015

The authors are grateful to Referee #1 for the interest and comments on the paper. We tried to improve the paper as requested with more details and data.

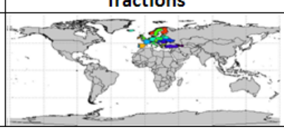
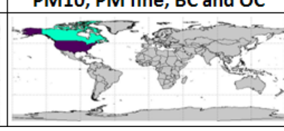
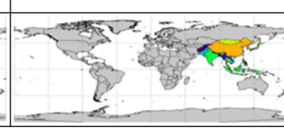
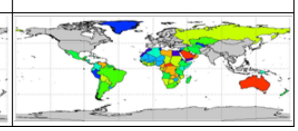
The modifications in reply to the comments of referee # 1 are highlighted "yellow" and "blue" in the paper.

Specific Comments

Page 12871, Line 17: We added to the paper – as suggested - that "The Lamarque et al. (2010) data used a similar methodology of combining country level inventories for most OECD countries with research inventories for Asia and EDGAR for other regions."

Section 2, general
We added the following overview table specifying the general source and characteristics for the data in each world region.

Table 1a: Overview of the data sources and their generic characteristics, as used for the different regions in HTAP_v2.2

Data source	EMEP - TNO (MACCII)	US EPA + Environ Can	MIX-ASIA (incl REAS2.1)	EDGARv4.3 (prelim.)
type of data source	country inventories + point sources	state inventories + point sources	county inventory for China + country inventories	country inventories
coverage of human activities	all except international shipping/aviation	all except international shipping/aviation	all, except international shipping/aviation and except agricultural waste burning	all inclusive international shipping/aviation
temporal resolution	yearly gridmaps (monthly profiles of EMEP model added)	monthly profiles	monthly gridmaps	monthly profiles (for 3 different lattitude bands
spatial resolution	0.125deg x 0.0625deg, after raster resampling 1/5 x 1/5 and aggregation of 4 x 8 converted into 0.1deg x 0.1deg	0.1deg x 0.1deg and height profiles	0.25deg x 0.25deg, after raster resampling 1/5 x 1/5 and aggregation of 2 x 2 converted into 0.1 deg x 0.1 deg	0.1deg x 0.1deg
substances	CO, NMVOC, NOx, SO2, NH3, PM coarse and fine and BC/OC fractions	CO, NMVOC with speciation profiles, NOx, SO2, NH3, PM10, PM fine, BC and OC	CO, NMVOC, NOx, SO2, NH3, PMcoarse, PM2.5, BC and OC	CO, NMVOC, NOx, SO2, NH3, PM10, PM2.5, BC and OC
in HTAPv2.2 used geo-coverage				

We added the explanation on the re-gridding procedure with special attention to the cells that cover borders between countries at the end of paragraph 2.2.5.
"This replacement took place after the gridmaps were converted into 0.1° x 0.1° using a raster resampling procedure. For EMEP-TNO the resampling implied a 25-fold division to 0.0025°x0.0125° followed by an aggregation of 4x8 gridcells. For the MICS-Asia the resampling needed also a 25th fold division to 0.05°x0.05° followed by an aggregation of

2x2 gridcells. The cells including country borders are split up and allocated to the different countries using the corresponding areal percentage."

We added – as requested – an additional section 2.3 on the temporal profiles supplementary, in which a comparison has become apparent with Fig. 1c.

Page 12876, section 2.2.1: The authors agree that it is important to detail where lack of data caused not actual but extrapolated data. Even though the 2008 and 2010 are mostly actual data for all data source, unavailability of data lead to few exceptions, which we more explicitly mentioned in the paper:

- "The 2010 data for Canada were missing and as such extrapolated by US EPA based on the 2008 National Emission Inventory of Environment Canada and assuming no trend but using updated point sources (Pouliot et al., 2014)."
- "The EMEP-TNO data were only available for 2006 and 2009. The 2008 data for Europe is based on the EMEP-TNO data for 2009 data and the 2010 data for Europe are based on the same 2009 data but using the trend in EMEP-TNO data between 2006 and 2009."

The trends between 2008 and 2010 in emissions and in the driving activity data are so small that no significant impact on the implied emission factors is observed.

Page 12877, Line 10: The authors edited the line as suggested. "EMEP-TNO data for country with only partial coverage …"

Page 12878, Line 6: The EMEP modeling group provided "the monthly profiles, which are with a monthly factor (varying around 1/12) specified for each country and for each sector, with a further compound-specific modulation for the agricultural sector". This has been added in the text.

Page 12880, Line 6: The paper Balsama et al. (2014) is indeed not describing the EDGARv4.3 gapfilling for HTAP_v2.2 but analysed the EDGARv4.3 preliminary dataset of EDGAR and its trends. This analysis was useful to identify similarities in the behavior of certain substances and supported the underlying methodology for deriving implied emission factors. The authors agree that it is not here at its correct place (shifted to section 3.6.)

Page 12880, Line 19: We added "EDGAR provides also sector-specific monthly profiles, defined with first-order estimated factors for each of the three different zones: Northern Hemisphere, Equatorial region and Southern Hemisphere (Table S1.2)."

A comparison of the monthly profiles is added in a new section 2.3:

2.3 Overview of the temporal profiles used in HTAP_v2.2

The modulation of annual emissions over time is necessary in order to provide the modelers emission data consistent with the seasonal pattern and activities. Monthly data were generated for all sectors except for the international shipping and international aviation, which are considered constant over the year. US-EPA, EMEP and EDGAR provided monthly profiles, but MICS-Asia provided directly and solely monthly emission gridmaps.

Figure 1c summarizes the sector-specific monthly profiles for each of the regional datasets. The temporal profiles are additive and specified with monthly factors modulating around 1/12 for each of the sectors. For the agricultural sector, EMEP provided compound-specific monthly factors, which are characterized by high NMVOC emission in spring and high CO emission in autumn. Agriculture (largely contributing to NH3 emissions) shows most seasonal variation, which differs also most between the different regions because of region-specific management practices (for e.g. crop cultivation), climate and geographical location and soil composition. The residential sector is characterized by a monthly distribution which is inversely related with the temperature and therefore with the use of heating systems, and in some developed countries with air conditioning (which is boosting emissions in some developed countries during hot summers). The seasonality remains relatively modest in all regions for the transport, industry and energy sectors.

The strongest variation over the year and between regions is observed for the agricultural sector (+215% in the EMEP-TNO profiles but only +45% in the MICS-Asia profiles), followed by the residential sector ([+70%, -75%] in the EMEP-TNO profiles, [+20%, -25%] in the US EPA profiles and [+115%, -40%] in the MICS-Asia profiles).

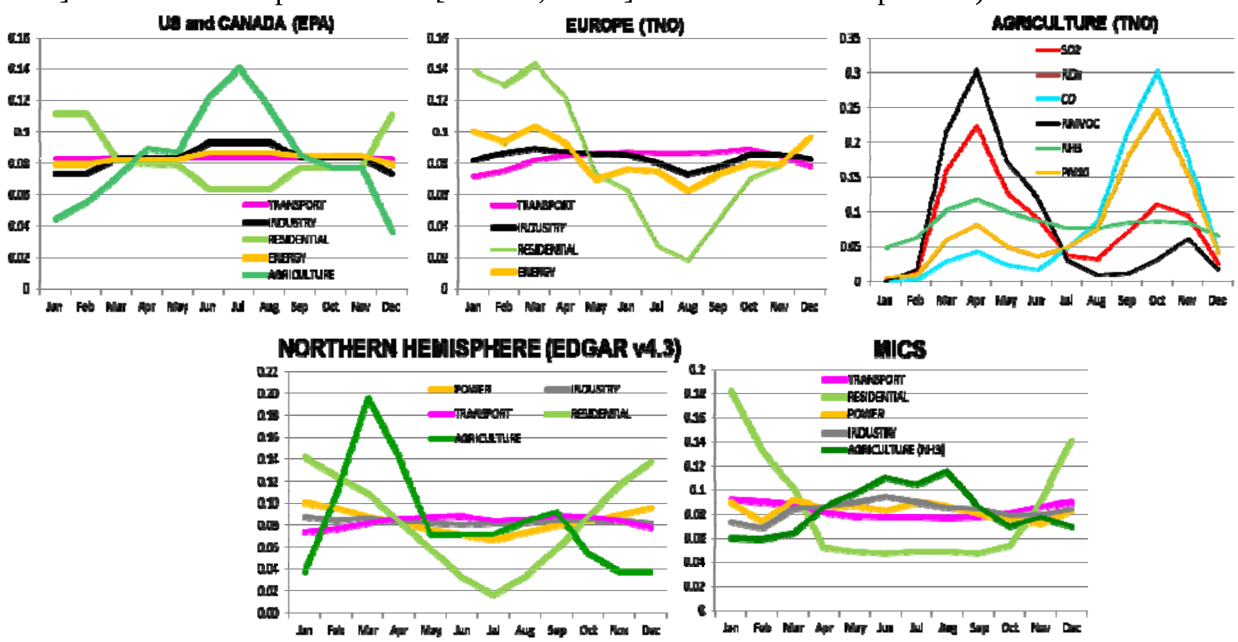


Figure 1c – Temporal profiles with relative factors varying around 1/12 and applied on the yearly emissions of the different data sources (US EPA for US and Canada, EMEP-TNO for Europe with compound-specific variation of the agricultural temporal profiles, EDGAR temporal profiles for the Northern hemisphere and MICS profiles for Asia).

Section 3.1:

Page 12882, Line 20: We reformulated as follows: “The Asian region is still characterized by a relative large contribution of SO2 from (coal fired) power plants and manufacturing industry.”

Page 12883, Line 3: The authors compared the International shipping emissions with the bottom-up and top-down estimated emissions reported in the "Third IMO GHG Study 2014" in Table 2a. We note that an agreement between the data of HTAP (EDGAR based), and IMO (both top down and bottom up estimates) is obtained for all compounds within 30% except for CO. The CO emission factor showed also in other inventories high uncertainty: the IMO (2009) used a more than twice as high emission factor than the new IMO study (2014). EDGAR shows a 55% and 70% higher estimate for the 2008 and 2010 than the bottom-up values of the IMO (2014) study, which on his turn is 55% respectively 33% higher than the 2008 and 2010 top down estimates of the IMO(2014) study. These observations and the IMO (2014) and IMO (2009) references are taken up in the main text of the paper.

Table 2a: Comparison of the international shipping emissions: IMO Bottom up (BU) and IMO Top Down (TD) emissions of the IMO(2014) study and the EDGAR emissions of the HTAP_v2.2 (2015) study.

kton /yr	BC	CO	NMVOC	NOx	OC	PM10	PM2.5	SO2
EDGAR 2008	34	1340	730	13762	458	1376	1376	8348
IMO BU 2008		864	727	20759		1545	1545	11041
IMO TD 2008		553	615	18442		1221	1221	8280
EDGAR 2010	33	1300	720	14000	430	1400	1400	8300
IMO BU 2010		763	593	16708		1332	1332	9895
IMO TD 2010		574	638	19098		1304	1304	9232

Section 3.2:
Pages 12886 – 12887: The authors consulted several trade databases to provide a quantitative indication of the consumption versus production-based emission inventories for sector 4_industry. With the World Input-Output Database, Boitier (2012) compared the production-based CO2 inventory with the consumption-based one and concluded a 14% higher emissions for OECD countries in 2008 (and even 23% for EU27) under the consumption-based approach and a 22% lower emissions for the BRIC countries (20% for China). This range (20% for Germany and 10% for USA whereas -10% for Brasil) matches also with the Global Trade Analysis data of Davis et al (2011). This affects the production-based inventory of air pollutants from the industry sector in a similar way, but probably more than linearly. For the air pollutants there is in addition a considerably lower emission factor of the industry in OECD countries than in developing countries because of an unequal implementation of end-of-pipe measures. Therefore the authors propose the following addition in the paper: “The importance of this consumption- versus production-based approach can be expected in 2008 (and also 2010) to be at least but probably even larger than what Boitier (2012) and Davis et al. (2011) amongst others reported for CO2. A consumption-based approach would yield at least 10% higher emissions for industrialised countries whereas 10% lower emissions for developing countries with emerging economy.”

Page 12887: Lines 3-4: Referee #1 points to a substantial difference between the per capita emissions of SO_2 of about 20%. This is indeed worth investigating. We downloaded the EUROSTAT data again and recalculated the per capita emissions. The 11.5 kg SO_2/cap of Eurostat is valid for 2008 and not for 2010. The 2010 value of EuroSTAT is 8.9 kg SO_2/cap, which is very close to our estimate of 9.1 kg SO_2/capita – the 0.2 difference can be due to different years of download (as different reporting years cause small fluctuations) as well as gapfilling by TNO for countries with incomplete time series, but is less than the range we get from using different reporting years. The large decrease of more than 2kg SO_2/cap between 2008 and 2010 is due to the large emission reduction in the (for some countries coal based) power industry (-26%) and a bit in industrial process industry (-16%).
The authors modified the sentence in the paper accordingly as: "For SO_2 the per capita emission in 2010 for EU-28 of 9.1 kg SO_2/cap is very close to the reported value of 8.9 kg SO_2/cap from EuroSTAT (2014) - the 0.2 difference is much less than the 20% higher per capita SO_2 emission in 2008 (11.5 kg SO_2/cap). EU's 9.1 kg SO_2/cap is about half the SO_2 per capita for China in 2010 and about one third of the SO_2 per capita for USA."

Section 3.3:
Page 12888, Line 15 and following: We reformulated the two sentences as follows: "The GDP is subject to heterogeneity (by the different economic activities), to heteroskedasticity (by the time-dependent inflation and currency exchange rates) and to incompleteness (by the not officially reported activities). It is not recommended to use this per unit of GDP emissions indicator for relative small countries with a substantial service sector (e.g. Luxembourg).

Section 3.4
The authors agreed to provide more details on the calculation of the implied emission factors. In fact, the lack of activity data for all data sources, except for EDGAR induced the following approximation of calculating the denominator of the formula with solely EDGAR activity data for that country and sector while accounting in the numerator the country- and sector-specific emissions as given by the original data source. Moreover the common HTAP sectors aggregated subsectors which are based on activity data with different units. This is mainly the case for the sector 4_Industry which accounts the combustion emissions (/TJ) and the process emissions (/ton product). With a commonly dominating energy-intensive industry (and a ratio of combustion over process emissions larger than 1), we opted to weigh the industry emissions with the energy needs (and as such partially skewed up the implied emission factor). But also the agricultural sector is skewed up, since we opted to weigh the total emissions of crop cultivation and of livestock with the number of animals elevated (mainly because 85% of the crops is used as animal food). We propose to clarify this in the text by clearly working out the formula for each of the sectors (indicating the use of EDGAR activity for all implied emission factors) and warning for a skewed up implied emission factor. We therefore replaced the single formula with the following:

$$EF_{C,3\_energy}(t,x) = \frac{\left.\sum_{sub\sec tor\ j} EM_{C,3\_energy,j}(t,x)\right|_{datasource\ of\ C}}{\left.\sum_{sub\sec tor\ j} AD_{C,3\_energy,j}(t)\right|_{EDGARv\ 4.3}} \quad [kton/TJ] \quad (1)$$

$$EF_{C,4\_ind.}(t,x) = \frac{\left.\left[\sum_{comb.\ sub\sec tor\ j} EM_{C,4\_ind.,j}(t,x) + \sum_{proc.sub\sec tor\ k} EM_{C,4\_ind.,k}(t,x)\right]\right|_{datasource\ of\ C}}{\left.\sum_{comb.\ sub\sec tor\ j} AD_{C,4\_ind.,j}(t)\right|_{EDGARv4.3}} \quad [kton/TJ] \quad (2)$$

$$EF_{C,5\_ransport}(t,x) = \frac{\left.\sum_{sub\sec tor\ j} EM_{C,5\_transport,j}(t,x)\right|_{datasource\ of\ C}}{\left.\sum_{sub\sec tor\ j} AD_{C,5\_transport,j}(t)\right|_{EDGARv\ 4.3}} \quad [kton/TJ] \quad (3)$$

$$EF_{C,6\_res.}(t,x) = \frac{\left.\left[\sum_{comb.\ sub\sec tor\ j} EM_{C,6\_res.,j}(t,x) + \sum_{waste\ prod.\ sub\sec tor\ k} EM_{C,6\_res.,k}(t,x)\right]\right|_{datasource\ of\ C}}{\left.\sum_{comb.\ sub\sec tor\ j} AD_{C,6\_res.,j}(t)\right|_{EDGARv4.3}} \quad [kton/TJ] \quad (4)$$

$$EF_{C,8\_agr.}(t,x) = \frac{\left.\left[\sum_{animal\ sub\sec tor\ j} EM_{C,8\_agr.,j}(t,x) + \sum_{crop\ sub\sec tor\ k} EM_{C,8\_agr.,k}(t,x)\right]\right|_{datasource\ of\ C}}{\left.\sum_{animal\ sub\sec tor\ j} AD_{C,8\_agr.,j}(t)\right|_{EDGARv4.3}} \quad [ton/head] \quad (5)$$

And we added in the main text (and in a footnote in the implied emission factors table): "It should be noted that the implied emission factors of sectors 4_industry, 6_residential and 8_agriculture are slightly skewed up because of an incomplete accounting of activity data which are for these sectors a combination of activities of different nature and as such expressed with different units. The emissions of sector 4_industry mainly originate from the energy-intensive subsectors and therefore are weighed with the energy needs (in TJ). We omitted the accounting of industrial process emissions, which are calculated per kton product manufactured. In sector 6_residential the waste is included, although calculated per kton dry or wet waste, which we could not combine with the residential energy consumption in TJ. The emissions of the 8_agricultural sector are weighed with the number of animals and not with the kton crops cultivated, because the crops serve for 85% as animal food and are therefore considered a justified measure of agricultural activity."

Results of implied emission factors in figure 4:

The authors recognized that statistics with small numbers are unreliable. Therefore the calculation of robust implied emission factor calculations was only carried out for larger countries with activities in all sectors. As such we left out the following countries:

For CO:

- for the htap_4_INDUSTRY sector: Togo, Eritrea, Congo, Côte d'Ivoire, Kenya, Benin.
- for the htap_6_RESIDENTIAL sector: Maldives.
- for the htap_5_TRANSPORT sector: North-Korea, Afghanistan, Laos, Tajikistan, Mongolia.

For SO2:

- for the htap_4_INDUSTRY sector: Namibia, Laos, Jamaica.

For NOx:

- for the htap_6_RESIDENTIAL sector: Maldives.
- for the htap_5_TRANSPORT sector: Afghanistan, Laos, North-Korea, Tajikistan.

For NMVOC:

- for the htap_3_ENERGY sector: Bhutan.
- for the htap_4_INDUSTRY sector: Togo, Eritrea, Côte d'Ivoire, Congo, Cameroon, Kenya, Benin, Aruba, Antigua, Bahamas, Ethiopia, Sudan, Senegal, Equatorial Guinea, Central African Rep., Sri Lanka, Angola, Mozambique, Zambia, Jamaica.
- for the htap_6_RESIDENTIAL sector: Am. Samoa, Gum, Maldives, Tonga.
- for the htap_5_TRANSPORT sector: Afghanistan, Laos, North-Korea.

For PM10:

- for the htap_4_INDUSTRY sector: Togo, Eritrea, Côte d'Ivoir, Congo, Kenya, Benin.
- for the htap_5_TRANSPORT sector: Afghanistan.

For PM2.5:

- for the htap_3_ENERGY sector: Tajikistan, Luxembourg.
- for the htap_4_INDUSTRY sector: Togo and Eritrea.
- for the htap_5_TRANSPORT sector: Afghanistan.

For BC:

- for the htap_3_ENERGY sector: Nigeria, Malaysia, Belgium, Oman, Finland, Georgia, Vietnam, Canada, Armenia, Tunisia, Jordan, The Netherlands, Trinidad and Tobago, Algeria, Latvia, United Arab Emirates, Brunei, Turkmenistan, Japan, Mozambique, Congo, Qatar, Bahrain, Moldova, Kyrgyzstan, South-Korea, Taiwan, Luxembourg, Bhutan, Tajikistan.
- for the htap_4_INDUSTRY sector: Trinidad and Tobago, Malta.
- for the htap_5_TRANSPORT sector: Afghanistan.

For OC:

- for the htap_3_ENERGY sector: Tunisia, Jordan, Trinidad and Tobago, Algeria, United Arab Emirates, Brunei, Turkmenistan, Tajikistan, Mozambique, Congo, Qatar, Bahrain, Kyrgyzstan, Taiwan, Myanmar, South-Korea, Vietnam.
- for the htap_4_INDUSTRY sector: Bahrain, Eritrea.
- for the htap_6_RESIDENTIAL sector: Greenland, Gibraltar, Faroe Islands, Saint Pierre et Miquelon

- for the htap_5_TRANSPORT sector: Afghanistan

For NH3:

- for the htap_8_AGRICULTURE sector: Faroe Islands, Tajikistan, Greenland, Falkland Islands, Kyrgyzstan, South-Korea, Brunei, Am. Samoa, Malaysia, Trinidad and Tobago, Bahamas, Saint Pierre et Miquelon, Sri Lanka, Suriname, Réunion, Thailand, Indonesia, Japan, Barbados, Bhutan, Guyana, Costa Rica

The authors propose to mention this list of countries in a footnote on Figure 4.

Page 12889, Line 13-15: We reformulated the text as follows: "It should be noted that emissions, in particularly those reported under country-specific point sources, are allocated to the reporting country solely, also for cells covering country borders. The areal fraction of these cells would incorrectly spread the emissions also to the neighboring country, which yield in the case of e.g. the power emissions for Canada up to 30% increase with the USA emissions along its borders."

Page 12890, Line 13-14: We reformulated the sentence as: "The high SO_2 implied emission factor (from EDGARv4.3) represents the use of lower quality fuels in sea transportation, especially in international waters: 85% of the sea bunker fuel in 2010 consists of residual fuel oil with an emission factor of 1.29 ton SO2 /TJ."

Section 3.5

The authors agree that the section should start mentioning where extrapolation in time has been undertaken. This was only done for Canada (US-EPA/Environ Canada) and for Europe (TNO-EMEP). Both regions were affected by the economic crisis of 2008, yielding stagnation and even downwards trends in the following years, mainly in the energy and industry sectors. The latter sectors are constructed for a large share by point source data, which were updated with the real estimates for 2010. As such, the emission gridmaps of 2010 are considered to represent also for Canada and Europe the actual 2010 estimates reasonably well. However every change for each country is not only caused by the change in activity but also and even more by the change in emission factor or implementation of end-of-pipe measures, which were occurring in some developing countries and caused relative large differences.

We propose to add in the beginning of section 3.5 (after the first sentence) the following paragraph: "It should be noted that the data provided for Canada by US-EPA/Environment Canada and for Europe by TNO were actually not representing 2010, but 2008 and 2009, respectively. However updates were undertaken: point source data of 2010 were used and implemented in the gridmaps. Both regions were affected by the economic crisis of 2008, yielding stagnation and even downwards trends in the following years, mainly in the energy and industry sectors. The latter sectors are primarily composed of point sources and as such the gridmaps of 2010 can be considered to represent also for Canada and Europe the actual 2010 situation."

We also reformulated the second last sentence after having (re) verified the increasing coal use: "For the developing countries (calculated with the EDGARv4.3 data and based on the IEA (2013) fuel statistics), the SO2 emissions of the energy sector slightly increase from 2008 to 2010 because of the increased coal use mainly in South-East Asia (as also observed by Weng et al., 2012) and the increased use of heavy fuel oil in the Middle East."

Section 3.6
By compiling the dataset with different data sources, it became apparent that at the borders of different datasets, large inconsistencies occur. As an example: the TNO-EMEP and MIX-Asia datasets cover respectively the European and the Asian part of Russia, but were showing ground transport emission differences of one order of magnitude. Even though both emission datasets are compiling a bottom-up inventory with similar methodology, different assumptions on emission factors and end-of-pipe measures can explain this. Therefore we opted to have single countries represented by the same dataset. However, each of the datasets used, calculates the emissions at country or county/province level and makes assumptions at this subregional level, which on its turn can lead to inconsistencies at the borders of each country/county/province.
This is clarified in the paper by modifying the introduction of section 3.6 as follows: "Even though the HTAP_v2.2 data sources are all bottom-up constructed inventories, they differ considerably in e.g. the assumptions taken on the modelling of technology and end-or-pipe measures and use different emission factors and quite different, and lead to inconsistencies at the borders between two adjacent inventories. On their turn the different bottom-up inventories are constructed with sub-regional (country, state, county or province level) activity data and emission factors. As such, inconsistencies can be expected at each country border and the variation of the emissions at cross-border cells gives already a first indication on the region- and sector-specific emission uncertainty.

Table 3
Even though the HTAP_v2.2 mosaic of final emission gridmap products does not allow for a full quantification of the error propagation, the authors agree that more information on the uncertainties can be provided in the main text of the paper. All data sources follow a similar methodology and face similar sources of uncertainty, which resemble the situation of the UNFCCC's CRF dataset of national inventories. Evaluation of their uncertainties by deterministic error propagation calculations or probabilistic Monte Carlo simulations has been addressed by e.g. Jonas et al (2010) (and references in there) and provides input on an uncertainty analysis of a bottom-up inventory per sector and per region. The GHG inventories are tackling with CO2 the combustion sectors, with CH4 also the agricultural (livestock and crops) and waste sectors and with N2O the industrial processes and agricultural sectors. The analysis for greenhouse gases is only a starting point, because for the air pollutants the emission factors strongly depend on the technology and end-of-pipe measures. Balsama et al. (2014) evaluated common behaviours between several species in the EDGARv4.2 data and observed that SO2 and NOx belong to the same cluster as CO2 (all strongly combustion related) and NH3 belongs to the same cluster as N2O.
The approach for assessing the CO2 uncertainty by Andres et al (2012), grouping countries on the basis of their statistical infrastructure was considered appropriate for the HTAP_v2.2 global dataset as well. Countries with well maintained statistical

infrastructure are the 24 OECD-1990 countries[1] as well as India - using the British statistical accounting system according to Marland et al. (1999). For the other countries, a larger range in uncertainty is present, for which we refer to Gregg et al. (2008) or Tu (2011) and Olivier (2002). For the annual CO2 inventory, the biofuel is carbon-neutral and not taken up, which leaves out a relative large source of uncertainty. For the N-related emissions, the division in countries could be based on the common agricultural practices of countries for which we refer to Leip et al (2011) and Rufino et al (2014). This explains the setup of Table 3 with qualitative indication of uncertainty ranges (using the terminology low (L), low medium (LM), upper medium (UM) or high (H)) for the different sectors and species.

In addition to the uncertainty of the activities, the quality and representativeness of the controlled emission factors play a crucial role. The standard range of uncertainty already varies according to the EMEP/EEA (2013) Guidebook's Uncertainties Chapter 5 for the absolute annual total of different pollutants between at least 10% for SO2, at least 20% for NOx and CO, at least 50% for NMVOC, an order of magnitude for NH3, and PM10, PM2.5, BC and OC. These considerations have been taken into account to indicate qualitatively a range for the different uncertainties (L, LM, UM, H).

For the combustion-related sectors is the uncertainty of the partially abated emission factor for air pollutants and in particular for aerosols larger than the uncertainty on the reported activity data, yielding a relative uncertainty that is larger than for CO2. In addition non-reported activities, in particular using non-reported biofuel or even rubbish, fall beyond this assessment and would need for an assessment the use of top-down derived emission estimates.

The Authors propose a shortening of the caption of Table 3 and the following addition in the main text of the paper: "Guidance on evaluation of emission uncertainties can be obtained from the evaluations of the national inventories reported to UNFCCC, addressed by e.g. Jonas et al (2010) (and references in there). With the evaluation of common behaviours between species in EDGARv4.2 of Balsama et al (2014) we propose the same approach of CO2 uncertainty assessment for SO2 and NOx (all driven by combustion-related activities), and the approach of N2O for NH3. As such Table 3 follows the grouping of countries by Andres et al (2012) and Marland et al (1999), based on their statistical infrastructure. Countries with well maintained statistical infrastructure are the 24 OECD-1990 countries plus India with a British statistical accounting system. For the other countries, a larger range in uncertainty is present, for which we refer to Gregg et al. (2008) or Tu (2011) and Olivier (2002). For the annual CO2 inventory, the biofuel is carbon-neutral and not taken up in the national inventories. However, for the air pollutants it is an additional large source of uncertainty, which is often not officially reported and as such missing. For the N-related emissions, the division in countries could be based on common agricultural practices (Leip et al, 2011 and Rufino et al, 2014).

In addition to the uncertainty of the activities, the quality and representativeness of the controlled emission factors play a crucial role. The standard range of uncertainty already varies according to the EMEP/EEA (2013) Guidebook's Uncertainties Chapter 5 for the absolute annual total of different pollutants between at least 10% for SO2, at least 20%

---

[1] Australia, Austria, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Ireland, Iceland, Italy, Japan, Luxembourg, The Netherlands, Norway, New Zealand, Portugal, Sweden, Turkey, and the United States

for NOx and CO, at least 50% for NMVOC, an order of magnitude for NH3, and PM10, PM2.5, BC and OC. These considerations have been taken into account to indicate qualitatively a range for the different uncertainties (using the terminology low (L), low medium (LM), upper medium (UM) or high (H)) for the different sectors and species."

Page 12891, Line 14: The HTAP modeling community is not only using the HTAP_v2.2 emission inventory but will also run the emission scenarios of ECLIPSEv5, which starts in 2010. The starting emission inventory (or base year inventory) of the ECLIPSEv5 scenarios is the important point of reference for all projections. Here we compare the ECLIPSEv5 emission inventory for 2010 with the HTAP_v2.2 2010 data, in order to evaluate how close the reference point is to the "officially accepted" regional inventories. We agree that the GAINS dataset can not be considered an external independent source of verification. The huge amount of information in GAINS on emission factors and reductions for certain technologies has also been flowing in the TNO-EMEP, MIX-Asia and EDGARv4.3 datasets. We added this to the paper.

Page 12892, Line 15: If for the same region two different data sources provide emission gridmaps for PM2.5 and PM10, it is not guaranteed that for each cell the flux of PM2.5 emissions is smaller than the flux of PM10 emissions and with non-compliance of the equation mass_PM2.5≤ massPM10. Another spatial proxy data set with and without point source can create a huge difference. The same applies for different data sources of BC and OC compared to PM2.5, for which BC+OC≤PM2.5 should hold. We reformulated this in the paper as follows: Another type of inconsistency in mass balance at grid cell level occurs when for the same region the data sources of the gridmaps for PM10 and PM2.5 or for PM2.5 and BC/OC are different. Already the application of different spatial proxy datasets (e.g. with and without point sources) results in an inconsistent allocation of multi-pollutant sources to different grid cells.

Page 12892, Line 24 – Page 12893, Line 3 has been rewritten as follows:
"Even though this mosaic inventory can not present the same consistency as one global bottom-up inventory, its extensive evaluation and use helped improving its quality. The evaluation was undertaken in particular in discussion with TNO and with US EPA to identify missing sources or misallocation of point sources. In addition the use of the dataset by global and regional climate and air quality modelers and the modelers' feedback (personal communications with L. Emmons of 5 November 2013 and D. Henze of 19 November 2013) were most useful and are further encouraged."

Page 12893, Line 6: The authors refer with the annotation "regionally accepted as reference" to the buy-in of each region for accepting this dataset as reference. The emission inventory for their region has been provided by their own regional inventory compilers. Therefore the dataset has a more official status than any global emission inventory that is not composed of regional inventories.
We propose to modify the sentence as follows: "This paper describes the HTAP global air pollutant reference emission inventory for 2010, which is composed of latest available data from regional inventory compilers."

Page 12893, Line 15: Indeed the sector-specific emissions are calculated according to the international standards such as IPCC/EMEP guidelines but for the activity data we needed to refer to consistent international statistics. The sentence is modified as follows: “Even though the HTAP_v2.2 dataset is not a self-consistent bottom-up database with activity data of consistent international statistics, with harmonized emission factors, and with global sets of spatial proxy data, it provides a unique set of emission gridmaps with global coverage and high spatial resolution, including important point sources.”

Figure 2
The captions for figure 2 are shortened with one single caption with: “Sector-specific breakdown of regional emission totals (Tg) for 2010: SO_2, NO_x, CO, NMVOC, PM10, PM2.5, BC, OC and NH_3”. The species name is placed within each sub-figure as suggested on top of the center of the Antartica region.

The sectors in Table 1b and used further in the main text of the paper (incl. the figures) are the same. The authors opted to use abbreviations which contain the names of the sectors as they are used in the figures: 1_AIR , 2_SHIPS, 3_ENERGY, 4_INDUSTRY, 5_TRANSPORT, 6_RESIDENTIAL and 8_AGRICULTURE. Table 1b and the main text of the paper has been modified accordingly.

“HTAP_v2: a mosaic of regional and global emission gridmaps for 2008 and 2010 to study hemispheric transport of air pollution” by G. Janssens-Maenhout et al., ACPD 15, C2857–C2864, 2015

The authors are grateful to Referee #2 for his interest and comments on the paper. We tried to improve the paper as requested with more details and data.

The modifications in reply to the comments of referee # 2 are highlighted “green” and “blue” in the paper.

Specific Comments

Page 12870, Lines 5-7 and Page 12890, Line 1-2. Referee # correctly indicates an incomplete wording in the abstract that leads to confusion. The authors meant that the energy and industry emissions of acidifying **gaseous** air pollutants differ strongly between industrialised and developed countries, whereas no such difference is observed in the acidifying gaseous air pollutant emissions from the residential sector. The authors agree that it is needed to mention explicitly SO2 and NOx to avoid confusion. Moreover the authors are happy to take up the suggestion of referee #2 to complete the abstract with the findings on the aerosols, which show almost the opposite effect. Large differences are not present in the energy (and industry) sector, but they are present in the residential sector.

The authors suggest to add in the abstract:

“An analysis of country-specific implied emission factors shows a large difference between industrialised countries and developing countries for acidifying gaseous air pollutant emissions (SO2 and NOx) from the energy and industry sectors. This is not observed for the particulate matter emissions, which show large differences between countries from the residential sector instead.”

Page 12879, Line 13: Raster-resample procedure and country totals in Table S1.1

At the time of compilation of the HTAP_v2.2, only monthly emission gridmaps, as the result, were delivered to the EDGAR team. We then applied the EDGAR table which allocates each grid cell to the country or countries it belongs to. Cells containing borders of countries allocate the area to the different countries with a percentage that reflects the areal coverage in the cell. This table works like a complete set of country masks. With the country masks, the EDGAR team derived also the country totals for the countries, which include a given error because of border issues. However, meanwhile the MICS-Asia team was so kind to deliver the original country totals, which have been compared in Table S1.3. This revealed that applying country masks to obtain country totals (as also done by modellers and e.g. in the ECCAD system) is only valid if the total emission value is larger than 0.2% of each of the country totals of the neighbouring countries. Otherwise a derived country-specific sector total that is 50% larger than the bottom-up one is observed, mainly in the energy sector with many point sources which are typically located on waterways or coastal areas, and end up in cross border cells. The latter caused derived sector totals for Kyrgyzstan, Tajikistan, Afghanistan, Laos, Myanmar,

Bangladesh, which deviated with one order of magnitude from the bottom-up totals. However, China shows good agreement between derived totals and bottom-up totals: within 5% for the energy sector, within 1.4% for Industry and Residential sectors, within 2.6% for the Transport and within 0.4% for the Agriculture sector. India idem: below 3% difference, with the exception of SO2, which differs 6% respectively 14% for the SO2 from the energy and transport sectors. All derived emissions are agreeing within 7% for Indonesia and within 12.5% for Thailand. Japan and South Korea show a bit more deviation of maximum 16.0% and 17.3%.
In Table S1.1: we replaced for the MICS-Asia region the previous values with the country totals received from the MICS-Asia team, to make the dataset more consistent. Now all the country totals are real bottom-up country totals and no longer with one part derived using a mask on a gridmap.
We added a more detailed explanation on the raster-resample procedure on Page 12879, Line 13: "As such, countries within the broad area, spanning from 89.875°N to 20.125°S in latitude and from 40.125°E to 179.875°E in longitude were inserted in the 0.1° x 0.1° emission gridmaps after converting the 0.25° x 0.25° with a raster resample procedure – dividing the cells in 5x5 and then aggregating the 0.05°x0.05° cells with 2x2.
The expertise in comparing the derived totals from the gridmaps with the real country bottom-up totals has been added in section 3.6: "It should be noted that derivation of country totals from the 0.1°x0.1° emission gridmaps (as e.g. done in the ECCAD system) is only valid if the country-specific total is larger than 0.2% of each of the totals of the neighbouring countries. Otherwise the derived country-specific sector total can be 50% larger than the bottom-up one, mainly in the energy sector with many point sources which are typically located on waterways or coastal areas and as such in cross border cells. Table S1.3 illustrates the deviations of derived country-specific sector totals to the bottom-up ones for the Asian region. The latter caused derived sector totals for Kyrgyzstan, Tajikistan, Afghanistan, Laos, Myanmar, Bangladesh, which deviated with one order of magnitude from the bottom-up totals. However, the relative small differences for China (≤5%), India (≤3% for all except for SO2 from energy where it is 14%), Indonesia (≤7%) and Thailand (≤12.5%), Japan (≤16.0%) and South Korea (≤17.3%) show a good agreement for the top 6 Asian emitters." (Table S1.3 is added in the supplementary.)

Table 1: names of the sectors and consistent use throughout the paper.
Referee # 2 correctly indicates an inconsistency in the naming of the sectors throughout the paper, which needs correction. The sectors in Table 1 and used further in the paper and in the figures are the same. The authors opted to shorten the name of the sectors in Table 1, and use the same names as used in the figures: 1_AIR , 2_SHIPS, 3_ENERGY, 4_INDUSTRY, 5_TRANSPORT, 6_RESIDENTIAL and 8_AGRICULTURE.

Page 12887, Lines 3-4: Referee #2 points to a substantial difference between the per capita emission of SO2 of about 20%. This is indeed worth investigating. We downloaded the EUROSTAT data again and recalculated the per capita emissions. The 11.5 kg SO2/cap of Eurostat is valid for 2008 and not for 2010. The 2010 value of EuroSTAT is 8.9 kg SO2/cap, which is very close to our estimate of 9.1 kg SO2/capita – the 0.2 difference can be due to different years of download (as different reporting years

cause small fluctuations) as well as gapfilling by TNO for countries with incomplete timeseries but is less than the range we get from using different reporting years. The large decrease of more than 2kg SO2/cap between 2008 and 2010 is due to the large emission reduction in the (for some countries coal based) power industry (-26%) and a bit in industrial process industry (-16%).
The authors modified the sentence in the paper accordingly as: ”For SO2 the per capita emission in 2010 for EU-28 of 9.1 kg SO2/cap is very close to the reported value of 8.9 kg SO2/cap from EuroSTAT (2014) - the 0.2 difference is much less than the 20% higher per capita SO2 emission in 2008 (11.5 kg SO2/cap). EU’s 9.1 kg SO2/cap is about half the SO2 per capita for China in 2010 and about one third of the SO2 per capita for USA.”

Table 2b: ranking of USA, Germany and China
The list of USA, Germany, China was based on the selection of the top CO2 emitters in 2010 of each of the three continents in the northern hemisphere. The ranking is a combination of the per capita activity and the level of implementation of end-of-pipe measurement technology. The activity level is best reflected by the per capita CO2 emissions, which is highest for USA explaining the high air pollutant emissions per capita. However China with lowest CO2 per capita is not having the lowest per capita air pollutant emissions, because of the level of technology and end-of-pipe implementation. To measure the latter we apply a kind of surrogate variable: the Human Development Indicator (2010) from UNDP(2015). This shows that Germany is more advanced and therefore having lower emissions per capita than China. In order to provide a more complete picture, the authors agreed to include the top 6 world CO2 emitters: China, USA, India, Russia, Germany and Japan.
For the paper we propose an extension of Table 2b with the CO2/cap and the HDI. Moreover we added the countries India, Russia and Japan.

Substance	USA	Germany	China	India	Russia	Japan
ton CO2(long cycle C) /yr/cap	17.6	9.9	6.4	1.5	11.9	9.7
HDI	0.91	0.9	0.7	0.57	0.77	0.88
kg SOx/yr/cap	32.6	5.2	21	8.0	31.9	5.2
kg NOx/yr/cap	43.6	14.2	20.8	7.9	25.1	14.5
kg VOC/yr/cap	43.1	11.9	16.9	14.0	26.9	9.1
kg CO/yr/cap	148.3	35.6	125.6	56.0	52.8	33.1
kg NH3/yr/cap	11.6	7.3	6.7	8.2	6.3	3.7
kg PM2.5/yr/cap	5.25	1.08	8.93	5.19	2.18	0.62
kg BC/yr/cap	0.95	0.20	1.29	0.85	0.29	0.16

In the main text of the paper, the findings of Table 2b are summarized in section 3.2 as follows:

The level of per capita air pollution results from a combination of the per capita activity and the level of implementation of end-of-pipe measurement technology. The activity level can be reflected by the per capita CO2 emissions, which is highest for USA explaining the high air pollutant emissions per capita. However not India with lowest CO2 per capita, but Japan and Germany are having the lowest per capita air pollutant emissions, because of the level of technology and end-of-pipe implementation. To measure the latter we apply a kind of surrogate variable: the Human Development Indicator (2010) from UNDP(2015). This shows that Germany and Japan are more advanced and have therefore lower emissions per capita for all air pollutants (except NH3 for Germany) and for the PM. We observe that the PM emissions per capita of Japan (0.16 kgPM2.5/yr/cap) are only 60% of those of Germany and Germany's one are about one fifth of the per capita emissions of the USA, which are on their turn only 60% of the per capita PM2.5 for China. Table S3 indicates that developing countries, in particular those with emerging economies but not yet fully penetrated clean technologies and end-of-pipe measures, have enhanced PM per capita emissions (China – 8.2 kgPM2.5/yr/cap, India – 5.2 kgPM2.5/yr/cap, Brasil – 3.1 kgPM2.5/yr/cap). Russia has relatively high per capita PM emissions (2.2 kg PM2.5/yr/cap because of fossil fuel production and consumption in the power sector, but much less than Canada (7.4 kg PM2.5/yr/cap), a much less populated country but with important fossil fuel production industry for export. Both countries, with important contribution in the Arctic region, show relatively high NMVOC and SO2 emissions (50.9 kg VOC/yr/cap and 48.7 kg SO2/yr/cap for Canada respectively 26.8 kg NMVOC/yr/cap and 31.9 kg SO2/yr/cap for Russia) due to their significant inland waterway transport using heavy residual fuel oil or diesel.

Air pollutant emissions per unit of GDP: extra Table 2c

Substance	USA	Germany	China	India	Russia	Japan
kg CO2(long cycle C) /yr/USD	339.71	287.79	240.88	136.6	644.58	267.08
GDP/cap	49307	39668	9230	4638	21663	34561
g SOx/yr/USD	0.668	0.132	2.310	1.719	1.482	0.150
g NOx/yr/USD	0.892	0.363	2.295	1.714	1.166	0.419
g VOC/yr/USD	0.882	0.305	1.863	3.013	1.249	0.263
g CO/yr/USD	3.036	0.910	13.830	12.069	2.449	0.957
g NH3/yr/USDP	0.236	0.187	0.735	1.770	0.291	0.108
g PM2.5/yr/USD	0.108	0.028	0.984	1.119	0.101	0.018
g BC/yr/USD	0.019	0.005	0.143	0.183	0.013	0.004

India's carbonaceous particulate matter emissions per unit of GDP are indeed higher than those of China, because of the per capita relative low GDP per capita and the use of less clean technologies. Those countries with relative high GDP per capita and

implementation of clean technology that score lowest are Germany and Japan with only 0.005 g BC per invested unit of GDP (USD PPP corrected in 2010).
This Table 2c and the following explanation are added to the paper: “In analogy with Table 2b, Table 2c provides for the world top 6 CO_2 emitters a comparison of the air pollutants per unit of GDP, which are linked to the country’s economic activity (in GDP per capita) and CO_2 per unit of GDP (measuring the energy intensive industry). It is directly apparent that again Germany and Japan are having high economic activity, with still important energy intensive industry but low air pollutant emissions per unit of GDP because of the investment in clean technology. On the other side, India has still much lower economic activity but nevertheless a much higher particulate matter emission per unit of GDP.”

More specific comments with the request for supporting information

Page 12882, Line 24-26: Based on the bottom-up inventory of MICS-Asia per sector and country, we observe that although India’s SO_2 emissions are only 32% of the Chinese one, the energy sector emits 67% of what the complete energy sector in China emits in SO_2. We modified the text as follows: “High annual SO_2 emissions are also observed for India, to which the energy sector contributes 59% and the energy-intensive manufacturing industry (iron & steel) 32%, both using also coking and bituminous coal according to IEA (2013).”

Page 12883, Line 8-10: Based on the data in Table S1.1, we observe a relative high contribution of the residential + industry sector for the total NO_x in Canada, but also The Netherlands and Norway. All are according to IEA(2013) characterized by a high percentage of natural gas in their fuel consumption for these sectors.
We reformulated the paragraph on NO_x with some more quantitative information as follows: “In Central and South America major emissions are attributed to the transportation sector and just to a minor extent to the energy sector (e.g. in Mexico 65% of the NO_x emissions originate from road transport). Those industrialised countries with a large share of natural gas as fuel for heating houses and commercial centres and for industry (such as Canada, the Netherlands, Norway) show relatively high emissions of NO_x: the share of the residential and industry NO_x emissions is around 30% of the total NO_x, whereas in USA this is only 20%.”

Page 12884, Line 7-9: Based on the data in Table S1.1 we addressed the observations on NMVOC with a quantification of the share. We also used underlying fuel statistics from IEA(2013), in particular to address the biofuel use and the charcoal production.
For the latter we summarized the data of 2008 and 2010 production for the top 3 charcoal producers in the table underneath, but which we feel that these fuel statistics fall outside the scope of the paper. In the Table underneath referee #2 can see that Brasil, Thailand and Kenya are (with distance from other producers) the world top 3. REAS2.1 however is not modeling charcoal production and therefore this emission source is missing for Thailand in HTAP_v2.2. In addition it is interesting that Brasil reduced considerably (to 46%) its charcoal production activity, whereas the other two countries kept a constant production.

The paragraph on NMVOC has been modified with a more balanced and quantitative description as follows: “In the Middle East NMVOC sources include oil production: the industry sector in Saudi-Arabia contributes 75% to its total NMVOC emissions. In China, particular high emissions are originating from industry (62%) and residential (27%), the latter also associated with the high use of solvents in paints. In Brazil particular high use of biogasoline is present resulting in a 52% NMVOC contribution of the transport sector. Also the production of charcoal is emitting strongly NMVOC and the world top 3 emitters (IEA, 2013) are Brasil, Thailand[2] and Kenya, which explains that their industry sector is contributing to the NMVOC total with respectively 35%, 37% and 80% in 2010.”

Table: TJ charcoal produced by the countries, which contribute more than 1% to the world total charcoal production (IEA, 2013)

TJ charcoal produced	Y_2008	Y_2010		share 2008	share 2010
Brasil	267549	122671.5		22.8%	11.8%
Thailand	137861	133779		11.7%	12.9%
Kenya	91168	96003.5		7.8%	9.2%
Sudan	53116	55135.5		4.5%	5.3%
South Africa	50204	51312		4.3%	4.9%
Tanzania	47340	48324.5		4.0%	4.6%
Ethiopia	35358	37360		3.0%	3.6%
Cote d'Ivoir	33664	35820.5		2.9%	3.4%
Nigeria	33264	34804		2.8%	3.3%
Angola	32894	34604		2.8%	3.3%
Zambia	31160	32708		2.7%	3.1%
Philippines	29221	29785.5		2.5%	2.9%
Ghana	21468	22330.5		1.8%	2.1%
Congo	20975	22391.5		1.8%	2.2%
Paraguay	20945	10659.5		1.8%	1.0%
Indonesia	20451	19911.5		1.7%	1.9%
Vietnam	17648	18079.5		1.5%	1.7%
Togo	16724	17525.5		1.4%	1.7%
Malaysia	15585	16139		1.3%	1.6%
Columbia	14815	14815		1.3%	1.4%
Senegal	14502	17276		1.2%	1.7%
Mozambique	13298	13899.5		1.1%	1.3%
Dominican Rep.	12104	12104		1.0%	1.2%

Page 12885, Line 11-16. We quantified the paragraph on text further as follows: “A decreasing trend from 2008 to 2010 is observed for Brazil due to decreases in emissions from charcoal production (with 23% share in the world production in 2008 and 12% in 2010, according to IEA, 2013). Emissions from charcoal production are also important for some African countries (Kenya, Sudan, South Africa, Tanzania, Ethiopia), with

[2] The charcoal production emissions for Thailand are missing because REAS2.1 is not accounting for this source.

country-specific shares in world production varying between 1.3% and 12.910% according to IEA (2013)."

Page 12885, Line 23-24: Indeed the coarse sector breakdown in fig. 2g does only show that the transport sector is mostly contributing. However the BC (controlled) emission factor is two orders of magnitude larger for diesel than for petrol (see Table underneath). Therefore the authors were confident to mention that these BC emissions are caused by the diesel transport.
Table: Emission factors for petrol and diesel vehicles (light duty, passenger car) with different types of end-of-pipe measures (as present in a European fleet).

fuel	vehicle	EOP			2008-2010	fuel	vehicle	EOP			2008-2010	EFpetrol/ EFdiesel
diesel	light duty	EU1	BC	kg/TJ	10.59147	petrol	light duty	EU1	BC	kg/TJ	0.05745	0.5%
diesel	light duty	EU2	BC	kg/TJ	9.35451	petrol	light duty	EU2	BC	kg/TJ	0.04532	0.5%
diesel	light duty	EU3	BC	kg/TJ	8.5041	petrol	light duty	EU3	BC	kg/TJ	0.03732	0.4%
diesel	light duty	EU4	BC	kg/TJ	4.25205	petrol	light duty	EU4	BC	kg/TJ	0.03732	0.9%
diesel	light duty	EU5	BC	kg/TJ	4.25205	petrol	light duty	EU5	BC	kg/TJ	0.03732	0.9%
diesel	light duty	no control	BC	kg/TJ	38.655	petrol	light duty	no control	BC	kg/TJ	0.07774	0.2%
diesel	light duty	pre EU	BC	kg/TJ	38.655	petrol	light duty	pre EU	BC	kg/TJ	0.07774	0.2%
diesel	passenger cars	EU1	BC	kg/TJ	14.813288	petrol	passenger cars	EU1	BC	kg/TJ	0.12405	0.8%
diesel	passenger cars	EU2	BC	kg/TJ	10.097136	petrol	passenger cars	EU2	BC	kg/TJ	0.08373	0.8%
diesel	passenger cars	EU3	BC	kg/TJ	6.95996	petrol	passenger cars	EU3	BC	kg/TJ	0.05681	0.8%
diesel	passenger cars	EU4	BC	kg/TJ	6.357456	petrol	passenger cars	EU4	BC	kg/TJ	0.05681	0.9%
diesel	passenger cars	EU5	BC	kg/TJ	6.357456	petrol	passenger cars	EU5	BC	kg/TJ	0.05681	0.9%
diesel	passenger cars	EU6	BC	kg/TJ	6.357456	petrol	passenger cars	EU6	BC	kg/TJ	0.05681	0.9%
diesel	passenger cars	no control	BC	kg/TJ	41.552	petrol	passenger cars	no control	BC	kg/TJ	0.12405	0.3%
diesel	passenger cars	pre EU	BC	kg/TJ	41.552	petrol	passenger cars	pre EU	BC	kg/TJ	0.12405	0.3%

We modified the sentence as follows: "Fig.2g shows that the largest contributing sector for BC in North America, Europe and the Middle East is road transport, which should be mainly from diesel vehicles given the much higher BC emission factor for diesel than for petrol."

Page 12886, Line 1-3: We quantified the shares of BC emissions of the industry and residential sector in China and India, and compared these with the shares in USA and Germany. We consulted the IEA (2013) fuel statistics and understood that the (bituminous) coal use in power plants, coke ovens, non-metallic minerals (cement) and even in the residential sector are causing this for China and the use of coal but also of solid biomass is causing the same high share in India.

Page 12886, Line 4-7. We quantified the shares of BC emissions of the residential sector in China and Russia. The emissions for Russia are calculated with EDGARv4.3 and all details are known. Therefore we comment the contribution of the different fuels in the residential sector in more detail, as taken from the EDGARv4.3 BC emissions of the Russian residential sector in the Table below. We consider it out of balance to include this detailed table in the paper but we updated the paragraph as follows: "The residential sector in China accounts for more than half (52%) of its BC total. Russia shows a similar high share of the residential sector (46%) to its total BC. Most important sources calculated in EDGARv4.3 for heating buildings in Russia include bituminous coal (57%), solid biomass (30%), lignite (6%) and industrial waste (3%) burning in the residential sector (for domestic housing as well as commercial services) (EC-JRC/PBL, 2011 and IEA, 2013)."

Table: Fuel-specific breakdown of the BC emissions from the residential sector of Russia in 2010 from EDGARv4.3 (EC-JRC/PBL, 2011)

type of building	fuel type	kton BC in 2010		
Farms	bituminous coal	1.14E-01		0.60%
Farms	diesel	6.66E-02		0.35%
Farms	industrial waste	8.57E-02		0.45%
Farms	lignite	1.08E-01		0.57%
Farms	LPG	2.07E-03		0.01%
Farms	natural gas	3.25E-03		0.02%
Farms	peat	2.86E-03		0.02%
Farms	solid biomass	8.80E-01		4.62%
Commercial services	BKB	8.79E-03		0.05%
Commercial services	bituminous coal	6.55E+00		34.38%
Commercial services	diesel	2.59E-02		0.14%
Commercial services	residual fuel oil	8.15E-03		0.04%
Commercial services	industrial waste	4.18E-01		2.19%
Commercial services	lignite	1.15E+00		6.04%
Commercial services	LPG	4.95E-03		0.03%
Commercial services	natural gas	1.01E-02		0.05%
Commercial services	Oven coke	1.73E-01		0.91%
Commercial services	solid biomass	2.27E+00		11.90%
Fisheries	bituminous coal	4.99E-03		0.03%
Fisheries	diesel	7.63E-03		0.04%
Fisheries	heavy residual fuel oil	1.57E-02		0.08%
Domestic housing	bituminous coal	4.23E+00		22.19%
Domestic housing	diesel	5.51E-03		0.03%
Domestic housing	heavy residual fuel oil	4.72E-03		0.02%
Domestic housing	lignite	1.65E-01		0.87%
Domestic housing	LPG	8.43E-02		0.44%
Domestic housing	natural gas	1.64E-01		0.86%
Domestic housing	peat	6.31E-03		0.03%
Domestic housing	solid biomass	2.48E+00		13.04%
	Totals	**1.90E+01**		

Page 12891, Line 2-3: The authors agree that a decrease in PM emissions from 2008 to 2010 in developing countries results from a combination of reduced activity and penetration of abatement technology. Only for the developing countries calculated with the EDGARv4.3 emissions database these two causes can be decoupled. Largest reductions over these two years were observed for Brasil, Mexico, Columbia, Venezuela, Kazakhstan, Cuba etc. in the industry (fuel transformation), energy and road transport sector. We added a table with the (sub)sectors contributing mostly to the reduction, demonstrating the relative reduction in activity and in (controlled) emission factor, as

modeled in EDGARv4.3. For the paper, we consider it most appropriate to mention only the two largest countries Kazakhstan and Brasil.
Table: Reductions in activity and in emission factor for some developing countries between 2008 and 2010 from EDGARv4.3 (EC-JRC/PBL,2011).

		(2010-2008)/2008	
developing country	activity	activity reduction	emission factor reduction
Brasil	charcoal production	-54.1%	-2.4%
Mexico	energy (bit. coal)	-13.9%	-2.5%
Columbia	energy (bit.coal)	6.3%	-9.0%
	charcoal production	0.0%	-1.0%
Kazakhstan	energy for coal mining	-44.9%	-3.9%
	power with lignite/coal	-11.1%	-30.9%
Venezuela	road transport	2.3%	-2.5%
Cuba	road transport	-43.0%	-2.5%
	energy (crude oil)	-5.9%	0%

In the paper we reformulated the last two sentence in this section with some more information as: “For the other developing countries (calculated with the EDGARv4.3 data and based on the IEA(2013) fuel statistics), the SO2 emissions of the energy sector slightly increase from 2008 to 2010 because of the increased coal use (as also observed by Weng et al., 2012) and the increased use of heavy fuel oil in the Middle East. The PM emissions from the energy and industry of some other developing countries show a decrease from 2008 to 2010, mainly due to the activity reduction but also in some cases due to the modelled decrease in controlled emission factor in EDGARv4.3. Largest reductions were seen for Brazil (with 54% reduction of its 2008 charcoal production) and Kazakhstan (11% reduction in coal power generation, which is modelled with a 31% decreasing BC emission factor).”

Reformulation of some sentence were undertaken, as suggested by referee #2 and resulted in:

Page 12870, Line 7-11: “The per capita emissions of all world countries, classified from low to high income, reveal an increase in level and in variation for gaseous acidifying pollutants, but not for aerosols. For aerosols an opposite trend is apparent with higher per capita emissions of particulate matter for low income countries.”

Page 12871, Line 5-9, “Responsibility of providing emission inventories to several international bodies is often distributed within a particular country: e.g. the methane inventory of some Annex I countries is provided by different national institutions. Although they represent the same region, they might be different, which is often the case and leads to confusion (Janssens-Maenhout et al., 2012).”

Page 12871, Line 24-27: “For example, the atmospheric modelling groups, which contributed to the HTAP multi-model experiments described in HTAP (2010), used their own best estimates for emissions for the year 2001, obtaining in some cases comparable global emissions (e.g. for NOx and SO2 model input), and sometimes getting larger differences in the model input (e.g. for NMVOC emissions)."

Minor comments

The authors made the typographic corrections as suggested on
Page 12872 (Line 5), Page 12875, Line 7, Page 12884, Line 20, Page 12885, Line 25, Page 12889, Line 7, Page 12890, Line 25, Page 12891, Line 17-18, Page 12904, Fig.1.

We prefer not to change the labeling of the agriculture with number 7, to avoid confusion with the former HTAP definitions. Agriculture was always number 8 but the former 7 and 4 are converted to 4. Therefore number 7 is no longer existing now.

The authors took the decision to refer to this database unambiguously as "HTAP_v2.2" and corrected this as such through the paper.

HTAP_v2.2: a mosaic of regional and global emission gridmaps for 2008 and 2010 to study hemispheric transport of air pollution

G. Janssens-Maenhout[1,*], M. Crippa[1], D. Guizzardi[1], F. Dentener[1], M. Muntean[1], G. Pouliot[2], T. Keating[3], Q. Zhang[4], J. Kurokawa[5], R. Wankmüller[6], H. Denier van der Gon[7], J.J.P. Kuenen[7], Z. Klimont[8], G. Frost[9], S. Darras[10], B. Koffi[1], M. Li[11,12]

[1]{European Commission, Joint Research Centre, Institute for Environment and Sustainability, Via Fermi, 2749, 21027 Ispra (VA), Italy}

[2]{U.S. EPA - Office of Research and Development, Research Triangle Park, North Carolina 27711, USA}

[3] {U.S. EPA – Office of Air & Radiation, 1200 Pennsylvania Av. NW, Washington DC 20460, USA}

[4] {Center for Earth System Science, Tsinghua University, Beijing, China}

[5] {Asia Center for Air Pollution Research, 1182 Sowa, Nishi-ku, Niigata, Niigata, 950-2144, Japan}

[6] {EMEP- Centre for Emission Inventory & Projection (CEIP), Federal Environment Agency, Spittelauer Lände, 5, 1090 Vienna, Austria}

[7] {TNO, Department of Climate, Air and Sustainability, Princetonlaan 6, 3584 CB Utrecht, The Netherlands}

[8] {International Institute for Applied Analysis, Schloßplatz, 1, 2361 Laxenburg, Austria}

[9] {NOAA Earth System Research Laboratory & University of Colorado/CIRES, Boulder, CO, USA}

[10] {Observatoire Midi-Pyrénées, CNRS, SEDOO, Toulouse, France}

[11] {Ministry of Education Key Laboratory for Earth System Modeling, Center for Earth System Science, Tsinghua University, Beijing, China}

[12] {State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing, China}

[*]{also at: Ghent University, Campus Ardoyen, Ghent-Zwijnaarde, Belgium}

Correspondence to: G. Janssens-Maenhout (greet.maenhout@jrc.ec.europa.eu)

Formatted: English (U.S.)

Abstract

The mandate of the Task Force Hemispheric Transport of Air Pollution (HTAP) under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) is to improve the scientific understanding of the intercontinental air pollution transport, to quantify impacts on human health, vegetation and climate, to identify emission mitigation options across the regions of the Northern Hemisphere, and to guide future policies on these aspects.

The harmonization and improvement of regional emission inventories is imperative to obtain consolidated estimates on the formation of global-scale air pollution. An emissions dataset has been constructed using regional emission gridmaps (annual and monthly) for SO2, NOx, CO, NMVOC, NH3, PM10, PM2.5, BC and OC for the years 2008 and 2010, with the purpose of providing consistent information to global and regional scale modelling efforts.

This compilation of different regional gridded inventories, including the Environmental Protection Agency (EPA)'s for USA, EPA and Environment Canada's for Canada, the European Monitoring and Evaluation Programme (EMEP) and Netherlands Organisation for Applied Scientific Research (TNO)'s for Europe, and the Model Inter-comparison Study for~~in~~ Asia (MICS-Asia III)'s for China, India and other Asian countries, was gap-filled with the emission gridmaps of the Emissions Database for Global Atmospheric Research (EDGARv4.3) for the rest of the world (mainly South-America, Africa, Russia and Oceania). Emissions from seven main categories of human activities (power, industry, residential, agriculture, ground transport, aviation and shipping) were estimated and spatially distributed on a common grid of 0.1° × 0.1° longitude-latitude, to yield monthly, global, sector-specific gridmaps for each substance and year.

The HTAP_v2.2 air pollutant gridmaps are considered to combine latest available regional information within a complete global dataset. The disaggregation by sectors, high spatial and temporal resolution and detailed information on the data sources and references used will provide the user the required transparency. Because HTAP_v2.2 contains primarily official

and/or widely used regional emission gridmaps, it can be recommended as a global baseline emission inventory, which is regionally accepted as a reference and from which different scenarios assessing emission reduction policies at a global scale could start.

An analysis of country-specific implied emission factors shows a large difference between industrialised countries and developing countries for acidifying gaseous ~~all~~ air pollutant emissions (SO_2 and NO_x) from the energy and industry sectors. This is ~~, but~~ not observed for the particulate matter emissions (PM_{10}, $PM_{2.5}$), which show large differences between countries in ~~from~~ the residential sector instead~~one~~. ~~A comparison of the population weighted emissions for all world countries, grouped into four classes of similar income, reveals that the per capita emissions are, with increasing income group of countries, increasing in level but also in variation for all air pollutants but not for aerosols.~~ The per capita emissions of all world countries, classified from low to high income, reveal an increase in level and in variation for gaseous acidifying pollutants, but not for aerosols. For aerosols an opposite trend is apparent with higher per capita emissions of particulate matter for low income countries.

1 Introduction

Intercontinental transport of air pollution occurs on timescales of days to weeks and, depending on the specific type of pollutant, may contribute substantially to local scale pollution episodes (HTAP, 2010). Common international understanding of global air pollution and its influence on human health, vegetation and climate, is imperative for providing a basis for future international policies and is a prime objective for the Task Force Hemispheric Transport of Air Pollution (TF HTAP)[1]. While nowadays many countries and regions report their air pollutant emissions, these estimates may not be readily accessible, or may be difficult to interpret without additional information, and their quality may differ widely, having various degrees of detail and being presented in different formats.

The UN Framework Convention on Climate Change (UNFCCC) requires official inventory reporting that complies with the TACCC principles of quality aiming at Transparency, Accuracy, Consistency, Comparability and Completeness[2], reviewed by UNFCCC roster

[1]More info on www.htap.org.

[2] Timeliness is recently also considered.

Formatted: Highlight

Formatted: Subscript, Highlight

Formatted: Highlight

Formatted: Subscript, Highlight

Formatted: Highlight

Formatted: Subscript, Highlight

Formatted: Highlight

Formatted: Subscript, Highlight

Formatted: Highlight

experts and made available at their website (UNFCCC, 2013). Under the CLRTAP the parties need to report emissions to the EMEP Centre for Emission Inventories and Projections (CEIP), which also reviews data on completeness and consistency. ~~Responsibility of providing emission inventories to several international bodies is often distributed within a particular country and so an inventory for, for example, methane can be provided by different organisations and although they represent the same region they might be different, in fact often are, leading to confusion we need to work with (Janssens-Maenhout et al., 2012).~~ Responsibility of providing emission inventories to several international bodies is often distributed within a particular country: e.g. the methane inventory of some Annex I countries is provided by different national institutions. Although they represent the same region, they might be different, which is often the case and leads to confusion (Janssens-Maenhout et al., 2012).

Formatted: Highlight

Currently available emission inventories differ in spatial and temporal resolution ("consistency"), in coverage of geographical area, time period and list of compounds ("completeness") and in the sector-specific details of the source calculation ("transparency"). Moreover the official inventories submitted by countries have at least one year time lag, are updated with different frequency and with or without review of the historical time series. The work of Lamarque et al. (2010) provides a unique example of a comprehensive 'composite' historical emissions dataset spanning from 1850 to 2000, ~~mainly based on scientific estimates~~ using a similar methodology of combining country level inventories for most OECD countries with research inventories for Asia and EDGAR for other regions. The dataset also provided harmonized base-year (2000) emissions that were used as a starting point for the development of the so-called RCP (Representative Concentration Pathways) emission scenarios (e.g. Moss et al., 2010; van Vuuren et al., 2011). For other years and specific model domains covering multiple regions, atmospheric modellers often compile their own emission inputs drawing upon different pieces of the available inventories. These compilations involve sometimes arbitrary choices, and are often not clearly described or evaluated. For example, the atmospheric modelling groups, which contributed to the HTAP multi-model experiments described in HTAP (2010), used their own best estimates for emissions for the year 2001, obtaining in some cases comparable global emissions (e.g. for NOx and SO2 model input), and sometimes getting larger differences in the model input (e.g. for NMVOC emissions). Moreover, Streets et al. (2010) evaluated the consistency of the emissions used in the various models and nationally reported emissions. For a follow-up study in HTAP Phase 2, it was

Formatted: Highlight

recommended to provide a harmonised emissions dataset for the years 2008 and 2010 in line with the following 4 major objectives:

1) To facilitate development of mitigation policies by making use of well documented national inventories;

2) To identify missing (anthropogenic) sources and gap-fill them with scientific inventories for a more complete picture at global scale;

3) To provide a reference dataset for further emission compilation activities (benchmarking or scenario exercises);

4) To provide a single entry point for consistent global and regional modelling activities focusing on the contribution of long-range (intercontinental) air pollution to regional air quality issues.

Formatted: Highlight

A harmonized global, gridded, air pollution emission dataset has been compiled with officially reported, gridded inventories at the national scale, to the extent possible and complemented with science-based inventories for regions and sectors where nationally reported data were not available.

Whereas for a preceding dataset[3] of EDGAR-HTAP_v1 the nationally reported emissions, combined with regional scientific inventories and gapfilled with the global set originating from EDGARv4.2 were all gridded with geospatial data from EDGAR (Janssens-Maenhout et al., 2012), this time we used regional gridded emissions, which are officially accepted and complemented with EDGARv4.3 gridmaps (Janssens-Maenhout et al., 2013) for countries or sectors without reported data.

The resulting dataset, named HTAP_v2.2, is a compilation of annual and monthly gridmaps of anthropogenic air pollution emissions (with a 0.1°×0.1° grid resolution). It contains region-specific information on human activity (concerning intensity and geospatial distribution) and

---

[3] EDGAR-HTAP_v1 completed in October 2010 comprises sector-specific annual gridmaps for the six years from 2000 to 2005 and covers air pollutants (CH4, CO, NH3, NMVOC, SO2 and NOx) and particulate matter with its carbonaceous speciation (PM10, PM2.5, BC and OC). The annual gridmaps of 0.1°x0.1° resolution are made available via http://edgar.jrc.ec.europa.eu/national_reported_data/htap.php and the CIERA and ECCAD servers. Documentation is available in the HTAP_v1 EUR25229EN report of Janssens-Maenhout et al (2012) (http://edgar.jrc.ec.europa.eu/htap/EDGAR-HTAP_v1_final_jan2012.pdf)

on fuel-, technology- and process-dependent emission factors and end-of-pipe abatement, but it is not as consistent as a globally consistent emission inventory using international statistics and global geospatial distributions. With the perspective of being used in chemical transport models, this inventory includes the atmospheric gaseous pollutants (SO_2, NO_x, CO, NMVOC[4], NH_3) and particulate matter with carbonaceous speciation (PM10, PM2.5, BC and OC)[5].

This paper provides a detailed description of the datasets and of the methodology used to compute the 0.1º×0.1º gridmaps for 2008 and 2010, which are delivered via the EDGAR JRC website (see Section 4). Section 2 defines the considered emitting sectors and presents the original data sources: a) the officially accepted regional/national gridded emission inventories, which were mainly provided by national and international institutions, and b) EDGAR_v4.3 for gap-filling the remaining regions and/or sectors for some substances. In the HTAP_v2.2 database, gridmaps were merged together with a "collage/mosaic" approach instead of gridding the global emission inventory with one single proxy dataset, as done in for the EDGAR-HTAP_v1 dataset compilation (Janssens-Maenhout et al., 2012). The HTAP_v2.2 inventory aims to obtain more local accuracy on the location of single point sources compared to the previous HTAP_v1, but the downside is that a consistent single location of a specific source of multi-pollutants is no longer ensured, when data originated from different sources, possibly leading to spurious chemical reactions involving non-linear chemistry in the air quality models. Section 3 discusses the resulting gridmaps and addresses the contents of the HTAP_v2.2 compilation methodology, the assumptions, dataflows and consistency of the data used to create the global gridmaps. Whereas HTAP_v2.2 uses more regional bottom-up data (local information on emission factors, on assumed penetration of

[4] The non-methane volatile organic compounds (NMVOC) of HTAP_v2.2 are defined as the total sum of Alkanols, Ethane, Propane, Butanes, Pentanes, Hexanes and higher, Ethene, Propene, Ethyne, Isoprenes, Monoterpenes, Other alk(adi)enes/alkynes, Benzene, Methylbenzene, Dimethylbenzenes, Trimethylbenzenes, Other aromatics, Esters, Ethers, Chlorinated hydrocarbons, Methanal, Other alkanals, Alkanones, Acids, Other Aromatics, all expressed in their full weight, not just C.

[5] Whereas PM10 is defined as primary emitted aerosols with aerodynamic diameter up to 10 micrometer, PM2.5 is a subset with aerodynamic diameter up to 2.5 micrometer, including elemental carbon (BC), organic carbon (OC), $SO4^{2-}$, $NO3^{1-}$, crustal material, metal and other dust particles. Note that BC and OC are additive to each other but not to PM2.5 ($\{BC,OC\} \subset \{PM2.5\}$ and $\{PM2.5\} \subset \{PM10\}$).

technology and end-of-pipe control measures in the facilities), the higher spatial accuracy is sometimes overshadowed by artefacts at borders- at least when graphically displaying the data. This is followed with an evaluation of the HTAP_v2.2 by comparing per capita emissions, emissions per unit of GDP and implied emission factors for the different countries. The concluding section 4 summarises the purposes, content and access to this dataset that is currently in use by the HTAP modellers community.

2 Methods

2.1 Defining the sector-specific breakdown

An overview of the data sources used is given in Table 1a. For the development of HTAP_v2.2, a detailed cross-walk table of the US EPA, EDGAR and EMEP (sub)sector-specific activities has been setup, using all human activities defined in detail by IPCC (1996) and applied for the reporting under the UNFCCC. The US EPA and the contributing dataset from Environment Canada, provided the most detailed cross-walk matrix between the categories used in their national inventory and the full-fledged set of all IPCC categories. However, a higher level of aggregation was needed to find a common basis with the Asian emission inventories, which led to the establishment of the 7 categories: Aircraft, International Shipping, Power Industry, Industry, Ground Transport, Residential and Agriculture (described in Table 1b underneath).

HTAP_v2.2 focusses only on anthropogenic emissions, in a comprehensive way, but excludes large-scale biomass burning (forest fires, peat fires and their decay) and agricultural waste or field burning. We refer to inventories such as GFED3 (van der Werf, 2010) for the forest, grassland and Savannah fires (IPCC categories 5A+C+4E) and to the $1^{\circ}x1^{\circ}$ gridmaps of Yevich ~~et~~and Logan (2003) or the $0.1^{\circ}x0.1^{\circ}$ EDGARv4.2 gridmaps (EC-JRC/PBL, 2011) for the agricultural waste burning (4F). Moreover, only NH3 emissions from the agricultural sector were taken up in the htap_8_AGRICULTURE sector of HTAP_v2.2 inventory, so that the occasionally reported NOx from agricultural waste burning or from biological N-fixation and crop residues (which is typically considered under S10 for Europe) are excluded.

Formatted: Highlight

Formatted: All caps

2.2 Gridded input datasets for HTAP_v2.2

As explained earlier, the goal of the HTAP_v2.2 inventory is to provide consistent and highly resolved information (see Fig. 1a) to global and regional modelling. It is important to realize that in the HTAP modelling exercise both global and regional models are participating. The HTAP global modelling is coordinated with the regional modelling exercise of Air Quality Model Evaluation International Initiative AQMEII (Galmarini et al., 2012 and 2015) that manages regional scale activities for Europe and North America, and the regional modelling exercise of the Model Intercomparison study for Asia MICS-Asia (Carmichael et al., 2008) that manages the regional modeling over Asia. Hence, the regional inventories used for HTAP_v2.2 are constructed and used in accordance with these regional activities.

2.2.1 USA and Canada: EPA and Environment Canada gridmaps and EPA temporal profiles

EPA (2013) provides the 2008 and 2010 areal and point source emissions for the complete North American domain at 0.1°x0.1° resolution, covering USA with a grid ranging from 180°W-63°W in longitude and 75°N-15°N in latitude and covering Canada with a grid from 142°W-47.8°W in longitude and 85°N-41°N in latitude. Mexico is not covered by these latitudes and it is gapfilled with EDGARv4.3 data (see section 2.2.4). For the northern latitudes above 45°N, Environment Canada provided the 2008 basis and an update of the point sources for 2010, from which US EPA prepared the full set of detailed gridmaps also for 2010. The 2010 data for Canada were missing and as such extrapolated by US EPA based on the 2008 National Emission Inventory of Environment Canada and assuming no trend but using updated point sources (Pouliot et al., 2014). The temporal profiles of US EPA were applied for USA and Canada with identical monthly distributions per sector for 2008 and 2010. More details about the US inventory are given by Pouliot et al. (2014) and (2015).

Formatted: Highlight

2.2.2 Europe: TNO gridmaps and EMEP temporal trends

Countries that are parties to the CLRTAP (http://www.unece.org/env/lrtap) need to report anthropogenic emissions of air pollutants and particulate matter, but neither BC nor OC. These reported/official inventories are reported on the national level to EMEP-CEIP[6] which

[6] More info on www.ceip.at.

provides the annual emission inventory data for CO, NH3, NMVOC, NOx, SOx, PM10 and PM2.5 (not BC and not OC). However, the currently used EMEP grid uses a polar-stereographic projection with about 50km x 50km grid cells centered over the European region and converting to a Mercator projection implied a loss of spatial accuracy. These reported data are incomplete according to the CEIP annual report of Mareckova et al. (2013) and for evaluation with the EMEP unified model further gapfilling is needed, resulting in a semi-official emission dataset. To overcome the problems of inconsistent emissions time series and fulfil the need for a higher spatial resolution to support AQ modelling in Europe in the European FP7 project Monitoring Atmospheric Composition and Climate (MACC), TNO established a scientifically complete and widely accepted dataset, which is fully documented by Kuenen et al (2014). This so-called TNO-MACC-II inventory of Kuenen et al (2014) covers the same European domain with areal and point source emission gridmaps at 1/8° x 1/16° resolution for SO2, NOX, CO, NMVOC, NH3, PM10, PM2.5 with point sources allocated to their exact location. The grid-domain ranges from 30°W-60°E in longitude and 72°N-30°N in latitude. The geographical area covered all EU-28 countries, Switzerland, Norway, Iceland and Liechtenstein, Albania, Bosnia-Herzegovina, Serbia, Macedonia, 6 Newly Independent States (Armenia, Azerbeijan, Belarus, Georgia, Moldova, Ukraine) and Turkey. EMEP-TNO data for ~~C~~countries with only partial coverage (Russia, Turkmenistan, Kazakhstan and Uzbekistan) were not used in the HTAP_v2.2 inventory because of inconsistencies with other datasets (see section 2.2.4). Sector-specific data (given by SNAP-code, see Table 1b) are used for all countries with complete coverage of their territory and for each substance the contribution from each sector is compared to EMEP and EDGARv4.3 estimates. Standard re-sampling is applied to obtain gridmaps at the common resolution of 0.1°x0.1°. Point-source, ground-level airport emissions in the transport sector (under SNAP 8) were taken out, in order to avoid a double counting with the aviation sector (HTAP–1_AIR), for which the same geospatial dataset taken from EDGAR_v4.3 was used globally.

The EMEP-TNO data were only available for 2006 and 2009. The 2008 data for Europe is based on the EMEP-TNO data for 2009 data and the 2010 data for Europe are based on the same 2009 data but using the trend in EMEP-TNO data between 2006 and 2009.

Formatted: Highlight

Formatted: Highlight

For NH3, the reporting of emissions from the energy, industry and residential sectors was apparently negligible for some countries[7] compared to the agricultural emissions and was therefore not gapfilled by EMEP and/or TNO.

BC and OC emission data are not available as emission gridmaps within the MACC-II dataset, but the PM gridmaps are accompanied by a recommendation on the PM composition describing the carbonaceous profiles per SNAP code and country. This so-called PM split table (per SNAP code and country) of TNO (TNO, 2009) is used to derive the BC and OC from PM10 and PM2.5 emission gridmaps (see Kuenen et al. (2014) for details).

Finally, to derive the monthly gridmaps the EMEP modelling group provided ~~we used the country-specific and sector-specific data~~ the monthly profiles, which are with a monthly factors varying around 0.0833~~1/12~~ specified for each country and for each sector, with a further substance-specific variation for the agricultural sector~~ per substance for the EMEP model~~ (personal communication with M. Schulz of 27 May 2013 and A. Nyiri of 4 June 2013).

Formatted: Highlight

2.2.3 Asia: monthly gridmaps from MIX

For Asia, a different challenge is faced, because no countries except Japan are legally required to yearly report detailed emission inventories under the LRTAP, UNFCCC or similar conventions. However, in Asia many scientific efforts aimed at establishing a detailed emission inventory, accepted by the different regions, using official or semi-official statistics collected at county level (by provinces for China). Under the Model Inter-comparison Study for Asia Phase III (MICS-Asia III), a mosaic Asian anthropogenic emission inventory was developed for 2008 and 2010 (Li et al., 2015). The mosaic inventory, named MIX, incorporated several local emission inventories including the Multi-resolution Emission Inventory for China (MEIC), NH3 emission inventory from Peking University (Huang et al., 2012), Korean emissions from the Clean Air Policy Support System (CAPSS) (Lee et al., 2011), Indian emissions from the Argonne National Laboratory (Lu et al, 2011), and fill the

[7] No NH3 emissions are reported in the energy sector: for the countries Albania, Bosnia-Herzegovina, Cyprus, Estonia, Greece, Ireland, Iceland, Luxembourg, Latvia, FRY Macedonia, Malta, Norway, Poland, Romania, Slovakia, and Slovenia; in the industry sector for the countries Albania, Bosnia-Herzegovina, Greece, Ireland, Iceland, and FRY Macedonia; and in the residential sector for the countries Greece, Iceland and Slovenia.

gap where local emission data are not available using REAS2.1[8] developed by Kurokawa et al. (2013).

MEIC is developed by Tsinghua University under an open-access model framework that provides model-ready emission data over China to support chemical transport models and climate models at different spatial resolution and time scale. In the MIX inventory, the MEIC v.1.0 data was used which contains the anthropogenic emissions of China for SO2, NOx, CO, NMVOC, NH3, CO2, PM2.5, PMcoarse, BC, and OC for the years 2008 and 2010 with monthly temporal variation at 0.25° x 0.25°. For India, MIX used the Indian emission inventory provided by ANL for SO2, BC, and OC and REAS2.1 for other species. With the input from different regions, the MIX inventory provided harmonized emission data at 0.25° x 0.25° grid resolution with monthly variation for both 2008 and 2010. The detailed mosaic process of the MIX inventory is documented in Li et al. (2015). Reported emissions from countries which are only partly covered by the MIX, like Russia, Turkmenistan, Uzbekistan and Kazakhstan were not taken up in the HTAP inventory and instead gap-filling by EDGARv4.3 was used (see section 2.2.4).

As such, countries within the a broad area, spanningranging from 89.875°N to 20.125°S in latitude and from 40.125°E to 179.875°E in longitude were inserted in the as after a raster resample procedure covered by 0.1° x 0.1° emission gridmaps after converting the 0.25° x 0.25° with a raster resample procedure – dividing the cells in 5x5 and then aggregating the 0.05°x0.05° cells 2x2. Monthly gridmap results (without distinction between point and areal sources and without temporal profiles) are given per sector (energy, industry, residential, transport, and agriculture only for NH3).

2.2.4 Rest of the world covered by EDGARv4.3

The Emission Database for Global Atmospheric Research (EDGAR) of EC-JRC/PBL (2011) provides historical (1970-2008) global anthropogenic emissions of greenhouse gases[9] CO2,

[8] The REAS2.1 inventory for Japan includes the data developed by Ministry of the Environment of Japan (MOEJ, 2009) for NMVOC evaporative emissions from stationary sources, the database developed by the Ocean Policy Research Foundation (OPRF, 2012) for the maritime sector, and the Japan Auto-Oil Program Emission Inventory-Data Base (JEI-DB) developed by Japan Petroleum Energy Center (JPEC, 2012a, b, c) for other sources.

Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight

CH4, N2O, HFCs, PFCs and SF6, of precursor gases, such as CO, NOx, NMVOC and SO2 and of aerosols (PM10), including PM10, PM2.5, BC and OC per source category at country level on 0.1° x 0.1° gridmaps. This dataset is in the version EDGARv4.3 extended to with the years 2009 and 2010 in EDGARv4.3 and covering with the carbonaceous speciesalso the substances PM2.5, BC and OC. For HTAP_v2.2 a preliminary version of the EDGARv4.3 (JRC-EC/PBL, 2015) is used. Emissions are calculated by taking into account human activity data of IEA (2013) for fuel consumption and of FAO (2012) for agriculture, different technologies with installed abatement measures, uncontrolled emission factors (IPCC, 2006) and emission reduction effects of control measures (EMEP/EEA, 2013). Anthropogenic emissions calculations are extended till 2010 for all 246 world countries for the emission source (sub)groups; (i) combustion/conversion in energy industry, manufacturing industry, transport and residential sectors, (ii) industrial processes, (iii) solvents and other product use, (iv) agriculture, (v) large scale biomass burning, (vi) waste and (vii) miscellaneous sources. A detailed overview of the EDGAR emissions database and how it can be used for gapfilling can be found in Balsama et al (2014).

The EDGAR emission data are spatially distributed using an extensive set of global proxy data, which are representative for major source sectors and documented in the EDGAR gridding manual of Janssens-Maenhout et al. (2013). For HTAP_v2.2, the EDGARv4.3 database provides yearly emission gridmaps with a resolution of 0.1x0.1 degree for the "rest of the world" countries of Table ASl.2 of Annex I in the Supplement for all pollutants (SO2, NOx, CO, NMVOC, NH3, PM10, PM2.5, OC, BC) and HTAP sectors for the years 2008 and 2010. The htap_2 SHIPS data are provided for the entire world, while the htap_1 AIRAviation data are provided for the entire world for the international aviationpart and for the world excluding USA and Canada for the domestic aviation. EDGAR provides also sector-specific monthly profiles, defined with first order -guestimated factors for each of the three different zones: Northern Hemisphere, Equatorial region and Southern Hemisphere (Table SA1.2). A reverse profile is applied for the two Hemispheres from the EDGAR v4.3 database, while no seasonal pattern is used for the Equatorial regions. Monthly emissions gridmaps are generated from the annual emission data per HTAP sector using these EDGAR

Formatted: Highlight

Formatted: Highlight

Formatted: All caps

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

---

[9] The methodology for the greenhouse gas emission time series applied in EDGARv4.2 is detailed in Olivier and Janssens-Maenhout (2012).

monthly factors, which res~~s~~emble most to the EMEP-TNO profiles (see section 2.3) ~~defined for the three different zones: Northern Hemisphere, Equatorial region and Southern Hemisphere (Table A1.2)~~.

The countries with partial geo-spatial coverage under the MACC-II and MIX inventories (see sections 2.2.2 and 2.2.3) are completely replaced with EDGARv4.3 data to avoid inconsistencies and artefacts at the border between two datasets within one country (such as Russia, Kazakhstan, Turkmenistan and Uzbekistan). This replacement took place after the gridmaps were converted into 0.1° x 0.1° using a raster resampling procedure. For EMEP-TNO the resampling implied a 25-fold division to 0.0025°x0.0125° followed by an aggregation of 4x8 gridcells. For ~~the MICS-Asia~~MIX the resampling needed also a 25th fold division to 0.05°x0.05° followed by an aggregation of 2x2 gridcells. The cells including country borders are split up and allocated to the different countries using the corresponding areal percentage.

2.3 Overview of the temporal profiles used in HTAP_v2.2

The modulation of annual emissions over time is necessary in order to provide the modelers emission data consistent with the seasonal pattern and activities. Monthly data were generated for all sectors except for the international shipping and international aviation, which are considered constant over the year. US-EPA, EMEP and EDGAR provided monthly profiles, but MIX~~CS-Asia~~ provided directly and solely monthly emission gridmaps.

Figure 1c summarizes the sector-specific monthly profiles for each of the regional datasets. The temporal profiles are additive and specified with monthly factors modulating around 1/12 for each of the sectors. For the agricultural sector, EMEP provided compound-specific monthly factors, which characterise high NMVOC emission in spring and high CO emission in autumn. Agriculture (largely contributing to NH3 emissions) shows most seasonal variation, which differs also most between the different regions because of region-specific management practices (for e.g. crop cultivation), climate and geographical location and soil composition. The residential sector is characterized by a monthly distribution which is inversely related with the temperature and therefore with the use of heating systems, and in some developed countries with air conditioning. In some developed countries with hot summers, the air conditioning is again boosting emissions during the summer. The seasonality remains relatively modest in all regions for the sectors transport, industry and energy.

The strongest variation over the year and between regions is observed for the agricultural sector (+215% in the EMEP-TNO profiles but only +45% in the MIX~~MICS-Asia~~ profiles), followed by the residential sector ([+70%, -75%] in the EMEP-TNO profiles, [+20%, -25%] in the US EPA profiles and [+115%, -40%] in the MIX~~MICS-Asia~~ profiles).

3 Results

Monthly global gridmaps were produced for 2008 and 2010 and are available per htap sector and substance at http://edgar.jrc.ec.europa.eu/htap_v2/index.php?SECURE=123. —We describe major characteristics of the gridmaps in section 3.1. We focus on 2010 but the observations remain valid for 2008 (in the same period of recession). A summary graph of the emission totals and their sector-specific composition is given in Fig. 1b. In sections 3.2 and 3.3 we put the country totals (given bottom-up except for the MICS-Asia regions, where we derived the totals from the gridmaps) in perspective with a comparative analysis of the emissions per capita and emissions per GDP for low, lower middle, upper middle and high income country groups. To estimate how polluting the activities are in the different regions, section 3.4 addresses the implied emission factors. Finally, we address the difference in emissions 2008 to 2010 in section 3.5 and we conclude with a qualitative assessment of the uncertainty of the gridmaps in 3.6.

3.1 Spatial distribution of global emissions per sector

An overview on the region-specific totals and the composition per region and sector is given in the 9 maps of Fig. 2a-i for the different substances for the year 2010. The sector-specific country-totals are given in Table ~~A~~S1.1 and the totals for each of the 16 HTAP source region, as defined for the source-receptor calculations of the HTAP modelling community and described in Table S~~A~~2.1 are given in Table S~~A~~2.2 of Annex II in the Supplement. Before focusing on the emissions over land surface, we assess the global shipping emissions. Table 2a. compares the international shipping emissions with the bottom-up and top-down estimated emissions reported by IMO (2014). We note that an agreement between the data of HTAP (EDGAR based), and IMO (both top down and bottom up estimates) is obtained for all compounds within 30%, except for CO. For the latter EDGAR shows a 55% and 70% higher

Formatted: Highlight

Formatted: Highlight

estimate for the 2008 and 2010 bottom-up values of the IMO (2014) study, which on his turn is 55% respectively 33% higher than the 2008 and 2010 top down estimates of the IMO(2014) study. It is worth mentioning that a 250% downscaling of the CO emission factor was undertaken in IMO (2014) compared to the previous study of IMO (2009).

Developing countries contribute from 70% to more than 90% to the current global anthropogenic pollutant emissions, depending on the considered compound and Asian countries are the major emitters, contributing from 40% to 70%. Among these countries, China and India represent two densely populated regions, producing together more than two thirds of the total Asian emissions. On the contrary, developed regions (like North America and Europe) produce much lower emissions, representing overall from 30% down to 10% of the total annual global anthropogenic emissions. Since the rest of the world group of countries includes a variety of regions, differing in population, human activities, types of industries, etc., it is crucial to disaggregate it into its components. In particular for PM2.5 and somewhat less for NOx, Asia strongly contributes to the global emissions compared to the contribution of North America and Europe.

Generally, higher emissions are observed for populated areas and coastal regions, but specific features can be highlighted depending on the pollutant and activity for specific countries per substance. The differences of the figures 2a-2i in the sector-specific composition (pie charts) of the emission sources for world regions (represented by the color scale) vary strongly between compounds. Some of the factors include:

- For SO2 the emissions will depend on the importance of coal used in the industry and residential sectors and the degree of flue gas desulphurization. In some regions non-ferrous metals industry will be of great importance.
- For NOx emissions industrial combustion and transport are key and with increasing level of activity the application of end-of-pipe controls, including catalytic reduction of flue gases, is playing an ever increasing role.
- CO and NMVOC emissions are dominated by incomplete combustion (cooking and heating stoves) and transport, especially in absence of advanced controls. For NMVOC additionally evaporative losses from solvent use and oil industry are of high relevance.

- Finally for PM, incomplete combustion (stoves) and in developing countries poor efficiency of filters installed on industrial boilers can be a source of large emissions while more recently transport emissions from diesel engines became of concern.

SO2

The Asian region ~~keeps sufferingi~~s still characterised by ~~from~~ a relative large contribution of SO2 from (coal fired) power plants and manufacturing industry. Most of the SO2 emitted in North America and Europe comes from coal power plants. However, in Europe Fig. 2a shows that SO2 is also emitted from the residential and waste disposal sector. Residential (heating and cooking) and waste disposal sources are particularly relevant in Africa. High annual SO2 emissions are also observed for India, to which the energy sector contributes 59% and the energy-intensive manufacturing industry (iron & steel) 32% ~~and correspond to high contributions from the industrial combustion~~, both using also coking and bituminous coal ~~in the power and iron & steel industry~~ according to IEA (2013). Finally, international shipping contributes ~10% to the global SO2 emissions. SO2 gridmaps clearly show the ship emission tracks connecting Asia and Europe with Africa and America.

NOx

Figure 2b shows that the major sources of NOx are ground transport and power generation and these source contributions show a rather uniform feature for all the considered regions. In Central and South America major emissions are attributed to the transportation sector and just to a minor extent to the energy sector (e.g. in Mexico 65% of the NOx emissions originate from road transport). Those industrialised countries with a large share of natural gas as fuel for heating houses and commercial centres and for industry (such as Canada, the Netherlands, Norway) show relatively high emissions of NOx: the share of the residential and industry NOx emissions is around 30% of the total NOx, whereas in USA this is only 20%. International shipping and, in particular, aviation contribute together more than 10% of global NOx emissions.

CO

CO is a product of incomplete combustion, which can therefore be emitted by any fuel combustion (ground transport, industrial processes involving combustion, as well as domestic heating). As presented in Fig. 2c, the power generation sector emits less CO than the residential one because of higher combustion efficiency and higher temperatures compared to

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

domestic burners. In Africa, there are large emissions of CO from the residential sector, mainly due to the use of wood and charcoal for cooking activities. As shown in Fig. 2c, some industrial activities emit CO, like the production of non-metallic minerals and crude steel and iron, which is particularly relevant for India and China, while non-ferrous metal and iron and steel production are dominant in Oceania.

NMVOC

NMVOCs (non-methane volatile organic compounds) are emitted from chemical and manufacturing industries, as well as fuel transformation processes, the production of primary fuels, the use of solvents and from the residential sector, inclusive waste (Fig.2d). Important sources of NMVOCs include also evaporative emissions from road transport, specifically gasoline engines and the use of biofuels. Major emission sectors in the USA emitting NMVOCs include oil refineries, oil and gas production, several industrial processes and motor vehicles. Most of the NMVOC emissions in Europe are due to solvent use, road transport, and the use of primary solid biomass in the residential sector. In the Middle East NMVOC sources include oil production: the industry sector in Saudi-Arabia contributes 75% to its total NMVOC emissions. ~~and in South-Eastern Asia charcoal production.~~ In China, particular high emissions are originating from industry (62%) and residential (27%), the latter also associated with the high use of solvents in paints. ~~and i~~In Brazil particular high use of biogasoline is present resulting in a 52% NMVOC contribution of the transport sector~~with the use of biofuels~~. Also the production of charcoal is emitting strongly NMVOC and the world top 3 emitters (IEA, 2013) are Brasil, Thailand[10] and Kenya, which explains that their industry sector is contributing to the NMVOC total with respectively 35%, 37% and 80% in 2010. NMVOC speciation is not provided by the HTAP_v2.2 emission database; however TNO has produced a breakdown into 23 NMVOC species, which has been used for the RETRO project and the RCP scenarios of IPCC AR5. Recommendations for the NMVOC splits are given on the HTAP wiki site http://iek8wikis.iek.fz-juelich.de/HTAPWiki/WP1.1.

NH3

NH3 is mainly emitted by the agricultural sector, including management of manure and agricultural soils (application of nitrogen fertilizers, incl. animal waste), as Fig. 2i shows,

[10] No charcoal production emissions are accounted for in the REAS2.1 inventory, which is a shortcoming mainly for Thailand.

Formatted: Highlight

Formatted: Highlight

Formatted: English (U.S.)

while a relatively small amount is emitted by the deployment of catalysts in gasoline cars. Minor contributions are also observed for Asian countries from the residential sector due to dung and vegetable waste burning and coal combustion. For industrialized regions, especially for countries using low sulphur fuel, Mejía-Centeneo et al. (2007) reported that the deployment of catalytic converters in gasoline cars enhanced the NH3 emissions from this source since mid-2000. This is also observed by the larger NH3 with increased transport activity and corresponding increased consumption of low sulphur fuels. In the USA gasoline vehicle catalysts represent ca 6% of total NH3 emissions, while a lower contribution is found for Europe due to the high deployment of diesel vehicles.

PM10 and PM2.5

Particulate matter (PM), both in the fine and coarse fraction, is mainly emitted by biomass and fossil fuel combustion in domestic and industrial activities (Figs. 2e and 2f). On the contrary, ground transportation contributes ~5% to total PM emissions (excluding non-exhaust road abrasion dust and tyre wear emissions). As depicted in Fig. 1b, developed countries (like USA and EU) represent ~10% of global emissions of PM and its components, while much higher contributions derive from developing countries where less strict legislation is applied in the industrial sector and in road transport. Figs. 2e and 2f show a similar composition of the contributing sectors to PM10 and PM2.5 globally. PM10 and PM2.5 gridmaps point out the enhanced PM emissions in Asian countries, due to industrial processes and the residential sector. A decreasing trend from 2008 to 2010 is observed for Brazil due to decreases in emissions from charcoal production (with 23% share in the world production in 2008 and 12% in 2010, according to IEA, 2013). Emissions from charcoal production are also important for ~~some South-Eastern Asia (Thailand, Philippines, Indonesia, Vietnam, Malaysia) and~~ some African countries (Kenya, Sudan, South Africa, Tanzania, Ethiopia), with country-specific shares in world production varying between 1.3% and 12.9~~10~~% according to IEA (2013). Western Africa generally emits more PM than the Eastern part because of more industrial activities.

BC and OC

Black carbon (BC), the light-absorbing component of the carbonaceous part of PM, and organic carbon (OC) are emitted from incomplete combustion. Major emission sources are residential cooking and heating (fossil fuel and biomass combustion) and for BC also ground transport (especially diesel engines). Very low emissions originate from the energy sector due

Formatted: Highlight

Formatted: Highlight

to higher process efficiencies and high combustion temperatures. Fig.2g shows that the largest contributing sector for BC in North America, Europe and the Middle East is road transport, which can be allocated ~~should be~~ mainly ~~from~~ to diesel vehicles given the much higher BC emission factor for diesel than for petrol. Heavy duty and light duty vehicles in these regions, as well as~~but~~ ~~also~~ diesel passenger cars in Europe and the Middle East, cause this relatively large contribution despite the use of particle filters, which have not yet fully penetrated the fleet. For Asia, Oceania, Africa and Central- and South-America, the residential sector is the main contributor of BC emissions. In China and India the industry and residential sectors contribute to respectively 84% and 91% of their total BC emissions, while this share in USA or in Germany is only 42% respectively 36%. ~~emit more BC than Western industrialized countries from~~ With the IEA (2003) data this indicates to the combination of high use of coal (mainly in China) and of biomass (mainly for India) in power plants, ~~the~~ coke ovens and non-metallic mineral industries, as well as the residential ~~from domestic~~ heating~~activities involving the combustion of solid biomass and bituminous coal and charcoal production~~. The residential sector in China accounts for more than half (52%) of its BC total. Russia shows a similar high share of the residential sector (46%) to its total BC. Most important sources calculated in EDGARv4.3 for heating buildings in Russia include bituminous coal (57%)and ~~primary~~ solid biomass (30%), lignite (6%) and industrial waste (3%) burning in the residential sector (for domestic housing as well as commercial services) ~~and other bituminous coal combustion in the commercial sector and in the cogeneration and heat plants~~ (EC-JRC/PBL, 2011 and IEA, 2013). A different situation is observed for Africa, where in addition to emissions from traffic and oil production, an important role is played by charcoal production and the use of primary solid biomass and charcoal in the residential sector. Nigeria has high flaring emissions from oil and gas production and Kenya and Sudan suffer from large charcoal production activities. For OC (Fig. 2h), all regions except the Middle East show that the largest emission contribution comes from the residential sector (combustion of charcoal and solid biomass). For the Middle East a relatively large contribution from industrial activities (fuel production) is observed.

3.2 Per capita emissions

To compare emissions from worldwide countries characterized by different degrees of development and numbers of inhabitants, per capita emissions were calculated. Country-

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

specific per capita total emissions are given in Table S~~A~~3.1 of Annex III in the Supplement. In Table 2b we compare ~~-and an example~~ for the world top 6 CO2 emitters~~three selected countries~~, China, USA, India, Russia, Japan and Germany~~ and China~~ the per capita air pollutant emissions while making the link with the country's activity level and level of clean technologies development. ~~is given in Table 2 below.~~ Country total population data were obtained from the United Nations Population Division (UNDP, 2013). This approach allocates the emissions from industrial production to a country without taking into account exports. No life cycle assessment of products at the point of consumption is considered here. This production-based approach has limitations as moving heavy industry from industrialized to developing countries under this production-based approach puts a large burden on countries (in particular those with small populations and mining/manufacturing activities for export). For example mining for export is having a growing impact in Oceania (with low population) and industrial production in China for international markets became increasingly important since 2002 when China entered the World Trade Organisation. The importance of this consumption- versus production-based approach can be expected in 2008 (and also 2010) to be at least but probably even larger than what Boitier (2012) and Davis et al. (2011) amongst others reported for CO_2. A consumption-based approach would yield at least 10% higher emissions for industrialised countries whereas 10% lower emissions for developing countries with emerging economy.

For SO2 the per capita emission in 2010 for EU-28 of 9.1 kg SO2/cap is ~~slightly lower than~~very close to the reported value of ~~11.5~~8.9 kg SO2/cap from EuroSTAT (2014) - the 0.2 difference is much less than the 20% higher per capita SO2 emission in 2008 (11.5 kg SO2/cap).~~.~~ EU's~~This~~ 9.1 kg SO2/cap is about half the SO2 per capita for China in 2010 and about one third of the SO2 per capita for USA. Significant reductions of the Chinese SO2 per capita emissions started due to the introduction of very strict emission limits followed by ambitious flue gas desulfurization programs in power plants (Lu et al. 2011; Klimont et al. 2013; Wang et al., 2014). China is expected to follow the European example, where the SO2 per capita decreased from 1995 to 2005 with 65% of the decrease occurring in Germany and UK according to Ramanathan & Feng (2009).

For NOx and NMVOC, China is similar to the European per capita levels. North America and Oceania double the level of European and Asian per capita emissions of NOx and NMVOC for industrial combustion and transport mainly due to their larger fuel consumptions in the

Formatted: Highlight

Formatted: Highlight

Formatted: Subscript, Highlight

Formatted: Highlight

Formatted: Highlight

industry (Olivier et al., 2013) and road transport (Anderson et al., 2011) sectors, while having similar abatement technologies.

The level of per capita air pollution results from a combination of the per capita activity and the level of implementation of end-of-pipe measurement technology. The activity level can be reflected by the per capita CO2 emissions, which is highest for USA explaining the high air pollutant emissions per capita. However not India with lowest CO2 per capita, but Japan and Germany are having the lowest per capita air pollutant emissions, because of the level of technology and end-of-pipe implementation. To measure the latter we apply a kind of surrogate variable: the Human Development Indicator (2010) from UNDP(2015). This shows that Germany and Japan are more advanced and have therefore lower emissions per capita for all air pollutants (except NH3 for Germany) and for the PM. ~~Whereas for NOx, NMVOC, CO and NH3, the ranking from lowest to highest per capita emitters in Table 2 is Germany – China – USA, for PM this order is not present.~~ We observe that the PM emissions per capita of Japan (0.16 kgPM2.5/yr/cap) are only 60% of those of Germany and Germany's one are about one fifth of the per capita emissions of the USA, which are on their turn only 60% of ~~and~~ the per capita PM2.5 for China ~~is more than double the per capita PM2.5 of the USA~~. Table S~~A~~3.1 indicates that developing countries, in particular those with emerging economies but not yet fully penetrated clean technologies and end-of-pipe measures, have enhanced PM per capita emissions (China – 8.2 kgPM2.5/yr/cap, India – 5.2 kgPM2.5/yr/cap, Brasil – 3.1 kgPM2.5/yr/cap). Russia has relatively high per capita PM emissions (2.2 kg PM2.5/yr/cap because of ~~for~~ fossil fuel production and consumption in the power ~~generation~~ sector, but much less than ~~, while~~ Canada (7.4 kg PM2.5/yr/cap), a much less populated country but with important fossil fuel production industry for export ~~shows high values for non-power industry~~. Both countries, with important contribution in the Arctic region, ~~-~~show relatively high NMVOC and SO2 emissions (50.9 kg NMVOC/yr/cap and 48.7 kg SO2/yr/cap for Canada respectively 26.8 kg NMVOC/yr/cap and 31.9 kg SO2/yr/cap for Russia) due to their~~of~~ significant inland waterway transport using heavy residual fuel oil or diesel.

Fig. 3 gives an overview of the per capita emissions for high, upper and lower middle and low income countries, as defined for the WGIII of AR5 of IPCC (2014). The largest variation between the different groups of countries is observed for SO2 and NOx, which represent the presence of industry. The median of per capita SO2 and NOx emissions are higher for high and upper middle income countries than for low or lower middle income countries. The

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

median of per capita CO and NMVOC is not strongly dependent on the income of the countries, whereas the median of per capita PM (and BC and OC) are definitely lower for high income countries than for low income countries.

3.3 Per GDP emissions

Another indicator of emission intensity of a country is the ratio of emissions and Gross Domestic Product (GDP) in USD, in constant Purchasing Power Parity (PPP), as given in Table S~~A~~3.2 of Annex III and shown in Fig. 3b. The GDP 2010 data for the different countries were obtained from World Bank (2014) and IMF (2014). This indicator is much more uncertain than the per capita emissions because the GDP is subject to heterogeneity (by the different~~more difficult to cover with the various inhomogeneous~~ economic activities), to heteroskedasticity (~~which are also influenced~~ by time-dependent inflation and currency exchange rates) and to incompleteness (by the not officially reported~~which are incomplete with the unrecorded unofficial~~ activities). It is not recommended to use this per unit of GDP emissions indicator ~~only for comparing levels because the correlation between emissions and GDP can be~~for relative small~~ for~~ countries with a substantial~~ly contributing~~ service sector (e.g. Luxembourg).

For 2010 Fig. 3b shows that EU and USA have similar low emissions per unit of GDP for all substances, except NO_x where EU's emission per unit of GDP is still significantly lower than in USA. China's emissions of SO_2 and NO_x per unit of GDP are at the high end, whereas for NH_3 and the carbonaceous particulate matter China is bypassed by India, which shows even higher emissions per unit of GDP. In analogy with Table 2b, Table 2c provides for the world top 6 CO_2 emitters a comparison of the air pollutants per unit of GDP, which are linked to the country's economic activity (in GDP per capita) and CO_2 per unit of GDP (measuring the energy intensive industry). It is directly apparent that again Germany and Japan are having high economic activity, with still important energy intensive industry but low air pollutant emissions per unit of GDP because of the investment in clean technology. On the other side, India has still much lower economic activity but nevertheless a much higher particulate matter emission per unit of GDP.

Formatted: Highlight

Formatted: Highlight

3.4 Implied emission factors

Energy-intensity is a widely used indicator to assess the fuel efficiency of manufacturing processes. Analogous to energy-intensity, we analyse in this section air pollution emission-intensity for all world countries. Emission intensity of economic activities for a given region are determined by~~-~~ implied emission factors. The region-specific implied emission factors (EF) present the emissions per unit of activity (per TJ energy consumed for all combustion-related activities inclusive ~~, per kg product for~~ industrial processes ~~and solvents~~ or per 1000 head of animals~~ha cultivated land~~ for agricultural related activities) and are defined for a substance x ~~with speciation l~~ at year~~time~~ t due to activities AD in activity subsectors j,k~~i~~ of each of the main HTAP sectors (htap_3_ENERGY, htap_4_INDUSTRY, htap_5_TRANSPORT, htap_6_RESIDENTIAL, htap_8_AGRICULTURE)~~with technologies j and end-of-pipe measures k,~~ in a country C as:

$$EF_{C,i}(t,x_l)=\frac{\sum_{j,k}\left[AD_{C,i}(t)*TECH_{C,i,j}(t)*EOP_{C,i,j,k}(t)*EF_{C,i,j}(t,x_l)*\left(1-RED_{C,i,j,k}(t,x_l)\right)*f_{C,i,j}(x_l)\right]}{\sum_{j,k}\left[AD_{C,i}(t)*TECH_{C,i,j}(t)*EOP_{C,i,j,k}(t)\right]}$$

~~with TECH representing the technologies, EOP the end-of-pipe measures, EF the emission factors and RED the emission reduction due to end-of-pipe control measures~~.

$$EF_{C,3\_energy}(t,x)=\frac{\sum_{subsector\ j} EM_{C,3\_energy,j}(t,x)\Big|_{datasource\ of\ C}}{\sum_{subsector\ j} AD_{C,3\_energy,j}(t)\Big|_{EDGARv4.3}}\quad [kton/TJ] \quad (1)$$

$$EF_{C,4\_ind.}(t,x)=\frac{\left[\sum_{comb.\ subsector\ j} EM_{C,4\_ind.,j}(t,x)+\sum_{proc.subsector\ k} EM_{C,4\_ind.,k}(t,x)\right]\Big|_{datasource\ of\ C}}{\sum_{comb.\ subsector\ j} AD_{C,4\_ind.,j}(t)\Big|_{EDGARv4.3}}\quad [kton/TJ] \quad (2)$$

$$EF_{C,5\_transport}(t,x)=\frac{\sum_{subsector\ j} EM_{C,5\_transport,j}(t,x)\Big|_{datasource\ of\ C}}{\sum_{subsector\ j} AD_{C,5\_transport,j}(t)\Big|_{EDGARv4.3}}\quad [kton/TJ] \quad (3)$$

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

$$EF_{C,6\_res.}(t,x) = \frac{\left[\sum_{comb.\ subsector\ j} EM_{C,6\_res.,j}(t,x) + \sum_{waste\ prod.\ subsector\ k} EM_{C,6\_res.,k}(t,x) \right]\Bigg|_{datasource\ of\ C}}{\sum_{comb.\ subsector\ j} AD_{C,6\_res.,j}(t)\Big|_{EDGARv4.3}} \quad [kton/TJ] \quad (4)$$

$$EF_{C,8\_agr.}(t,x) = \frac{\left[\sum_{animal\ subsector\ j} EM_{C,8\_agr.,j}(t,x) + \sum_{crop\ subsector\ k} EM_{C,8\_agr.,k}(t,x) \right]\Bigg|_{datasource\ of\ C}}{\sum_{animal\ subsector\ j} AD_{C,8\_agr.,j}(t)\Big|_{EDGARv4.3}} \quad [ton/head] \quad (5)$$

It should be noted that the implied emission factors of sectors htap_4_INDUSTRY and htap_8_AGRICULTURE are slightly skewed up because of an incomplete accounting of the activity data which are for these sectors a combination of activities of different nature and as such expressed with different units. The emissions of sector htap_4_INDUSTRY mainly originate from the energy-intensive subsectors and therefore are weighted with the energy needs (in TJ). We omitted the accounting of industrial process emissions, which are calculated per kton product manufactured. In sector htap_6_RESIDENTIAL the waste is included, although calculated per kton dry or wet waste, which we could not combine with the residential energy consumption in TJ. The emissions of the htap_8_AGRICULTURE sector are weighted with the number of animals and not with the kton crops cultivated, because the crops serve for 85% as animal food and are therefore considered a justified measure of agricultural activity.

Thereto, emissions of sector-specific gridmaps for 2010 have been aggregated to country level and divided with the activity data for that sector in that country from EDGARv4.3, which are for energy-related activities based on IEA (2013) statistics and for agricultural-related activities on FAO (2012) statistics. It should be noted that emissions in particularly those reported under country-specific point sources are allocated to the reporting country solely, also for cells covering country borders. The areal fraction of these cells would incorrectly spread the emissions also the the neighbouring country, which yield in the case of e.g. the power emissions for Canada up to 30% increase with the USA emissions along its borders. ~~the aggregation of the country cells, taking into account the relative areal fraction of that country in cross-border cells, needed to be corrected with country-specific reporting, in order to allocate point sources (e.g. power plants) at borders (e.g. waterways) to the responsible country.~~ The implied emission factor results are given for all world countries and for 2010 in the Table S~~A~~4 of Annex IV in the Supplement.

Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: German (Germany)
Formatted: Highlight
Formatted: English (U.S.)

Fig. 4 gives an overview per sector of the range of different implied emission factors for each country with the maximum/minimum, the percentiles and the median. In addition the position in this range of EU27, USA, China and India is indicated to evaluate the level of emission-intensity of the different activities. EU 27 and USA show very similar implied emission factors for the energy and industry sectors, which are much lower than the median for all pollutants. China also shows implied emission factors for energy and industry that are lower than the medians, but still larger than USA and EU 27. India shows much higher implied emission factors for energy and industry, which are for CO, PM2.5, BC, and OC above the median. In the case of the residential sector, the range of variation of the implied emission factors is the smallest for SO2 and NOx, but the largest for PM2.5 and BC. For the transport sector a relatively large variation is present for CO, with an implied emission factor for China that is above the median. For agriculture it is remarkable that China and India, ~~but also~~as well as the USA and EU 27, have implied emission factors that are above the median, with China reaching the maximum compared to all other world countries.

Even though only implied emissions factors for country emissions are presented in Fig. 3b, the implied emission factors were also calculated for the international bunker fuel and indicated that the implied emission factors are at the high end of the range for SO2 (0.98 ton SO2/TJ similar to the road transport emission factor of Laos or Panama), NOx (with 1.65 ton NOx/TJ similar as for transport in Bangladesh or Myanmar), PM2.5 (with 0.17 ton PM2.5/TJ similar as for transport in China), but are relatively low for CO, NMVOC and BC. ~~The high SO2 implied emission factor might indicate the use of lower quality fuels in sea transportation, especially in international waters.~~ The high SO2 implied emission factor (from EDGARv4.3) represents the use of lower quality fuels in sea transportation, especially in international waters: 85% of the sea bunker fuel in 2010 consists of residual fuel oil with an emission factor of 1.29 ton SO2 /TJ.

3.5 Emission changes 2008-2010

The emission change from 2008 to 2010 is given in Table S~~A~~2.3 of Annex II. It should be noted that the data provided for Canada by US-EPA/Environment Canada and for Europe by TNO were actually not representing 2010, but 2008 respectively 2009. However updates were undertaken: point source data of 2010 were used and implemented in the gridmaps. Both regions were affected by the economic crisis of 2008, yielding stagnation and even

Formatted: Highlight

Formatted: Highlight

Formatted: English (U.S.)

Formatted: Highlight

downwards trends in the following years, mainly in the energy and industry sectors. The latter sectors are primarily composed of point sources, ~~and~~therefore the gridmaps of 2010 ~~can be considered to~~ represent also for Canada and Europe the actual 2010 situation. For the developed countries in North America and Europe the decline of emissions between 2008 and 2010 for most of the pollutants are driven mostly by continued implementation of emission reduction technologies. In some cases this also leads to increases in sectorial emissions, although insignificant for the total, as is estimated for NH_3 in the energy and transport sectors, due to the use of catalysts.

For the MICS-Asia region, the emissions are mostly increasing except for the energy sector, where the SO_2 and PM emissions are reduced in 2010 due to the wide deployment of flue-gas desulfurization (FGD) and particulate matter filters in the power plants, consistent with Wang et al. (2014). For the other developing countries (calculated with the EDGARv4.3 data and based on the IEA(2013) fuel statistics), the SO_2 emissions of the energy sector slightly increase from 2008 to 2010 ~~in the energy sector, possibly due to the impact~~because of the increas~~ing~~ed coal use (as also observed by Weng et al., 2012) and the increased use of ~~even~~ heavy fuel oil ~~(~~in the Middle East~~ power sector according to IEA (2013) activity data)~~. The PM emissions from the energy and industry of some ~~the~~ other developing countries show a decrease from 2008 to 2010, mainly due to the activity reduction and ~~but also~~ in some cases due to the modelled decrease in controlled emission factor in EDGARv4.3. Largest reductions were seen for Brazil (with 54% reduction of its 2008 charcoal production) and Kazakhstan (11% reduction in coal power generation, which is modelled with a 31% decreasing BC emission factor)~~indicating slow penetration of end-of-pipe abatement~~.

3.6 Qualitative assessment of the uncertainty of emission gridmaps

Even though the HTAP_v2.2 data sources are all bottom-up constructed inventories, they differ considerably in e.g. the assumptions taken on the modelling of technology and end-or-pipe measures and use different emission factors, which ~~quite different, and~~ lead to inconsistencies at the borders between two adjacent inventories. On their turn the different bottom-up inventories are constructed with sub-regional (country, state, county or province level) activity data and emission factors. As such, inconsistencies can be expected at each country border and the variation of the emissions at cross-border cells gives already a first indication on the region- and sector-specific emission uncertainty.~~over borders, a bottom-up~~

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

methodology with activity data and emission factors is applied to calculate emission totals and distribute these on the grid. The propagation of uncertainty is given by the effect of variables' uncertainties (or errors) on the uncertainty, i.e. the variance of the activity data and that of the emission factor. Table 3 provides some insight in the estimation of the uncertainty range, however the approach followed in HTAP v2.2 inhibits an overall consistent uncertainty assessment because it is not aone single bottom-up inventory.

Guidance on evaluation of emission uncertainties can be obtained from the evaluations of the national inventories reported to UNFCCC, addressed by e.g. Jonas et al (2010) (and references in there). With the evaluation of common behaviours between species in EDGARv4.2 of Balsama et al (2014) we propose the same approach of CO2 uncertainty assessment for SO2 and NOx (all driven by combustion-related activities), and the approach of N2O for NH3. As such Table 3 follows the grouping of countries by Andres et al (2012) and Marland et al (1999), based on their statistical infrastructure. Countries with well maintained statistical infrastructure are the 24 OECD-1990 countries plus India with a British statistical accounting system. For the other countries, a larger range in uncertainty is present, for which we refer to Gregg et al. (2008) or Tu (2011) and Olivier (2002). For the annual CO2 inventory, the biofuel is carbon-neutral and not taken up in the national inventories. However, for the air pollutants it is an additional large source of uncertainty, which is often not officially reported and as such missing. For the N-related emissions, the division in countries could be based on common agricultural practices (Leip et al, 2011 and Rufino et al, 2014).

Formatted: Highlight

In addition to the uncertainty of the activities, the quality and representativeness of the controlled emission factors play a crucial role. The standard range of uncertainty already varies according to the EMEP/EEA (2013) Guidebook's Uncertainties Chapter 5 for the absolute annual total of different pollutants between at least 10% for SO2, at least 20% for NOx and CO, at least 50% for NMVOC, an order of magnitude for NH3, and PM10, PM2.5, BC and OC. These considerations have been taken into account to indicate qualitatively a range for the different uncertainties (using the terminology low (L), low medium (LM), upper medium (UM) or high (H)) for the different sectors and species.

The HTAP modelling community is expected to run in addition to the actual 2008 and 2010 simulations with the HTAP_v2.2 emission inventory also the emission scenarios of ECLIPSEv5 We can only compare the HTAP v2.2 with the ECLIPSEv5 dataset of (Klimont et al., (in preparation 2015). ECLIPSEv5 starts with a 2010 emission inventory (or, which is a

Formatted: Highlight

~~fully consistently built global bottom-up inventory and serves as~~ base year inventory), that serves also as reference point for all projections. Here we compare the ECLIPSEv5 emission inventory for 2010 with the HTAP_v2.2 2010 data, in order to evaluate how close the reference point is to the “officially accepted” regional inventories of HTAP_v2.2. ~~for the HTAP scenarios.~~ At global level, a relatively good agreement is found with small relative emission differences (ECLIPSEv5 – HTAPv2.2) / HTAPv2.2 for the aggregated sectors in 2010. It should be noted that the GAINS dataset, another bottom inventory, can not be considered an external independent source of verification, because similar information on emission factors and reductions for certain technologies have been applied in the TNO-EMEP, MIX-Asia and EDGARv4.3 datasets. The relative difference for NOx and CO is only -4% respectively +5%. For SO2 a larger difference of -8% reflects the recent important S-reductions for the non-ferrous metal smelters in ECLIPSEv5 (Klimont et al., 2013). For NH3 a relative difference of +17% is acceptable because of the larger uncertainty in emission factors driven by lack of information about manure management practices and also by incomplete data on the agricultural activities. For NMVOC a difference of -27% stems primarily from the assumptions about emissions from solvent use. The information about activity levels is scarce and even less is known about the emission factors for some important sources. Both regional inventory compilers and modellers often make assumptions about per capita or per GDP solvent use NMVOC emissions from particular sectors. Here assumptions employed in the ECLIPSEv5 lead to lower emissions from these activities. As anticipated (and reflected in Table 3) larger differences of 48% and 29% are present for PM2.5 and BC, respectively. While for PM2.5, assumptions about penetration and efficiency of filters in industrial and small-scale residential boilers as well as emission factors and activity data for biomass used in cooking stoves play a key role, for BC assumptions about coal consumption in East Asia are of relevance since ECLIPSEv5 relied on provincial statistics for China which results in higher coal consumption than reported in national statistics and IEA. Additionally, ECLIPSEv5 includes emissions from kerosene wick lamps, especially relevant for South Asia and parts of Africa according to Lam et al. (2012), gas flaring and high emitting vehicles, which together result in about 30% higher emissions.

In addition, the spatial allocation is subject to other types of errors, with a spatial variance for point sources and a more important systematic error when a spatial proxy is used to distribute the emissions. Geo-spatial consistency is lower in the HTAP_v2.2 database than if the national totals would have been spatially redistributed with one harmonised spatial proxy

Formatted: Highlight

dataset. It should be also noted that derivation of country totals from the 0.1°x0.1° emission gridmaps (as e.g. done in the ECCAD system) is only valid if the country-specific total is larger than 0.2% of each of the totals of the neighbouring countries. Otherwise the derived country-specific sector total can be 50% larger than the bottom-up one, mainly in the energy sector with many point sources which are typically located on waterways or coastal areas and as such in cross border cells. Table ~~S~~A1.3 illustrates the deviations of derived country-specific sector totals to the bottom-up ones for the Asian region. The latter caused derived sector totals for Kyrgyzstan, Tajikistan, Afghanistan, Laos, Myanmar, Bangladesh, which deviated with one order of magnitude from the bottom-up totals. However, the relative small differences for China (≲5%), India (≲3% for all except for SO2 from energy where it is 14%), Indonesia (≲7%) and Thailand (≲12.5%), Japan (≲16.0%) and South Korea (≲17.3%) show a good agreement for the top 6 Asian emitters.

Another type of inconsistency in mass balance at grid cell level occurs when for the same region the data sources providing the emission gridmaps for PM10 and PM2.5 or for PM2.5 and BC/OC are different. Already the application of different spatial proxy datasets (e.g. with and without point sources) result in an inconsistent allocation of multi-pollutant sources to different grid cells. ~~speciation of a substance is done with gridmaps of different data sources~~. This was another reason not to use the PM gridmaps of EMEP, as no BC and OC speciation is available from the same EMEP data source. Instead we used the gridmaps of TNO for all PM components (PM10 and PM2.5) and the TNO speciation file for BC and OC. In addition a check was performed to ensure that the sum of BC and OC emissions in every grid cell is smaller than the PM2.5 emission in that grid cell. Thereto a re-allocation of the emissions of some point sources (industrial facilities) was needed within Europe (e.g. Poland) and performed in consultation with TNO.

~~Another check was to estimate per grid cell the change in emission from 2008 to 2010 and allowed to find missing sources. However,~~ Even though this mosaic inventory can not present the same ~~global~~ consistency as one global bottom-up inventory, its extensive evaluation and use helped improving its quality. ~~cannot be guaranteed and a comparison of different countries or of different years cannot be conclusive.~~ The evaluation was undertaken in particular in discussion with TNO and with US EPA to identify missing sources or misallocation of point sources. In particular point sources are very important input, but their strengths and locations are subject to input errors with larger consequences and cannot be extrapolated in time. (Closure of power plants as large point sources can change the emission distribution pattern from one year to another.) In addition the use of the dataset by global and regional climate and air quality modellers and the modellers' fFeedback from users of the emission dataset has already helped to improve its quality (personal communications with L. Emmons of 5 November 2013 and D. Henze of 19 November 2013) were most useful and isare further encouraged.

Formatted: Highlight

4 Conclusions and recommendations

This paper describes the HTAP global air pollutant baselinereference emission inventory for 2010, which is composed of latest available data from regional inventory compilersalso regionally accepted as reference. It assures a consistent input for both regional and global modelling as required by the HTAP modelling exercise. The HTAP_v2.2 emission database makes use of consolidated estimates of official and latest available regional information with air pollutant gridmaps from US EPA and EnvironCanada for North America, EMEP-TNO for Europe, MIX for Asia, and the EDGARv4.3 database for the rest of the world. The mosaic of gridmaps provides comprehensive local information on the emission of air pollutants, because it results from the collection of point sources and national emission gridmaps at 0.1° (for some regions 0.25°) resolution. Even though the HTAP_v2.2 dataset is not a self-consistent bottom-up database, with activity data of consistentdefined according to international statisticsndards, with harmonized emission factors, and with global sets of spatialemissions gridded with global proxy data, it provides a unique set of emission gridmaps with global coverage and high spatial resolution, including in particular important point sources. The compilation of implied emission factors and per capita emissions for the different world regions using multiple sources provides the regional and national emission inventory compilers with a valuable asset for comparison with their own data for cross checking and analysis which may lead to identification of future improvement options.

Formatted: Highlight

Formatted: Highlight

This dataset was prepared as emission input for the HTAP community of modellers and its preparation has involved outreach to global and regional climate and air quality modellers (collaborating also within the AQMEII and MICS-Asia modelling exercises). The TF HTAP needed an emission inventory that was suitable for simultaneous and comparable modelling of air quality at the regional scale and at the global scale to deliver consistent policy support at both scales. The HTAP-v2.2 emission inventory presented in this paper is tailor-made to allow the TF HTAP to fulfil its prime objectives and contribute to a common international understanding of global and regional air pollution and its influence on human health, vegetation and climate. The use of the HTAPv2.2 inventory will substantially help to provide a basis for future international policies because it combines and is consistent with the inventories that are used for regional (EU, US Canada, China) policy analysis and support.

Access to the data

The 0.1° x 0.1° emission gridmaps can be downloaded from the EDGAR website on http://edgar.jrc.ec.europa.eu/htap_v2/index.php?SECURE=123 per year, per substance and per sector either in the format of netcdf-files or .txt files. The emissions in the netcdf-files are expressed in kg substance/m^2/s but the emissions in the .txt are in ton substance / gridcell. For the NMVOC speciated gridmaps we refer to the link on the ECCAD data portal: http://eccad2.sedoo.fr/eccad2/mapdisplay.xhtml?faces-redirect=true.

Acknowledgement

This research was partially funded by EC-DG Environment under AA 070402/2007/47597/MAR/C5 and 33075. S. Galmarini (JRC) and A. Zuber (DG Environment) are thanked for the continuing support to the HTAP project. The authors would also like to thank all HTAP-modelers providing first feedback. Colleagues of the ECCAD project, C. Granier, A. Mieville, of the TNO-MACC project~~, J. Kuenen,~~ and of EMEP-MSCW are gratefully acknowledged for help received during the preparation of this work.

References

Anderson, S.T., Parry, I.W.H., Sallee, J.M., Fischer, C.: Automobile Fuel Economy Standards: Impacts, Efficiency, and Alternatives, Review of Environmental Economics and Policy, volume 5, issue 1, winter 2011, pp. 89–108 doi:10.1093/reep/req021, 2011.

Balsama, A., De Biase, L., Janssens-Maenhout, G., Pagliari, V.: Near-term forecast of anthropogenic emission trends using neural networks, J. Atmospheric Environment, vol. 89 p. 581-592, 10.1016/j.atmosenv.2014.02.046, 2014.

Boitier, B., CO2 emissions production-based accounting vs consumption: Insights from the WIOD databases, WIOD Final Conference - Causes and Consequences of Globalization, Groningen, 24th-26th April, 2012.

Carmichael, G.R., Sakurai, T., Streets, D., Hozumi, Y., Ueda, H., Park, S.U., Funge, C., Han, Z., Kajino, M., Engardt, M., Bennet, C., Hayami, H., Sartelet, K., Holloway, T., Wang, Z., Kannari, A., Fu, J., Matsuda, K., Thongboonchoo, N., Amann, M.: MICS-Asia II: The model intercomparison study for Asia Phase II methodology and overview of findings, Atm. Env., 42 (15), 3468–3490, doi:10.1016/j.atmosenv.2007.04.007, 2008.

EC-JRC/PBL, European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL): Emission Database for Global Atmospheric Research (EDGAR), release EDGAR version 4.2. http://edgar.jrc.ec.europa.eu/, 2011.

EC-JRC/PBL, European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL): Emission Database for Global Atmospheric Research (EDGAR), release EDGAR version 4.3. http://edgar.jrc.ec.europa.eu/, 2015.

EMEP: Draft Guidelines for Estimating and Reporting Emissions Data, prepared by the Task Force on Emission Inventories and Projections and the secretariat (eb.air.ge.1.2002.7.pdf), 2002.

Davis, S.J., G.P. Peters, K. Caldeira, K.: The Supply Chain of CO2 Emissions. PNAS www.pnas.org/cgi/doi/10.1073/pnas.1107409108, 2011

EMEP/EEA: EMEP/EEA air pollutant emission inventory guidebook 2013: Technical guidance to prepare national emission inventories, ISSN 1725-2237, EEA Techn. Report 12/2013, http://www.eea.europa.eu/publications/emep-eea-guidebook-2013, 2013.

EPA, U.S.: The 2008 National Emissions Inventory, 2008 NEI version 3, Techn. Support Documentation, http://www.epa.gov/ttnchie1/net/2008inventory.html, 2013.

Eurostat, European Statistics Database of the European Commission, (datasets tsdpc260 and demo_pjan), http://ec.europa.eu/eurostat/data/database, 2014.

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

FAO: Food and Agricultural Organization of the United Nations: Statistics Division, Livestock, Crop and Fertilizer data: faostat.fao.org, and Geonetwork Digital Soil Map of the World, http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116&currTab=simple, 2012.

Galmarini, S., Rao, S.T., and Steyn, D., Preface: Special issue of Atmospheric Environment for AQMEII. Atm. Env. Elsevier Science Ltd, New York, NY, 53(June):1-3, 2012.

Galmarini S., Hogrefe, C., Brunner, D., Baklanov, A., Makar, P.: Preface: Special issue of Atmospheric Environment for AQMEII phase 2, J. Atmospheric Environment, 2015.

Gregg, J.S., Andres, R.J., Marland, G., China: Emissions pattern of the world leader in CO2 emissions from fossil fuel consumption and cement production, Geophysical Research Letters, 35, doi:10.1029/2007gl032887, 2008.

HTAP, UNECE: Hemispheric Transport of Air Pollution 2010: Part A: Ozone and Particulate Matter, Air Pollution Studies No. 17, Dentener, F., Keating, T., Akimoto, H. (eds.), ECE/EN.Air/100, ISSN 1014-4625, ISBN 978-92-1-117043-6, 2010.

Huang, X., Song, Y., Li, M., Li, J., Huo, Q., Cai, X., Zhu, T., Hu, M., and Zhang, H.: A high-resolution ammonia emission inventory in China, Global Biogeochem. Cy., 26, GB1030, doi: 10.1029/2011GB004161, 2012.

IEA: Energy Statistics of OECD and Non-OECD Countries, data.iea.org (personal communication Roberta Quadrelli (IEA/EXD/ECD3), 2013.

IMF: World Economic Outlook Database. International Monetary Fund, http://www.imf.org/external/pubs/ft/weo/2014/02/weodata/index.aspx, October 2014.

IMO: Reduction of GHG Emissions from Ships – Third IMO GHG Study 2014, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx, June 2014

IMO: Second IMO Greenhouse Gas Study 2009, http://www.ce.nl/publicatie/second_imo_ghg_study_2009/941, April 2009

IPCC: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, IPCC National Greenhouse Gas Inventory Programme, Hayama, Japan, 2006.

IPCC: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, P., Savolainen, J., Schlömer, S., von

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

Stechow, C., Zwickel, T., Minx J.C. (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.

Janssens-Maenhout, G., Dentener, F., van Aardenne, J., Monni, S., Pagliari, V., Orlandini, L., Klimont, Z., Kurokawa, J., Akimoto, H., Ohara, T., Wankmüller, R., Battye, B., Grano, D., Zuber, A., and Keating, T.: EDGAR-HTAP: a harmonized gridded air pollution emission dataset based on national inventories, EUR 25229 EN Report, 2012. ISBN 978-92-79-23122-3, ISSN 1018-5593, doi: 10.2788/14069, 2012.

Janssens-Maenhout, G., Pagliari, V., Guizzardi, D., Muntean, M.: Global emission inventories in the Emission Database for Global Atmospheric Research (EDGAR) – Manual (I): Gridding: EDGAR emissions distribution on global gridmaps, JRC Report, EUR 25785 EN, ISBN 978-92-79-28283-6, doi.10.2788/81454, 2013.

Jonas, M. Marland, G., Winiwarter, W., White, T., Nahorski, Z., Bun, R., Nilsson, S., Benefits of dealing with uncertainty in greenhouse gas inventories: introduction, Climatic Change, Vol 103: 3-18, doi 10.1007/s10584-010-9922-6, 2010

JPEC (Japan Petroleum Energy Center): Emission inventory of road transport in Japan, JPEC Technical Report, JPEC-2011AQ-02-06, 136pp [in Japanese], 2012a.

JPEC: Emission inventory of sources other than road transport in Japan, JPEC Technical Report, JPEC-2011AQ-02-07, 288pp [in Japanese], 2012b.

JPEC: Speciation profiles of VOC, PM, and NOx emissions for atmospheric simulations of PM2.5, JPEC Technical Report, JPEC-2011AQ-02-08, 69pp [in Japanese], 2012c.

Klimont, Z., Smith, S., Cofala, J.: The last decade of global anthropogenic sulfur dioxide: 2000–2011 emissions, Environ. Res. Lett. 8 (1), 014003, 2013.

Klimont, Z., Hoeglund-Isaksson, L., Heyes, C., Rafaj, P., Schoepp, W., Cofala, J., Borken-Kleefeld, J., Purohit, P., Kupiainen, K., Winiwarter, W., Amann, M., Zhao, B., Wang, S., Bertok, I., Sander, R., in preparation. Global scenarios of air pollutants and methane: 1990-2050., in preparation for Atmos. Chem. Phys. 2015.

Kuenen, J. J. P., A. J. H. Visschedijk, M. Jozwicka, and H. A. C. Denier van der Gon: TNO-MACC_II emission inventory: a multi-year (2003–2009) consistent high-resolution European emission inventory for air quality modelling, Atmos. Chem. Phys. Discuss., 14, 5837-5869, doi:10.5194/acpd-14-5837-2014, 2014.

Kurokawa, J., Ohara, T., Morikawa, T., Hanayama, S., Janssens-Maenhout, G., Fukui, T., Kawashima, K., and Akimoto, H.: Emissions of air pollutants and greenhouse gases over

Formatted: English (U.S.), Highlight

Formatted: Highlight

Formatted: English (U.S.)

Asian regions during 2000–2008: Regional Emission inventory in ASia (REAS) version 2, Atmos. Chem. Phys., 13, 11019–11058, 2013.

Lam, N.L., Chen, Y., Weyant, C., Venkataraman, C., Sadavarte, P., Johnson, M.A., Smith, K.R., Brem, B.T., Arineitwe, J., Ellis, J.E., Bond, T.C.: Household Light Makes Global Heat: High Black Carbon Emissions From Kerosene Wick Lamps. Environmental Science & Technology 46, 13531–13538. doi:10.1021/es302697h, 2012.

Lamarque, J. F., Bond, T.C., Eyring, V., Granier, C., Heil, A., Klimont, Z., Lee, D., Liousse, C., Mieville, A., Owen, B., Schultz, M.G., Shindell, D., Smith, S.J., Stehfest, E., van Aardenne, J., Cooper, O.R., Kainuma, M., Mahowald, N., McConnell, J.R., Naik, V., Riahi, K., van Vuuren, D.P.: Historical (1850-2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application, Atmospheric Chemistry and Physics, 10, 7017-7039, 2010.

Lee, D. G., Lee, Y.-M., Jang, K.-W., Yoo, C., Kang, K.-H., Lee, J.-H., Jung, S.-W., Park, J.-M., Lee, S.-B., Han, J.-S., Hong, J.-H., and Lee, S.-J.: Korean national emissions inventory system and 2007 air pollutant emissions, Asian J. Atmospheric Environment, 5, 278–291, 2011.

Leip, A., Achermann, B., Billen, G., Bleeker, A., Bouwman, A.F., de Vries, W., Dragosits, U., Döring, U., Fernall, D., Geupel, M., Herolstab, J., Johnes, P., Le Gall, A.C., Monni, S., Nevečeřal, R., Orlandini, L., Prud'homme, M., Reuter, H.I., Simpson, D., Seufert, G., Spranger, T., Sutton, M.A., van Aardenne, J., Voβ, M., Winiwarter, W.: Integrating nitrogen fluxes at the European scale, Chapter 16 in The European Nitrogen Assessment (ed. M.A. Sutton, C.M. Howard, J.W. Erisman, G. Billen, A. Bleeker, P. Grennfelt, H. van Grinsven and B. Grizzetti, Published by Cambridge University Press, 2011

Li, M., Zhang, Q., Kurokawa, J., Woo, J.-H., He, K.B., Lu, Z., Ohara, T., Song, Y., Streets, D.G., Carmichael, G.R., Cheng, Y.F., Huo, H., Liu, F. Su, H., Zheng, B.: MIX: a mosaic Asian anthropogenic emission inventory for the MICS-Asia and the HTAP projects, in preparation for Atmos. Phys. Chem, 2015.

Lu, Z., Zhang, Q., Streets, D. G.: Sulfur dioxide and primary carbonaceous aerosol emissions in China and India, 1996–2010, Atmos. Chem. Phys., 11, 9839-9864, doi:10.5194/acp-11-9839-2011, 2011.

Mareckova, K., Wankmueller, R., Moosmann, L., Pinterits, M.: Inventory Review 2013: Review of emission data reported under the LRTAP Convention and NEC Directive: Stage 1 and 2 review; Status of gridded and LPS data, EMEP/EEA, Technical Report CEIP 1/2013, 2013.

Marland, G., Brenkert, A., Olivier, J., CO2 from fossil fuel burning: a comparison of ORNL and EDGAR estimates of national emissions, Environmental Science & Policy, 2, 265-273, doi:10.1016/21462-9011 (99)00018-0, 1999.

Mejía-Centeno, I., Martínez-Hernández, A., and Fuentes, G.A.: On The Enhanced Emission Of NH3 And Fine Particles From Gasoline Vehicles Operating With Low Sulfur Gasoline, Topics Catal, 2007, AIChe, Ann. M., 2007.

MOEJ (Ministry of Environment of Japan): Report on Volatile Organic Compound (VOC) Emission Inventory Compiled [in Japanese], available at http://www.env.go.jp/air/osen/voc/inventory.html, 2009.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J.: The next generation of scenarios for climate change research and assessment, Nature, 463, pp. 747-756, 2010.

Olivier, J. G. J.: On the Quality of Global Emission Inventories: Approaches, Methodologies, Input Data and Uncertainties, PhD thesis University Utrecht, ISBN 90-393-3103-0, 2002.

Olivier, J.G.J., Janssens-Maenhout, G.: CO2 Emissions from Fuel Combustion -- 2012 Edition, IEA CO2 report 2012, Part III, Greenhouse-Gas Emissions, ISBN 978-92-64-17475-7, 2012.

Olivier J.G.J., Janssens-Maenhout G., Peters, J.A.H.W.: Trends in global CO2 emissions. 2013 report, EUR 26098 EN 2013, October 2013.

OPRF (Ocean Policy Research Foundation (Ship and Ocean Foundation)): Report for comprehensive study for environmental impact lead by the establishment of emission control area in Japan, ISBN978-4-88404-282-0, 524pp [in Japanese], 2012.

Pouliot, G., Keating, T., Janssens-Maenhout, G., Chang, C., Beidler, J., Cleary, R.:The Incorporation of the US National Emission Inventory into Version 2 of the Hemispheric Transport of Air Pollutants Inventory, in Air Pollution Modeling and its Application XXIII, edited, pp. 265-268, Springer International Publishing, 2014.

Pouliot, G., van der Gon, H.A.D., Kuenen, J., Zhang, J., Moran, M.D., Makar, P.A.: Analysis of the emission inventories and model-ready emission datasets of Europe and North America for phase 2 of the AQMEII project, J. Atmospheric Environment, 2015.

Ramanathan, V., and Feng, Y.: Air pollution, greenhouse gases and climate change: Global and regional perspectives, Atmos. Environ., 43, 37-20, 2009.

Rufino, M.C., Brandt, P., Herrero, M., Butterback-Bahl, K., Reducing uncertainty in nitrogen budgets for African livestock systems, Environmental Research Letters, Vol 9 (2014), doi: 10.1088/1748-9326/9/10/105008

Streets, D., van Aardenne, J., Battye, B., Garivait, S., Grano, D., Guenther, A., Klimont, Z., Lamarque, J.-F., Lu, Z., Janssens-Maenhout, G., Ohara, T., Parrish, D., Smith, S., Vallack, H.: HTAP Report, Part A: Chapter 3: Emission Inventories and Projections, 2010.

Tu, K.J., Industrial organisation of the Chinese coal industry. Freeman Spogli Institute for International Studies, Working Paper 103, http://pesd.standford.edu/publications/23284, 2011.

UNFCCC: NIR submissions of the greenhouse gas inventories for Annex I countries, http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/7383.php, 2013.

UNPD (UN Population Division): World Population Prospects (WPP), The 2012 Revision, UN Department of Economic and Social Affairs, Population Division, 2013.

van der Werf, G.R., Randerson, J.T., Giglio, L., Collatz, G.J., Mu, M., Kasibhatla, P.S., Morton, D.C., DeFries, R.S., Jin, Y., van Leeuwen, T.T.: Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009), Atmospheric Chemistry and Physics, 10, 11707-11735, doi:10.5194/acp-10-11707-2010, 2010.

van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Matsui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S.K.: The representative concentration pathways: an overview, Climatic Change, 2011.

Wang, S. X., Zhao, B., Cai, S. Y., Klimont, Z., Nielsen, C., McElroy, M. B., Morikawa, T., Woo, J. H., Kim, Y., Fu, X., Xu, J. Y., Hao, J. M., and He, K. B.: Emission trends and mitigation options for air pollutants in East Asia, Atmos. Chem. Phys. Discuss., 14, 2601-2674, 10.5194/acpd-14-2601-2014, 2014.

Weng, Z., Mudd, G. M., Martin, T., Boyle, C. A.: Pollutant loads from coal mining in Australia: Discerning trends from the National Pollutant Inventory (NPI), Environ. Sci. Pol., 19, 78, 2012.

Formatted: Highlight

World Bank: Data from database: World Development Indicators. Last Updated: 11/06/2014, http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators#, 2014.

Yevich, R., Logan, J.A.: An assessment of biofuel use and burning of agricultural waste in the developing world, Global Biogeochemical Cycles, 17 (4), 1095, doi: 10.1029/2002GB001952, 2003.

Tables

Table 1a~~:~~ - Overview of the data sources and their generic characteristics, as used for the different regions in HTAP_v2.2

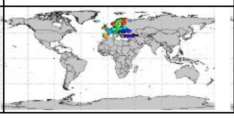
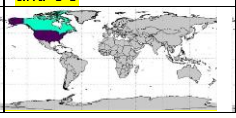
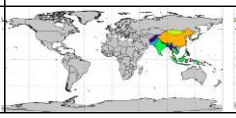
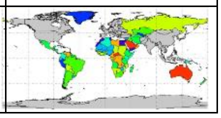
Data source	EMEP-TNO (MACCII)	US EPA _ Environ Can	MICS-Asia (+ REAS2.1)	EDGARv4.3 (prelim.)
Type of data source	Country inventories + point sources	State inventories + point sources	County inventory for China + country inventories from CAPSS & REAS 2.1	Country inventories from the preliminary version of EDGARv4.3
Coverage of human activities	All except international shipping and except international aviation	All except international shipping and except international aviation	All except international shipping, international aviation and agricultural waste burning	All inclusive international shipping and international aviation
Temporal resolution	Yearly gridmaps (monthly profiles of EMEP model added)	Monthly profiles	Monthly gridmaps	Monthly profiles (for 3 different latitude bands)
Spatial resolution	0.125° x 0.0625° converted to 0.1°x0.1° by raster resampling with factor 1/5x1/5 and aggregation of 4x8	0.1° x 0.1° and height profiles	0.25° x 0.25° converted to 0.1° x 0.1° by raster resampling 1/5x1/5 and aggregation of 2x2	0.1° x 0.1°
Substances	CO, NMVOC, NOx, SO2, NH3, PM coarse and fine and BC/OC fractions	CO, NMVOC with speciation, NOx, SO2, NH3, PM10, PMfine, BC and OC	CO, NMVOC, NOx, SO2, NH3, PM10, PM2.5, BC and OC	CO, NMVOC, NOx, SO2, NH3, PM10, PM2.5, BC and OC
Geocoverage used in HTAP_v2.2				

Table 1b ~~-~~ Sectors in the HTAP_v2.2 inventory (only anthropogenic sources are included) and the corresponding Nomenclature for Reporting (NFR) and the Selected Nomenclature for Sources of Air Pollution (SNAP) codes as spelled out in the EMEP (2002) Reporting Guidelines.

Tag	Description	IPCC level (NFR code)	EMEP SNAP code
htap_1_AIR~~ircraft~~	International and domestic aviation	1.A.3a(i)+(ii)	S8(*)
htap_2_SHIPS~~International Shipping~~	International shipping	1.A.3d(ii)	
htap_3_ENERGY~~Power industry~~	Power generation	1.A.1a	S1
htap_4_INDUSTRY~~Industry~~	industrial non-power but large-scale combustion emissions and emissions of industrial processes (**) and product use	1.A.1b+c, 1.A.2, 1.B.1+2, 2.A+B+C+D+G, 3	S3 + S4 + S5 + S6 (***)

Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight

	inclusive solvents.		
htap_5_TRANSPORTGround transport	Ground tTransport by road, railway, inland waterways, pipeline and other ground transport of mobile machinery (#). Htap_5 does not include re-suspended dust from pavements or tyre and brake wear.	1.A.3b+c+d(ii)+e	S71 + S72 + S73 + S74 + S75 + S8 (##)
htap_6_RESIDENTIALResidential	Small-scale combustion, including heating, cooling, lighting, cooking and auxiliary engines to equip (###) residential, commercial buildings, service institutes, and agricultural facilities and fisheries; solid waste (landfills/ incineration) and wastewater treatment.	1.A.4+5 6.A+B+C+D	S2 + S9
htap_8_AGRICULTUREgriculture	Agricultural emissions from livestock, crop cultivation but not from agricultural waste burning and not including Savannah burning	4.A+B+C+D	S10

Notes: (*) S8 (point source) includes local emissions of aircrafts around the airport only below 3000ft,

(**) Product testing by the manufacturer inside is not considered an emission of the building (htap_6) but taken up under the industry (htap_4). The oil production sector is completely covered in htap_6 and includes the fugitive (evaporative) emissions (mainly NMVOC) during the oil & gas exploration and production and transmission. As such, there are NMVOC emissions along the oil tanker tracks visible under the htap_4 sector).

(***) Note that S34=S3+ S4 in the TNO-MACC-II inventory (Kuenen et al., 2014). Fuel transformation processes (and refineries) are included here.

(#) The pipeline transport does not include transmission of natural gas and crude oil, because the latter is included in the oil and gas production industry under htap_4 but it does include the transport of refined products (motorgasoline, diesel, liquefied petroleum gas) or goods. The other ground transport includes all mobile (non-stationary) machinery (as used in the agriculture, forestry or construction sector).

(##) For the split-up of SNAP7 into S71 S72, S73, S74 and S75 we refer to the definitions used for the TNO-MACCII inventory documented in (Kuenen et al., 2014)

(###)In particular industrial, commercial and/or agricultural buildings can be more extensively equipped with auxiliairy stationary (non-mobile) infrastructure in and around the building (e.g. lifting devices).

Table 2a - Comparison of the international shipping emissions: IMO Bottom up (BU) and IMO Top Down (TD) emissions of the IMO(2014) study and the EDGAR emissions of the HTAP_v2.2 (2015) study

kton /yr	BC	CO	NMVOC	NOx	OC	PM10	PM2.5	SO2
EDGAR 2008	34	1340	730	13762	458	1376	1376	8348
IMO BU 2008		864	727	20759		1545	1545	11041
IMO TD 2008		553	615	18442		1221	1221	8280
EDGAR 2010	33	1300	720	14000	430	1400	1400	8300
IMO BU 2010		763	593	16708		1332	1332	9895
IMO TD 2010		574	638	19098		1304	1304	9232

Formatted: Highlight

Table 2b. - Comparison of per capita emissions in 2010 for USA, Germany, and China, India, Russia and Japan from HTAP_v2.2

Formatted: Highlight

Substance	USA	Germany	China
kg SOx/yr/cap	32.6	5.2	20.9
kg NOx/yr/cap	43.6	14.2	20.8
kg VOC/yr/cap	43.1	11.9	16.7
kg CO/yr/cap	148.3	35.6	125.6
kg NH3/yr/cap	11.6	7.3	6.7
kg PM2.5/yr/cap	5.3	1.1	12.2
kg BC/yr/cap	0.9	0.2	1.3

Substance	USA	Germany	China	India	Russia	Japan
ton CO2(long cycle C) /yr/cap	17.6	9.9	6.4	1.5	11.9	9.7
HDI	0.91	0.9	0.7	0.57	0.77	0.88
kg SOx/yr/cap	32.6	5.2	21	8.0	31.9	5.2
kg NOx/yr/cap	43.6	14.2	20.8	7.9	25.1	14.5
kg VOC/yr/cap	43.1	11.9	16.9	14.0	26.9	9.1
kg CO/yr/cap	148.3	35.6	125.6	56.0	52.8	33.1
kg NH3/yr/cap	11.6	7.3	6.7	8.2	6.3	3.7
kg PM2.5/yr/cap	5.25	1.08	8.93	5.19	2.18	0.62
kg BC/yr/cap	0.95	0.20	1.29	0.85	0.29	0.16

Formatted: Highlight

Table 2c - Comparison of emissions per unit of GDP in 2010 for USA, Germany, China, India, Russia and Japan from HTAP_v2.2

Substance	USA	Germany	China	India	Russia	Japan
kg $CO2_{(long\ cycle\ C)}$ /yr/USD	339.71	287.79	240.88	136.6	644.58	267.08
GDP/cap	49307	39668	9230	4638	21663	34561
g SOx/yr/USD	0.668	0.132	2.310	1.719	1.482	0.150
g NOx/yr/USD	0.892	0.363	2.295	1.714	1.166	0.419
g VOC/yr/USD	0.882	0.305	1.863	3.013	1.249	0.263
g CO/yr/USD	3.036	0.910	13.830	12.069	2.449	0.957
g NH3/yr/USDP	0.236	0.187	0.735	1.770	0.291	0.108
g PM2.5/yr/USD	0.108	0.028	0.984	1.119	0.101	0.018
g BC/yr/USD	0.019	0.005	0.143	0.183	0.013	0.004

Table 3. Variables' uncertainties for sector- and country-specific totals per region with qualitative classification using the abbreviations Low (L), Low-Medium (LM), Upper-Medium, and High (H). The legend provides an interpretation of the level Low, Low-Medium, Upper-Medium and High, which is indicatively specified for two groups of countries with two different statistical infrastructures.

	SO2	NOx	CO	NMVOC	NH3	PM	BC/OC	With legend:	
htap1_AIRair	L	LM	LM	UM	LM	UM	UM	countries with well maintained statistical infrastructure	Countries with poorly maintained statistical infrastructure
htap2_SHIPSship	L	LM	LM	UM	LM	H	H		
htap3_ENERGYenergy	L	LM	LM	UM	LM	UM	UM		
htap4_INDUSTRYindustry	LM	LM	LM	UM	UM	LM	LM	L< 15%	L< 35%
htap5_TRANSPORTground transport	LM	UM	UM	UM	H	H	H	15% ≤ LM < 50%	35% ≤ LM < 70%
htap6_RESIDENTIALresidential	LM	UM	UM	UM	H	H	H	50%≤UM<100%	70%≤UM<150%
htap8_AGRICULTUREagriculture	UM	UM	UM	UM	H	H	H	100% ≤ H	150% ≤ H

Note: The statistical infrastructure of a country determines the uncertainty of the country's emission inventory. Andres et al. (2012) consider under the countries with well maintained statistical infrastructure: the 24 OECD-1990 countries (Australia, Austria, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Ireland, Iceland, Italy, Japan, Luxembourg, The Netherlands, Norway, New Zealand, Portugal, Sweden, Turkey, and the United States) as well as India (using the British statistical accounting system according to Marland et al. (1999). For the other countries, a larger range in uncertainty is present, for which we refer to Gregg et al. (2008) or Tu (2011) and Olivier (2002). The sector-specific uncertainty of the activity and the quality and representativeness of the controlled emission factors play an important role. The standard range of uncertainty already varies according to tThe EMEP/EEA (2013) Guidebook's Uncertainties Chapter 5 for the absolute annual total of different pollutants between at least 10% for SO2, at least 20% for NOx and CO, at least 50% for NMVOC, an order of magnitude for NH3, and PM10, PM2.5, BC and OC. These considerations have been taken into account to qualitatively indicate a low (L), low medium (LM), upper medium (UM) or high (H) uncertainty for the different sectors and speciesubstances. Countries with well maintained infrastructure are mainly the 24 OECD(1990) countries and India. Other countries are considered to have a relative poorly maintained statistical infrastructure.

Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight

Figures

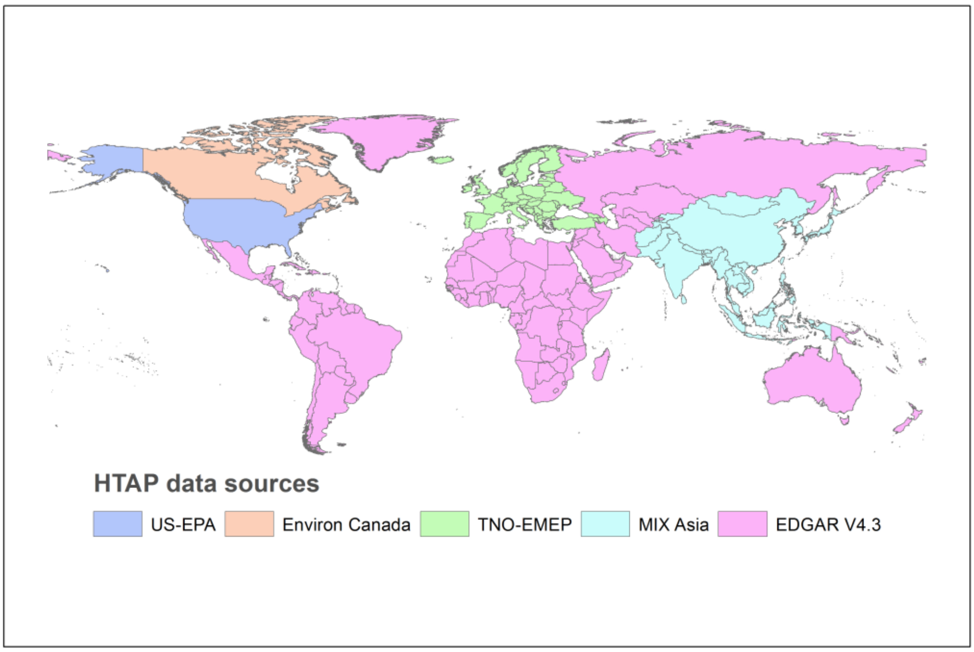


Figure 1a – Collection of regional emission inventories (US-EPA, Environ Canada, TNO-EMEP, MIX (MICS-Asia III), EDGARv4.3 for the global air pollutants and their use for world countries in dataset HTAP v2.2

Formatted: Highlight

Formatted: Highlight

Formatted: Highlight

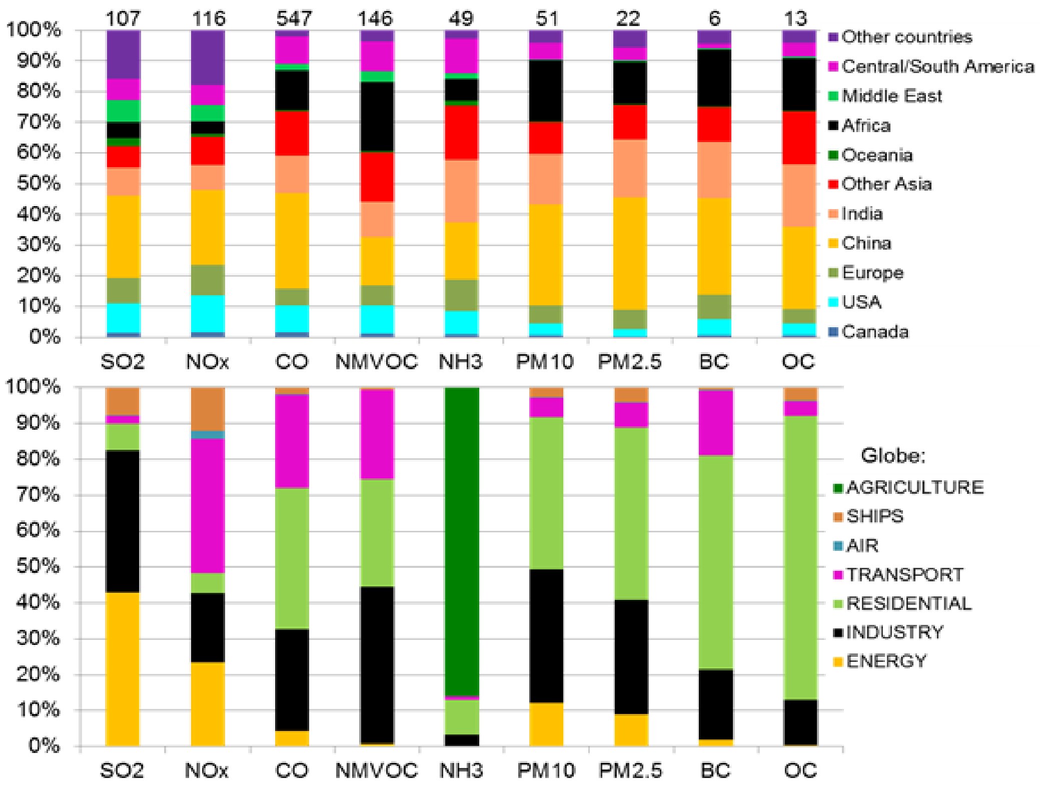


Figure 1b - Regional relative contribution to 2010 pollutant emissions (upper panel). Asian emissions have been divided into China, India and other Asia fractions from the MIX~~CS~~ database. The region "rest of the world" has been disaggregated into Oceania, Africa, Middle East, Central/South America and other countries making use of the EDGAR v4.3 inventory. Global sector-specific anthropogenic emissions of gaseous pollutants and particulate matter components for the year 2010 (lower panel). Global absolute emissions are reported on top of each bar in Tg species per year. Large scale open-biomass burning is not included in the analysis.

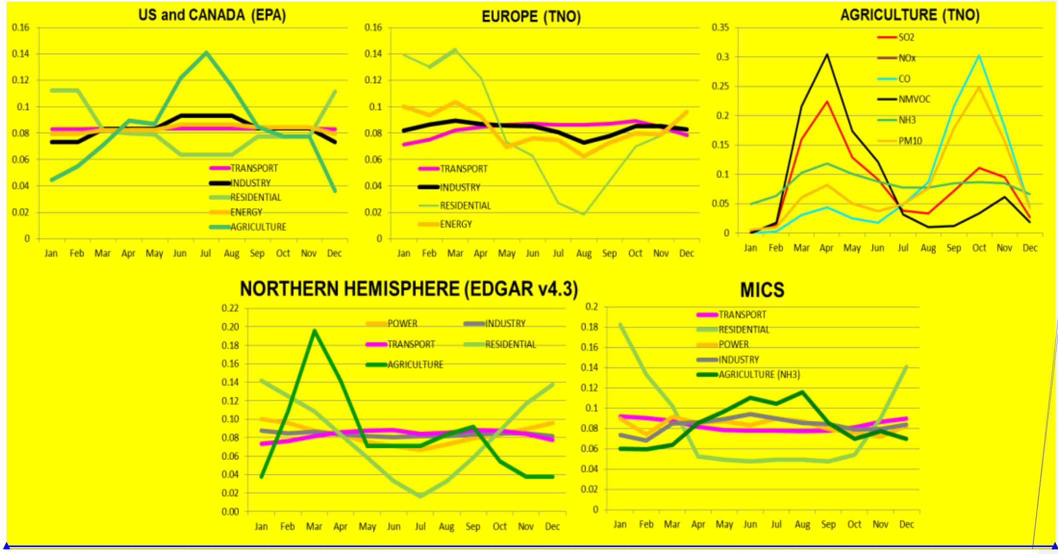
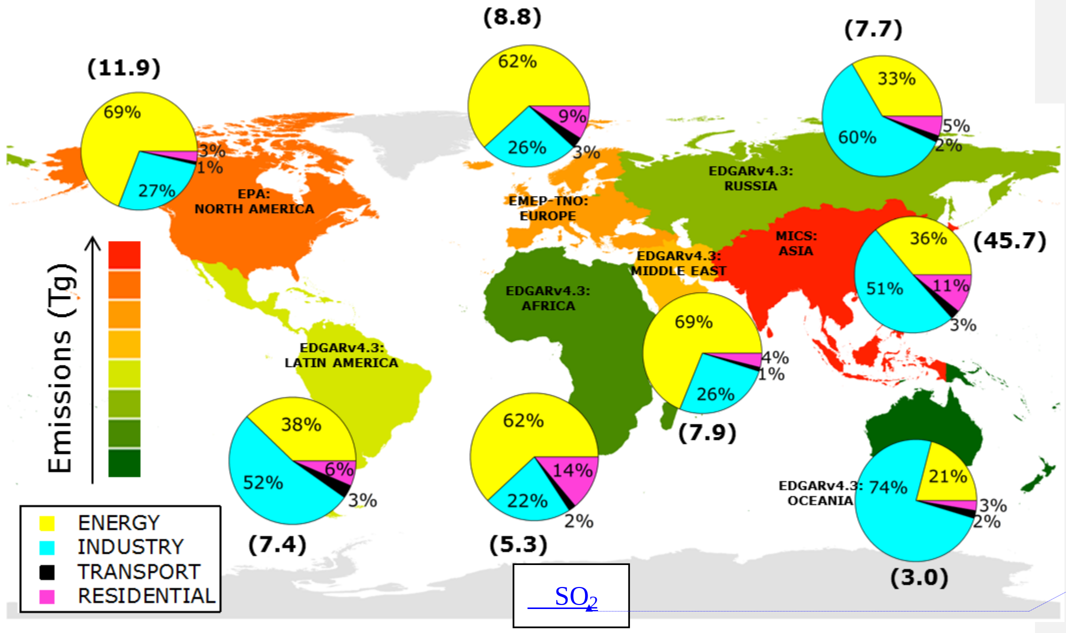


Figure 1c – Temporal profiles with relative factors varying around 1/12 and applied on the yearly emissions of the different data sources (US-EPA for US and Canada, EMEP-TNO for Europe with compound-specific variation of the agricultural temporal profiles, EDGAR temporal profiles for the Northern hemisphere and MICS profiles for Asia).



Formatted: Highlight

Formatted: Highlight

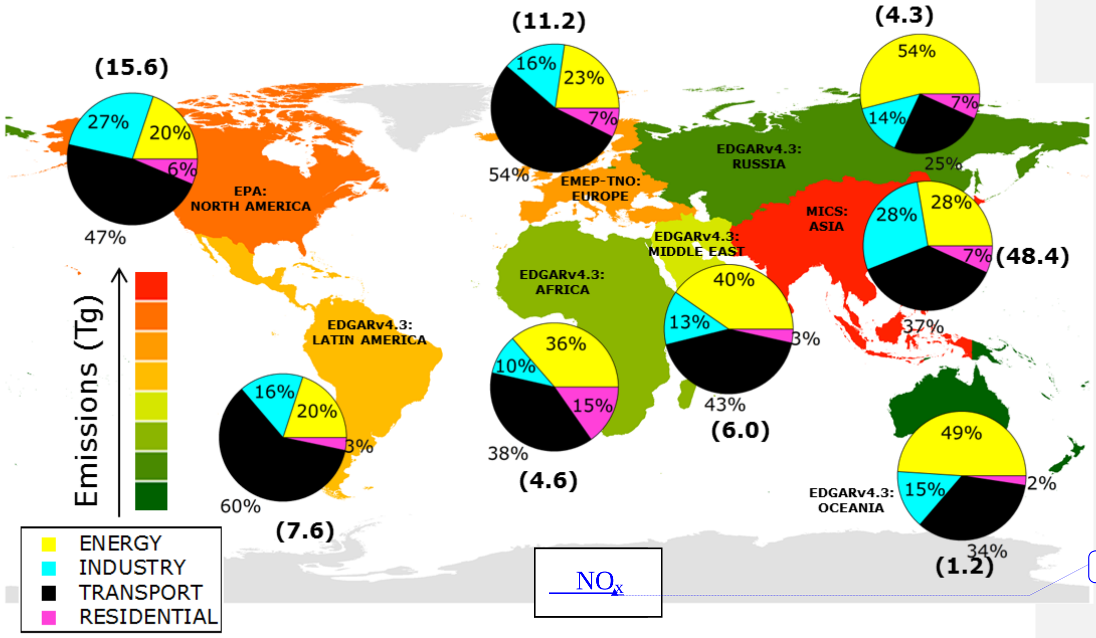
Formatted: Justified

Formatted: Highlight

Formatted: English (U.K.)

Formatted: Subscript

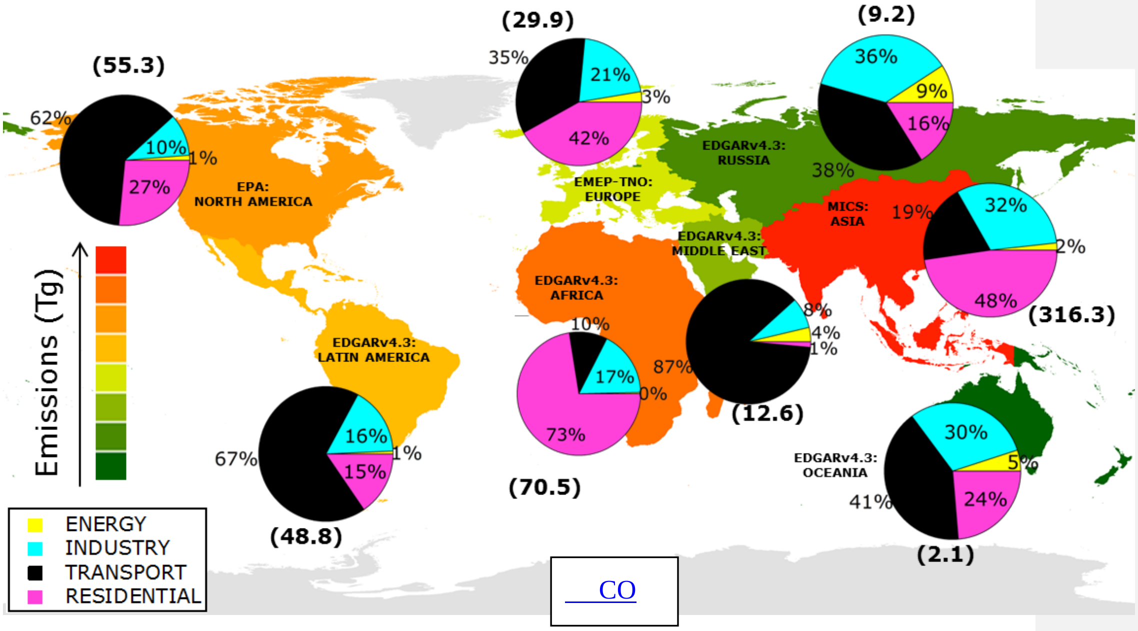
~~Figure 2a- Total Tg SO2 emissions for 2010 (in brackets) and sector-specific composition for world regions.~~



NO$_x$

Formatted: Subscript

~~Figure 2b- Total Tg NOx emissions for 2010 (in brackets) and sector-specific composition for world regions.~~



CO

Figure 2c- Total Tg CO emissions for 2010 (in brackets) and sector-specific composition for world regions.

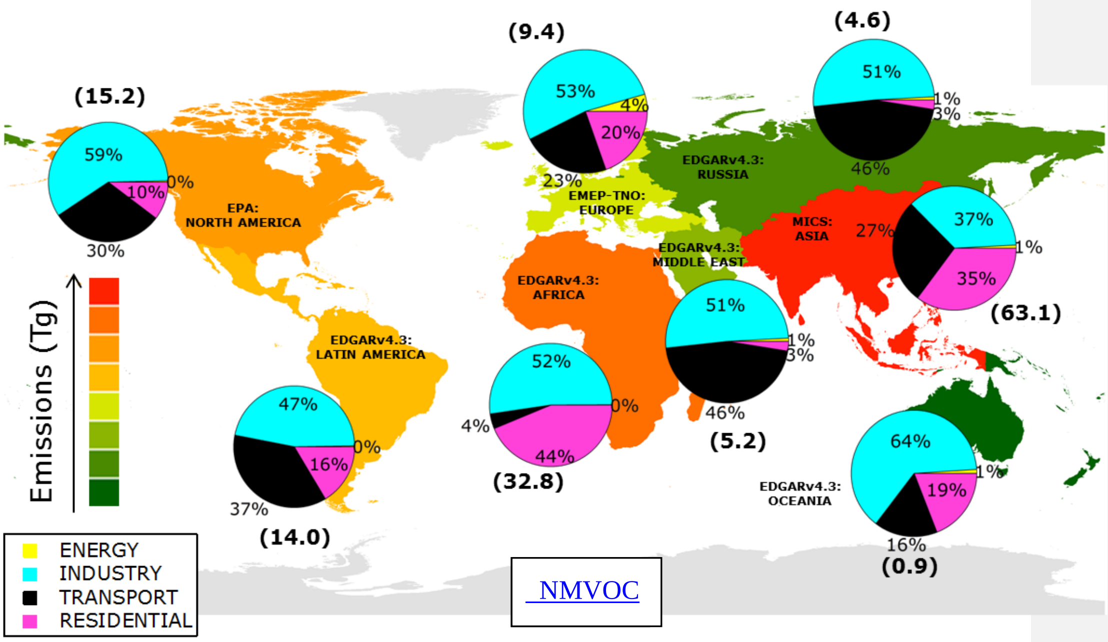
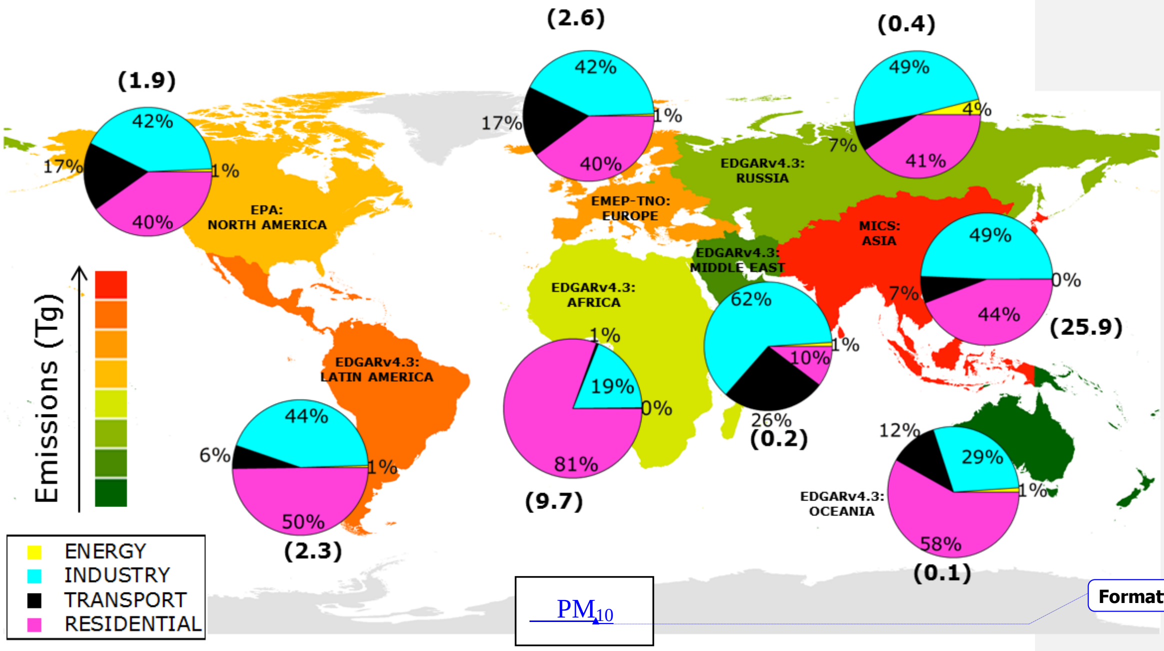
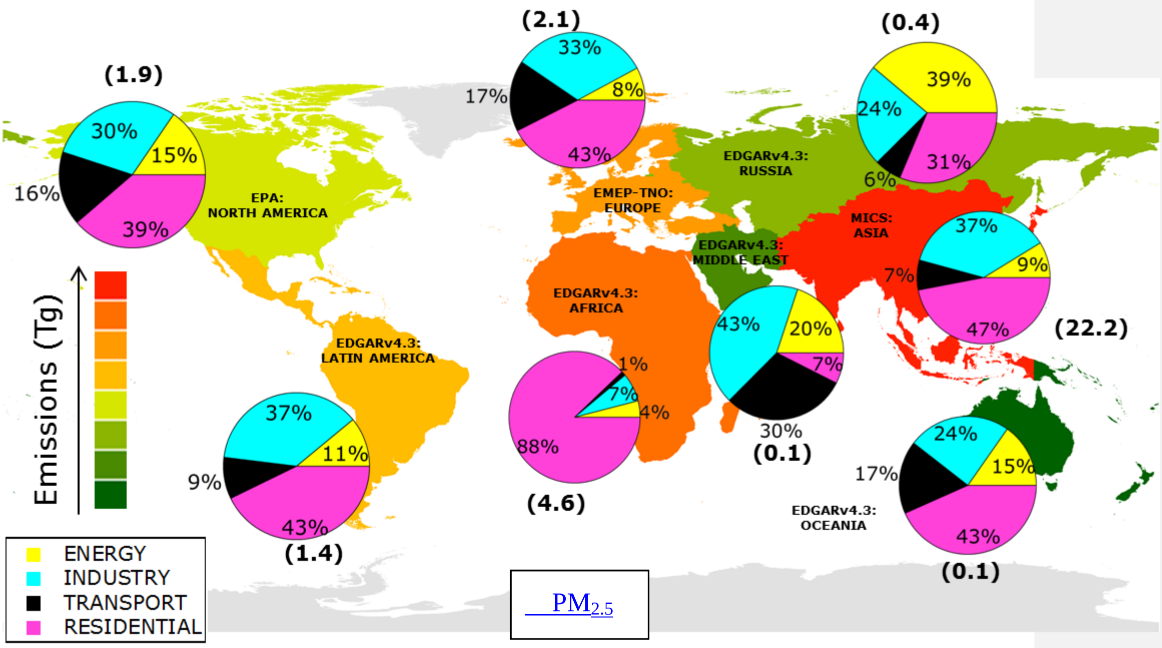


Figure 2d- Total Tg NMVOC emissions for 2010 (in brackets) and sector-specific composition for world regions.

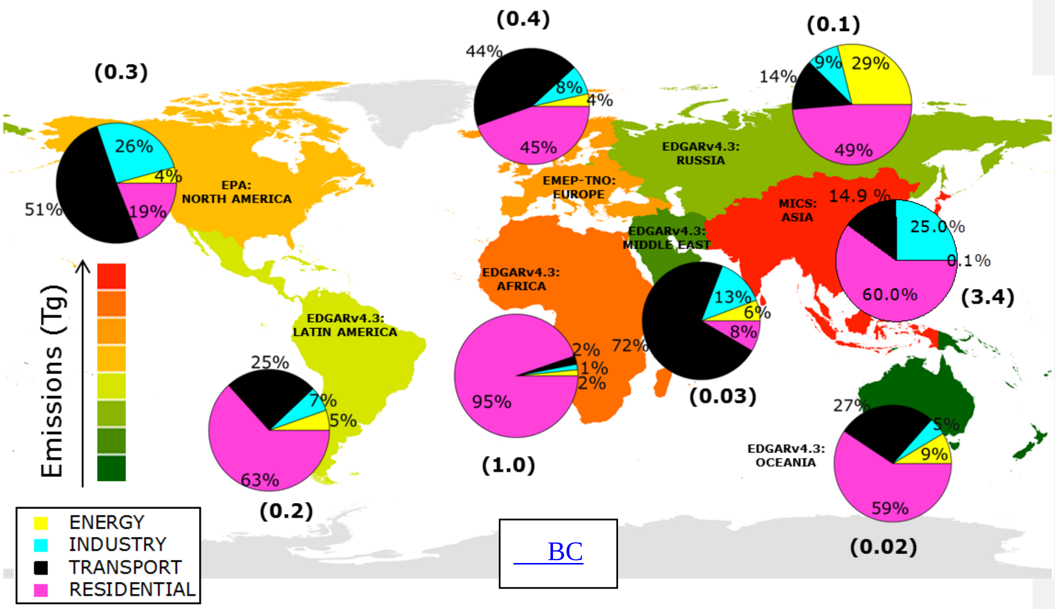


Formatted: Subscript

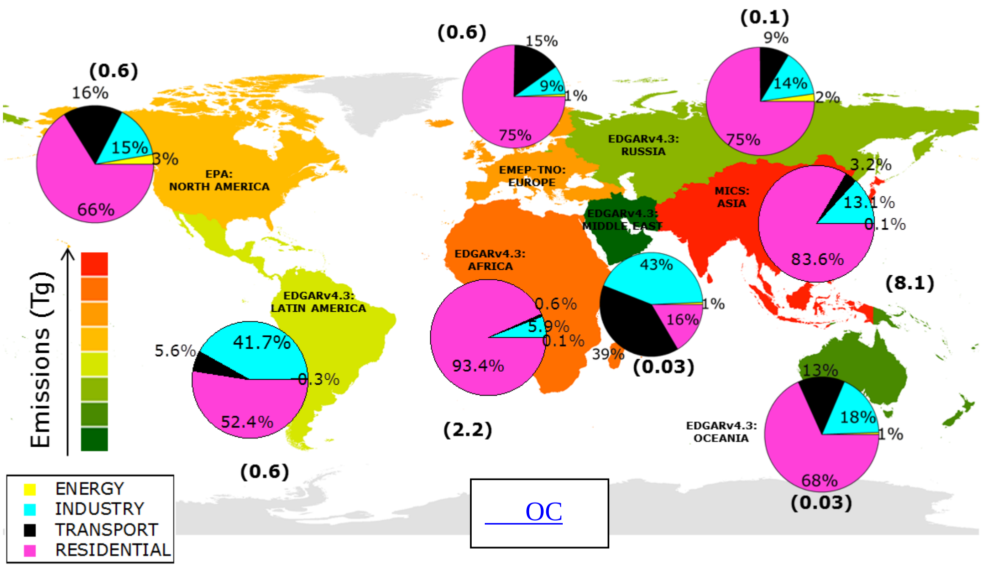
~~Figure 2e- Total Tg PM_{10} emissions for 2010 (in brackets) and sector-specific composition for world regions.~~



~~Figure 2f- Total Tg $PM_{2.5}$ emissions for 2010 (in brackets) and sector-specific composition for world regions.~~

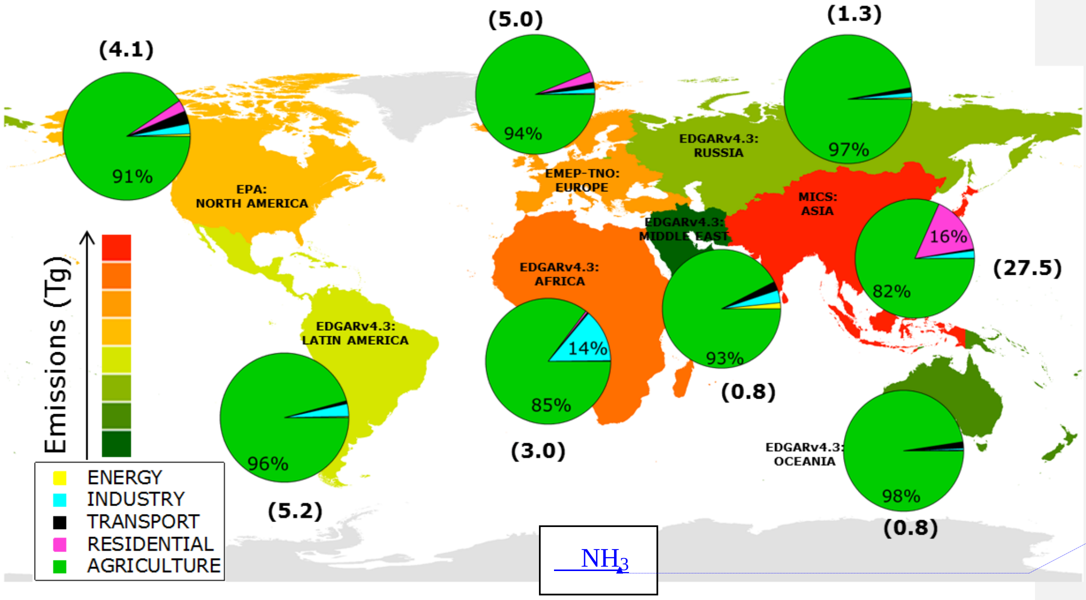


~~Figure 2g- Total Tg BC emissions for 2010 (in brackets) and sector-specific composition for world regions~~.



OC

~~Figure 2h- Total Tg OC emissions for 2010 (in brackets) and sector-specific composition for world regions.~~



NH_3

Formatted: Subscript

Figure 2: Sector-specific breakdown of regional emission totals (Tg) for 2010: SO2, NOx, CO, NMVOC, PM10, PM2.5, BC, OC and NH3.~~i- Total Tg NH3 emissions in 2010 (in brackets) and sector-specific composition for world regions~~.

Formatted: Highlight

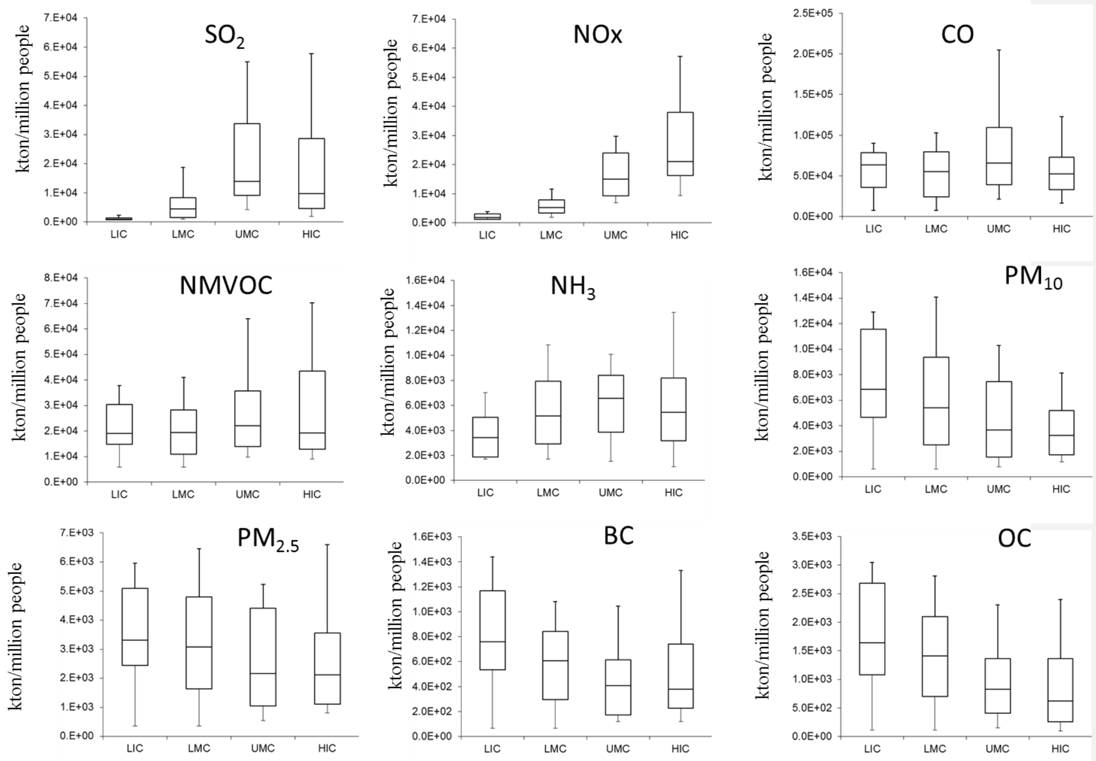


Figure 3a 2010 per capita emissions per substance and per group of countries: low income (LIC), lower middle income (LMC), upper middle income (UMC) and high income (HIC) with the maximum, and minimum and the percentiles reported in the box plot (10°, 50°, 90°) and the maximum and minimum in each group of countries.

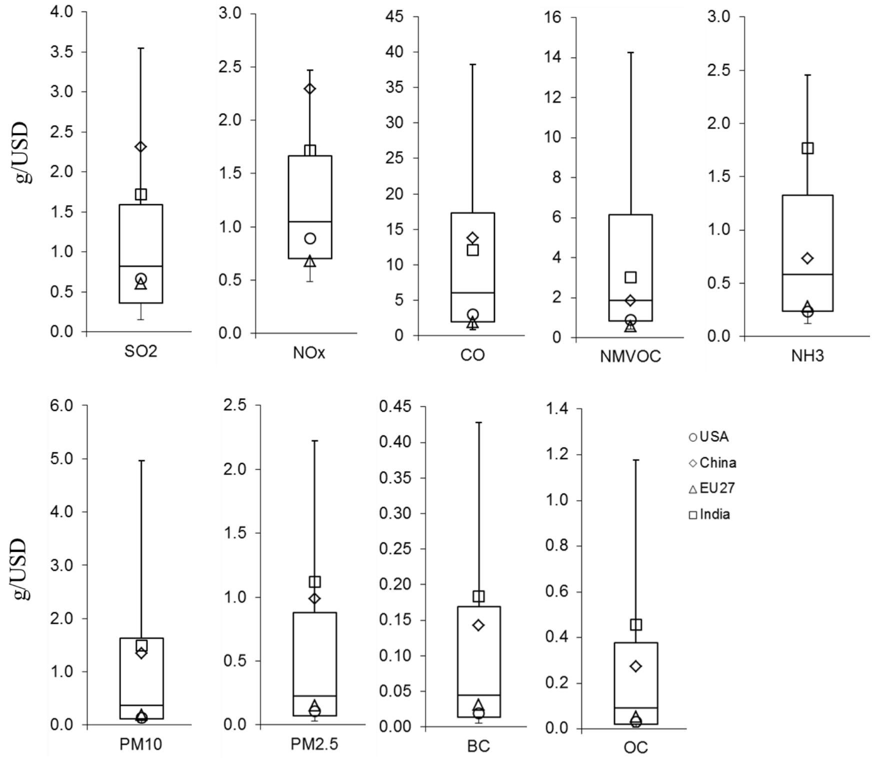


Figure 3b – Pollutant specific emissions divided by GDP (g/USD) for the year 2010. Percentiles are reported in the box plots (10°, 25°, 50°, 75°, 90°) together with emission/GDP for specific regions (EU27, USA, China and India).

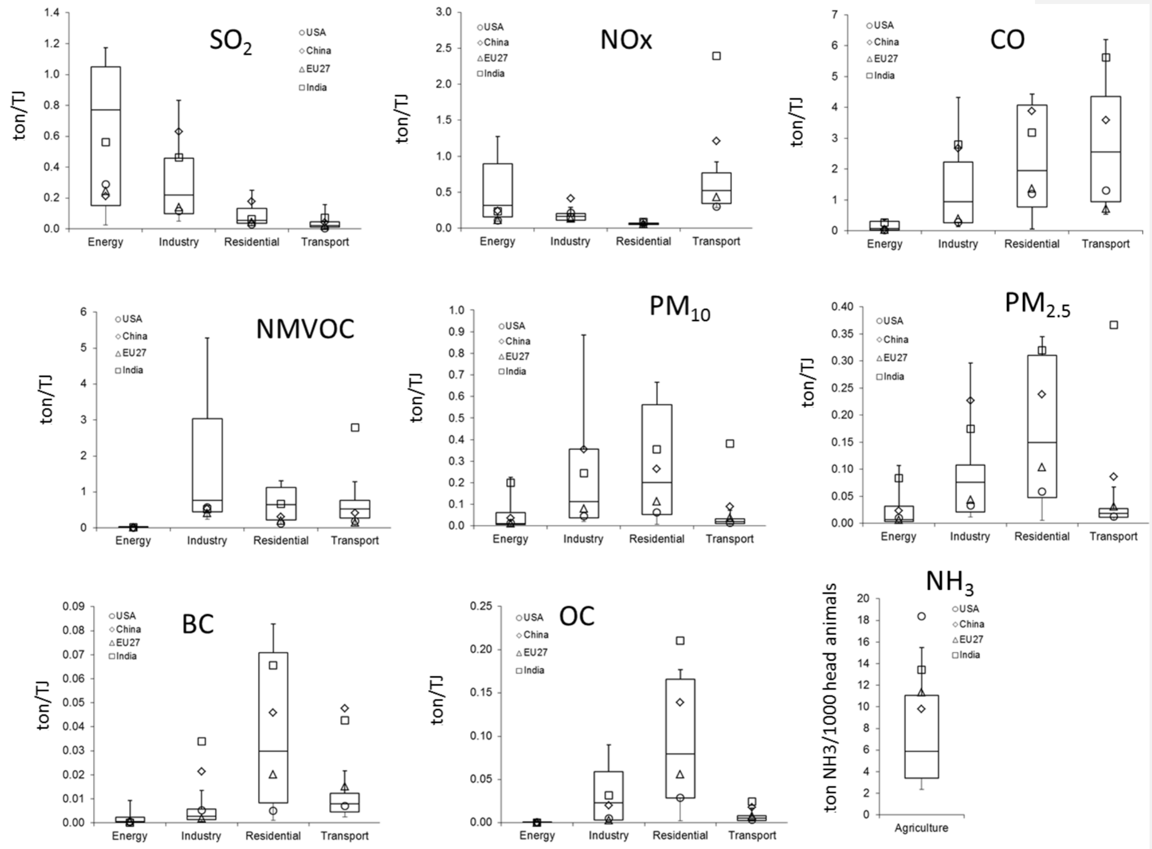


Figure 4 - Sector specific implied emissions (ton/TJ) for the year 2010. Percentiles are reported in the box plots (10°, 25°, 50°, 75°, 90°) together with implied emission factors for specific regions (EU27, USA, China and India). For the percentiles the following countries are left out:

For CO: for the INDUSTRY sector: Togo, Eritrea, Congo, Côte d'Ivoire, Kenya, Benin; for the RESIDENTIAL sector: Maldives; for the TRANSPORT sector: North-Korea, Afghanistan, Laos, Tajikistan, Mongolia.

For SO2: for the INDUSTRY sector: Namibia, Laos, Jamaica.

For NOx: for THE RESIDENTIAL sector: Maldives; for the TRANSPORT sector: Afghanistan, Laos, North-Korea, Tajikistan.

For NMVOC: for the ENERGY sector: Bhutan; for the INDUSTRY sector: Togo, Eritrea, Côte d'Ivoire, Congo, Cameroon, Kenya, Benin, Aruba, Antigua, Bahamas, Ethiopia, Sudan, Senegal, Equatorial Guinea, Central African Rep., Sri Lanka, Angola, Mozambique, Zambia, Jamaica; for the RESIDENTIAL sector: Am. Samoa, Gum, Maldives, Tonga; for the TRANSPORT sector: Afghanistan, Laos, North-Korea.

For PM10: for the INDUSTRY sector: Togo, Eritrea, Côte d'Ivoir, Congo, Kenya, Benin, for the TRANSPORT sector: Afghanistan.

For PM2.5: for the ENERGY sector: Tajikistan, Luxembourg; for the INDUSTRY sector: Togo and Eritrea; for the TRANSPORT sector: Afghanistan.

For BC: for the ENERGY sector: Nigeria, Malaysia, Belgium, Oman, Finland, Georgia, Vietnam, Canada, Armenia, Tunisia, Jordan, The Netherlands, Trinidad and Tobago, Algeria, Latvia, United Arab Emirates, Brunei, Turkmenistan, Japan, Mozambique, Congo, Qatar, Bahrain, Moldova, Kyrgyzstan, South-Korea, Taiwan, Luxembourg, Bhutan, Tajikistan; for the INDUSTRY: Trinidad and Tobago, Malta; for the TRANSPORT sector: Afghanistan.

For OC: for the ENERGY sector: Tunisia, Jordan, Trinidad and Tobago, Algeria, United Arab Emirates, Brunei, Turkmenistan, Tajikistan, Mozambique, Congo, Qatar, Bahrain, Kyrgyzstan, Taiwan, Myanmar, South-Korea, Vietnam; for the INDUSTRY sector: Bahrain, Eritrea; for the RESIDENTIAL sector: Greenland, Gibraltar, Faroe Islands, Saint Pierre et Miquelon; for the TRANSPORT sector: Afghanistan

For NH3: for the AGRICULTURE sector: Faroe Islands, Tajikistan, Greenland, Falkland Islands, Kyrgyzstan, South-Korea, Brunei, Am. Samoa, Malaysia, Trinidad and Tobago, Bahamas, Saint Pierre et Miquelon, Sri Lanka, Suriname, Réunion, Thailand, Indonesia, Japan, Barbados, Bhutan, Guyana, Costa Rica.