Attributing and Verifying European and National Greenhouse Gas and Aerosol Emissions and Reconciliation with Statistical Bottom-up Estimates

Deliverable 3.1
Input data for aerosol inversions

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Attributing and Verifying European and National Greenhouse Gas and Aerosol Emissions and Reconciliation with Statistical Bottom-up Estimates (AVENGERS)

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1 Introduction WP3 Aerosol emissions and radiative forcing

AVENGERS work package 3 (WP3) is devoted to the radiative impacts of anthropogenic aerosols, which will be quantified for Europe and the 5 case-study countries (SE, DE, NL, CH and IT) to allow a comparison with radiative impacts of national GHG emissions. The quantification of aerosol radiative forcing will include contributions from Aerosol-Radiation Interactions and Aerosol-Cloud Interaction. Forcings are calculated in a two-step approach. First, primary aerosol emissions are estimated from ground-based measurements networks and satellites, using data assimilation systems that have been developed for aerosols. Secondly, the EC-Earth earth system model is used to calculate the radiative forcing arising from those emissions. Output from this WP will be combined with that of WP2 in a consistent manner to derive radiative forcings by country in WP1 that account for the contribution from long-lived GHGs and aerosols.

1.1 Prior emission datasets for aerosols

Under task 3.1 Prior emission datasets and observational data for aerosols, two different regional European prior emission datasets for aerosols are nested in a global emission grid The first dataset is based on the CAMS-REG inventory (Kuenen et al, 2022) and also includes aerosol precursor emissions (SO2, NH3, NOx etc.). This dataset is in line with official reporting by national inventory agencies. The second dataset is a modified version of the CAMS-REG dataset that includes the contribution from the condensable PM fraction for residential wood/coal combustion in a consistent way for all countries. This dataset is following the aerosol emission estimation including condensable particulate matter as first described in Denier van der Gon et al. (2015), which was recently updated (Simpson et al. 2022).

2 Methodology for the aerosol emissions dataset

The task started with Milestone 2 of the AVENGERS project “Test sets for aerosol emission data” (delivered in March, 2023). The milestone consisted of a test data set to the modelers within AVENGERS WP3 with the request to check if the format is suitable and if the resolution and species would be satisfactory. The proposed dataset is the HTAPv3 emission data set (Crippa et al., 2023). The advantage of the HTAPv3 dataset is that it includes the TNO European emission data nested in a recent global dataset and the documentation is available in the form of peer-reviewed paper. It was confirmed that the resolution (0.1 x 0.1 degree) is sufficient and all species needed are available. Additional work on the dataset is needed to have the desired years (2011 and 2021) and the aerosol emission scenarios as outlined in the AVENGERS DoW. The following steps were taken.

- Emission grids for the years 2011 and 2018 from HTAP_v3 are used as the basis. 2018 is the most recent year available in HTAPv3.
- Since 2018 is the most recent year in HTAPv3 it was investigated if the change in emission (for both particulate matter and its precursors) in the European domain between 2018 and 2021 was significant. It was confirmed that the change in emissions between 2018 and 2021 is significant, implying that 2018 is not a good representation for the year 2021. This means additional work on the European data in the HTAPv3 dataset is needed to provide 2021 emissions.
- For the non-European part of HTAPv3 (rest of the world) we will not extrapolate from 2018 to 2021 because data to do this in a transparent and consistent way are lacking.
- Next TNO constructed two consistent European datasets for both years 2011 and 2021;
    1. Base case: Emission data based on the most recent official reporting (CAMS-REGv5 which is also the basis for HTAPv3). For 2011 this is the version already present in HTAPv3.
    2. AVENGERS_Ref 2: Emission data with consistent inclusion of condensable PM emission from residential combustion. For both years, PM10, PM2.5, BC and OC emissions are replaced with the so called “Ref2_v2 emissions[1]” that have been developed by TNO.
- The resolution of the TNO datasets were aggregated from 0.05°x0.1° to 0.1 °x0.1° to match the resolution of HTAPv.3. It was also necessary to make small changes to the emission sector grouping for road transport and agriculture to match with the HTAPv3 sectors.
- Scaling factors between HTAPv3 2018 European emissions and the new 2021 data sets have been calculated for both the standard CAMS-REG 2021 emission data and the CAMS-REG-v6.1_Ref2_extrapolated (produced by TNO in 2023 for the CAMS2_61 project)
- These ratios are applied to the HTAPv3 2018 grids to compile the 2021 grid
- International global emission sectors (shipping and aviation) were excluded from the scaling exercise and remain as in HTAPv3. Also Russia was excluded since it is partly covered by the European domain and partly outside.
- The merging was performed by first spatially masking out all grid cells from HTAP that coincided with the 42 European countries in the CAMS-REG grid. Then the emission data for these 42 countries was added from the CAMS-REG dataset.
- Due to the methodology described above and the fact that HTAP_v3 is based on CAMS-REG-v5 and not on the latest version 6, there are differences between the AVENGERS emission inventory and the latest CAMS-REG-v6 emission inventory. The differences are caused by the country inventory submissions (use of a different reporting year) because countries may revise their methodology and then recalculate all historic data. However, also for most of the non-EU

[1] Ref2 refers to a “science-based reference scenario” to be used next to official reported data (Ref1). The most recent description can be found in Simpson et al. (2022) which is a further elaboration on the dataset developed and tested in Denier van der Gon et al (2015).

countries some of the emission data were updated for CAMS-REG-v6 using the for example results from the IIASA GAINS model. We have investigated these discrepancies and found that mostly NMVOC and CO are affected by this difference between versions, which are not very relevant for the AVENGERS aerosol inventory. We therefore concluded that the current methodology is fit-for-purpose. We did notice that the CAMS-REGv5 partly relied on EDGARv4.3 for some countries at the edge of the CAMS-REG domain (Figure 1). EDGAR4.3 is an older version than the EDGAR version used in HTAPv3. We therefore made sure that for those countries the original HTAPv3 emission data remained in the dataset (see Annex for details).

The first products made available through the TNO ftp site to the AVENGERS WP3 modellers on June 5, 2023 are annual total emissions gridded datasets. These will be further checked for consistency and errors.

- The model teams indicated to work with monthly emission datasets. TNO will make monthly files from the European datasets and follow the same procedure as done for the annual total to provide monthly emission maps.

3 Results

The result of the work following the previously described methodology are four global emission data grids representing 2 years (2011 and 2021) with two different types of European emission data. The first data set (2011 in line with official reported European emissions) is exactly as already included in HTAPv3 (Figure 1).

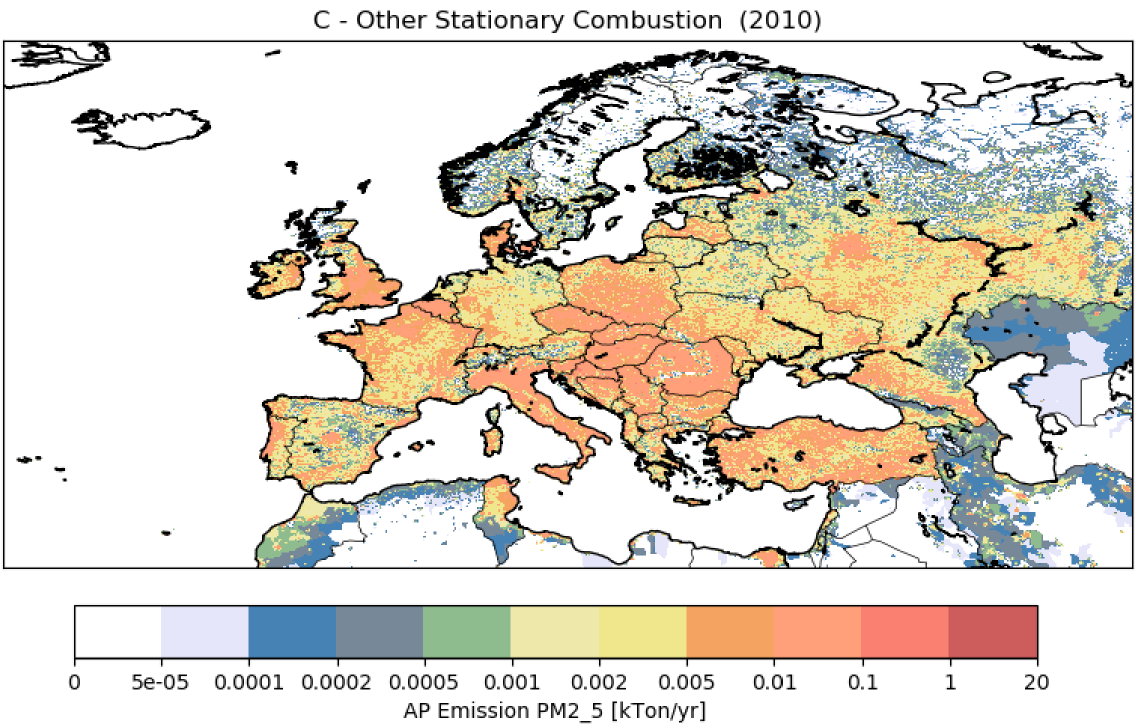

Figure 1 Example of the European domain emissions (here PM2.5) for stationary combustion as used in the HTAPv3 datset (see also Annex 6.1)

Figure 2 shows the comparison between the two datasets for the year 2011, i.e. in line with country reporting (CAMS-REGv5 / HTAP_v3) and this work, where PM2.5 (and BC/OC) emissions are replaced with bottom-up estimates which consistently include condensables. Since the discussion on inclusion of condensable PM started around 2015, countries increasingly started to report with condensables included. The Figure shows that overall emissions are largely in line, with some exceptions. This in contrast to the comparison as shown in e.g. Denier van der Gon et al. (2015). A key country is Poland, where condensables from residential combustion were not included in the official reported emissions that were the basis for HTAP_v3. From 2022 onwards, the official inventories from Poland do include the condensable component in PM emissions from residential combustion. Therefore the AVENGERS dataset is even more close to official reporting than shown in Figure 2. Overall the AVENGERS dataset as shown in Figure 2 is less than 10% higher than the HTAPv3 datset.

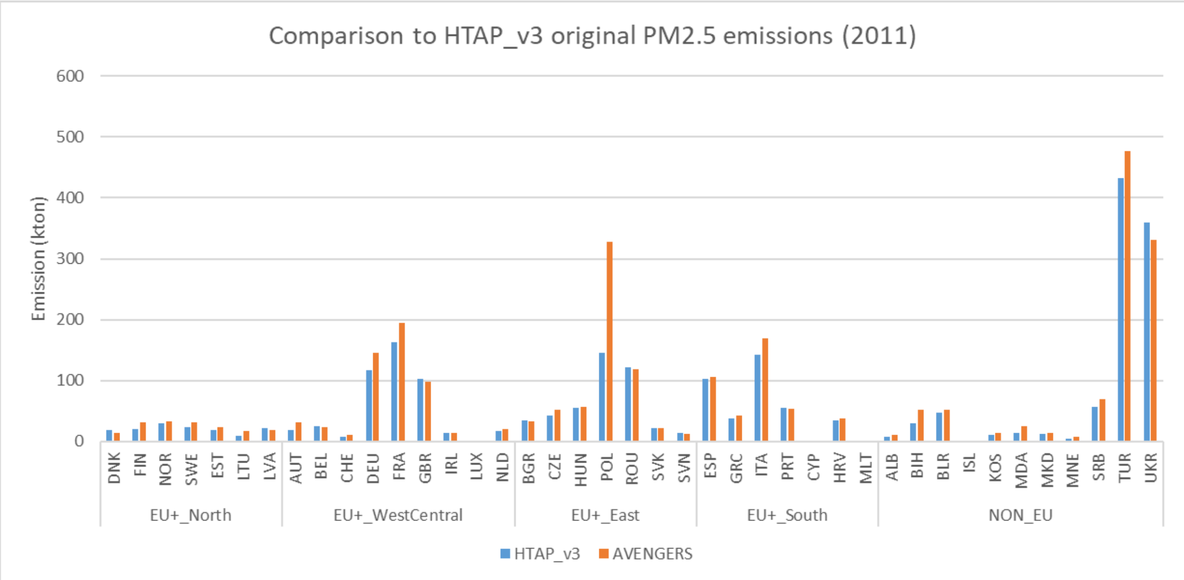

Figure 2 Comparison of the results from this work against the original HTAP_v3 emissions for PM2.5 in the year 2011

The total European emissions for the years 2011 and 2021 for the AVENGERS aerosol dataset are shown in Figure 3. The data for 2018 are also shown because 2018 is the most recent year directly available in HTAPv3. The 2018 data also illustrate that, depending on the pollutant, there is a continuing decrease in emissions since 2018. In Figure 3 the aerosol fractions and components PM10, PM2.5, black carbon (BC) and organic carbon (OC) are presented separately. However, BC and OC are by definition also included in PM10 and PM2.5, so these emissions should not be added together because that would lead to double counting.

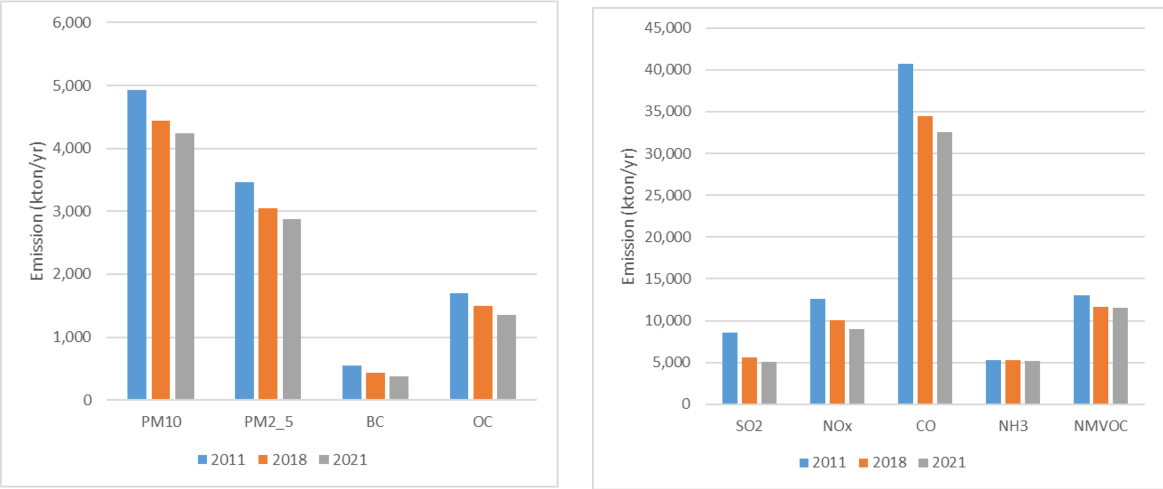

Figure 3 Total European emissions in scenario 2 (CAMS-REG + Ref2) for aerosol components (left) and other air pollutants (right) for the years 2011, 2018 and 2021.

The change in emission over time is also shown in Table 1. For most species (CO, NOX, NMVOC, PM2.5) there is around 20% emission reduction in 10 years' time (2011-2021). For SOx the emission reduction is larger (40%) while for NH3 it is negligible.

Table 1 Emissions for the EU27+Norway, Switzerland and the UK for the years 2011 and 2021 in the CAMS-REG + Ref2 + extrapolation.

species	Emission (kton)			
	2011	2021	Difference	diff-%
CO	37958	30108	-7850	-21%
NOX	11955	8884	-3071	-26%
NH3	5106	5135	29	1%
NMVOC	13303	10388	-2914	-22%
SOX	7928	4670	-3257	-41%
PM2_5	3468	2819	-649	-19%

4 Next steps

The model teams indicated to work with monthly emission datasets. TNO will make monthly emission files available for both years in June 2023. To start the modelling HTAPv3 year 2011 can already be used. This would be a no-regret exercise because comparison of results with the AVENGERS set will inform us on how important these choices are and if there are additional problems with the datasets. Therefore, first test and model runs can already be performed by the model teams.

It is recommended to evaluate the outcomes of the AVENGERS 2011 and 2021 model runs as well as the 2011 HTAPv3 vs AVENGERS dataset before making a 2021 dataset fully consistent with HTAPv3.

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5 Annex

5.1 Construction of the HTAPv3 dataset

The HTAP_v3 dataset, an ad-hoc global mosaic of anthropogenic inventories, has been developed by integrating official inventories over specific areas (North America, Europe, Asia including Japan and Korea) with the independent Emissions Database for Global Atmospheric Research (EDGAR) inventory for the remaining world regions. The results are spatially and temporally distributed emissions of SO2, NOx, CO, NMVOC, NH3, PM10, PM2.5, Black Carbon (BC), and Organic Carbon (OC), with a spatial resolution of 0.1 x 0.1 degree and time intervals of months. It is described in detail by Crippa et al. (2023). The figure below shows the different datasets that have been integrated in HTAPv3.

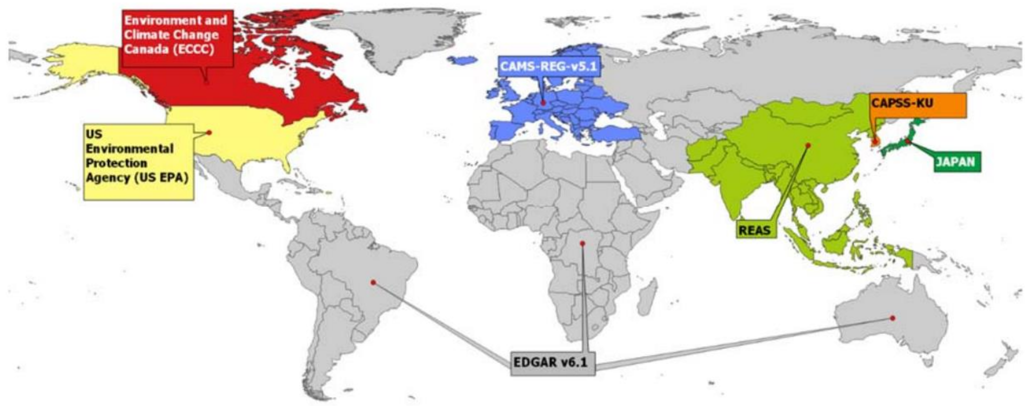

Figure 4 Overview of the HTAP_v3 mosaic data providers. Data from officially reported emission 3 gridmaps were collected from the US Environmental Protection Agency, Environment and Climate Change 4 Canada, CAMS-REG-v5.1 for Europe, REASv3.2.1 for most of the Asian domain, CAPSS-KU for Korea 5 and JAPAN (PM2.5EI and J-STREAM) for Japan.

5.2 Comparison EDGARv4.3.1 and EDGAR v6.1

Since the CAMS-REG dataset uses EDGAR data for a set of countries within the European model domain we checked the older EDGAR data against the latest version. This led to the conclusion that it was important to stay fully consistent with the HTAP set also for the Non-European countries in the CAMS-REG domain. The result is given in Table 2. This is information is provided to motivate choices made. It is not used as such.

Table 2 Comparison between EDGAR version V4.3.1 and V6.1 for the year 2010 for the countries in the CAMS-REG domain where EDGAR emission data are used.

Comparison for year 2010																			
		BC	BC	OC	OC	PM2_5	PM2.5	PM10	PM10	CO	CO	NOX	NOX	NMVOC_f	NMVOC	NH3	NH3	SO2	SO2
		v4_3_1	v6_1	v4_3_1	v6_1	v4_3_1	v6_1	v4_3_1	v6_1	v4_3_1	v6_1	v4_3_1	v6_1	v4_3_1	v6_1	v4_3_1	v6_1	v4_3_1	v6_1
	ARM	0.11	0.06	0.24	0.27	0.98	0.79	1.86	1.60	24.27	23.69	17.16	13.17	19.58	24.75	19.12	11.25	0.78	0.91
	AZE	0.45	0.88	1.15	1.97	5.01	5.32	8.01	9.19	134.43	120.50	59.97	74.64	226.15	151.87	72.72	54.20	22.84	8.07
	DZA	8.74	12.82	5.59	10.96	22.57	39.43	31.98	50.03	535.54	1083.80	334.47	385.55	674.64	922.33	57.61	65.49	78.28	69.73
	EGY	14.47	23.83	17.05	27.37	72.64	105.25	106.47	148.39	1437.82	2250.32	577.79	656.57	415.63	1126.25	515.28	339.17	682.17	688.57
	GEO	1.28	1.06	3.58	2.79	9.63	7.14	16.37	13.55	136.04	99.19	21.03	28.88	22.97	46.98	35.36	23.14	11.51	4.94
	GRL	0.00	0.06	0.00	0.04	0.00	0.18	0.00	0.20	0.00	3.20	0.01	3.57	0.09	0.83	0.02	0.05	0.00	4.00
	IRN	27.27	16.59	17.22	15.62	83.43	89.45	129.73	163.21	9391.55	1277.31	2271.23	1389.59	3404.61	1576.94	615.08	605.36	1372.80	1233.24
	IRQ	10.79	6.26	9.24	7.29	35.93	25.21	43.27	34.38	2344.79	400.31	723.92	510.77	1275.43	495.38	32.35	74.11	1038.37	952.89
	ISR	1.05	3.00	1.53	3.25	21.67	28.30	35.53	50.08	115.18	167.18	206.03	274.68	55.77	125.66	29.33	29.01	152.97	164.88
	JOR	0.63	0.84	0.47	0.56	3.58	4.16	5.34	6.62	64.79	51.26	51.88	73.30	46.72	46.85	9.49	10.31	57.40	107.31
	KAZ	19.02	13.52	19.46	41.56	122.45	142.06	160.04	186.34	1207.48	1636.75	625.83	758.21	613.75	520.53	126.52	136.91	1645.32	1600.18
	KWT	1.78	2.07	0.78	1.19	8.44	9.33	13.59	13.87	151.11	147.26	230.57	217.49	744.33	401.63	11.86	10.94	990.26	745.62
	LBN	0.81	0.84	1.75	1.63	7.42	7.26	12.34	13.52	186.62	127.55	107.49	132.43	80.91	50.46	16.46	14.78	190.72	175.54
	LBY	6.53	7.29	4.75	7.72	16.59	24.52	24.00	31.72	765.38	1069.82	309.31	266.78	608.58	837.38	26.72	25.12	347.49	243.73
	MAR	4.96	9.59	8.31	16.10	28.77	53.69	51.82	94.74	177.47	523.45	171.92	223.46	44.10	265.93	125.11	104.16	278.11	341.93
	PSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SAU	14.69	21.77	6.21	11.95	53.47	76.01	75.35	105.10	1483.27	985.01	1579.44	1848.47	3318.07	1511.22	144.81	99.40	2814.48	2684.74
	SYR	2.90	2.75	9.51	5.62	28.51	16.12	32.98	20.44	356.66	197.16	220.23	212.23	161.16	221.15	96.77	70.87	459.78	402.94
	TKM	0.50	1.06	4.21	1.80	14.38	4.61	16.88	6.62	276.47	147.43	83.30	139.51	70.78	76.60	76.20	64.47	12.08	18.91
	TUN	4.21	4.98	9.21	8.05	26.55	25.46	63.66	56.24	414.47	436.27	71.09	90.86	54.01	228.65	47.38	44.56	84.16	34.42
	UZB	1.04	1.09	6.37	5.66	19.44	12.33	27.61	19.08	576.33	246.82	194.10	204.07	132.27	195.37	211.57	194.03	84.13	71.08
	SUM	**121.24**	**130.36**	**126.63**	**171.40**	**581.44**	**676.63**	**856.84**	**1024.92**	**19779.67**	**10994.27**	**7856.78**	**7504.23**	**11969.55**	**8826.75**	**2269.75**	**1977.33**	**10323.66**	**9553.62**
	Difference		8%		35%		16%		20%		-44%		-4%		-26%		-13%		-7%