,
Horizon 2020 Societal challenge 5:
Climate action, environment, resource
efficiency and raw materials

VERIFY

Observation-based system for monitoring and verification of greenhouse gases

GA number 776810, RIA

Deliverable number (relative in WP)	**D2.3** (TNO GHGco emission inventory v3.0)
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Responsible	H.A.C. Denier van der Gon
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Internal reviewer:	XXX

Changes with respect to the DoA
In the original DoA deliverable 2.2. covers the years 2005-2017. However, because some delays in the start of the project it was possible with limited additional effort and a short delay in delivery dates to make the timeseries up to 2018. This is valuable especially for the case studies in VERIFY as well as being in line with the latest UNFCCC country reporting as done in 2020. It was checked that this was not causing any delays in the VERIFY synthesis modelling cycle (which starts in summer 2021). Therefore it was decided previously to deliver an extra year (2018) and move the deliverable due date from Jan 2021 (M36) to April 2021 (M39). Due to the delays associated with Covid-19, the busy schedule including VERIFY GA in April and the extension of the VERIFY project, the delivery was moved to June 2021. The delivery will still be in time for the VERIFY synthesis cycle.
Dissemination and uptake **(Who will/could use this deliverable, within the project or outside the project?)**
VERIFY WP2, 5 , 6 **Greenhouse gas modelling community with a European focus**
Short Summary of results (<250 words)
This document describes the final version of the TNO greenhouse gas and co-emitted species (GHGco) emission database at a resolution of ~ 6x6 km, as input for modelling of CO_2 and its co-emitted species across Europe. It contains annual emissions for the years 2005-2018. This document briefly describes the methodology followed, the improvements compared to the previous version and provides a summary of the results. The dataset covers the entire European domain for the GHGs: carbon dioxide (distinguishing between fossil fuel CO_2 and biofuel CO_2 emissions) and methane (CH_4), as well as key co-emitted species that may be used as tracers for CO_2 from combustion sources: carbon monoxide (CO, also distinguishing between fossil and biofuel) and nitrogen oxides (NOx). This data set will be complementary to the upcoming deliverable 2.6 for the recent years (2019,2020) which will be input for the VERIFY synthesis cycle.
Evidence of accomplishment **(report, manuscript, web-link, other)**
Gridded data on ftp site available to VERIFY partners as of May 15 2021 (link communicated together with report by e-mail) **Figures in the current D2.3. report**

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Version	Date	Description	Author (Organisation)
V0	06/01/2021	Creation/Writing	Stijn N. C. Dellaert, Antoon J. H. Visschedijk, Jeroen Kuenen, Ingrid Super, Hugo A. C. Denier van der Gon (TNO)
V1	06/02/2021	Writing/Formatting/Delivery	Hugo A. C. Denier van der Gon, Stijn N. C. Dellaert (TNO)
V2	06/18/2021	Additional analysis of pollutant ratios added	Stijn N. C. Dellaert, Hugo A. C. Denier van der Gon (TNO)

Glossary

Abbreviation / Acronym	Description/meaning
AIS	Automatic Identification System
bf	Bio fuel (solid, liquid, gaseous)
CAMS	Copernicus Atmosphere Monitoring Service
CarMA	Carbon Monitoring for Action (database)
CEIP	Centre on Emission Inventories and Projections
CH4	Methane
CO	Carbon monoxide
CO2	Carbon dioxide
CSV	Comma Separated Values
EDGAR	Emission Database for Global Atmospheric Research
EMEP	The co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (inofficially 'European Monitoring and Evaluation Programme' = EMEP)
E-PRTR	European Pollutant Release and Transfer Register, established under EU Regulation (EC) No 166/2006 of the European Parliament and of the Council of 18 January 2006
ESA CCI	European Space Agency – Climate Change Initiative
EU	European Union
ff	Fossil fuel
FRP	fire radiative power
GAINS	Greenhouse Gas - Air Pollution Interactions and Synergies
GFAS	Global Fire Assimilation System
GHGs	Greenhouse gases
GNFR	Gridding Nomenclature For Reporting
ISO3	three-letter country codes defined by the International Organization for Standardization (ISO)
MODIS	Moderate Resolution Imaging Spectroradiometer
NetCDF	Network Common Data Form
NMVOC	Non-Methane Volatile Organic Carbon
NOx	Nitrogen oxides
STEAM	Ship Traffic Emission Assessment Model
TNO_GHGco	TNO greenhouse gas and co-emitted species (emission inventory)
TNO_MACC	TNO Monitoring Atmospheric Composition and Climate (emission inventory)
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

This document describes the final version of the TNO greenhouse gas and co-emitted species (GHGco) emission database at a resolution of ~ 6x6 km, as input for modelling of CO_2 and its co-emitted species across Europe. It contains annual emissions for the years 2005-2018. This document briefly describes the methodology followed, the improvements compared to the first versions and provides a summary of the results. The dataset covers the entire European domain for main the GHGs: carbon dioxide (distinguishing between fossil fuel CO_2 and biofuel CO_2) and methane (CH_4). Additionally, the dataset includes key co-emitted species that may be used as tracers for CO_2 from combustion sources: carbon monoxide (CO, also distinguishing between fossil and biofuel) and nitrogen oxides (NOx). While co-emitted species show stronger trends, fossil fuel CO_2 emissions remain rather stable, especially the later years (Figure 1). CO_2 from biofuels shows an increasing trend, partly compensating the reduction in CO_2 from fossil fuels. CO_2 from biofuel in the context of this report comes from a range bioenergy sources, mostly solid biomass (including wood), other biomass and liquid biofuels.

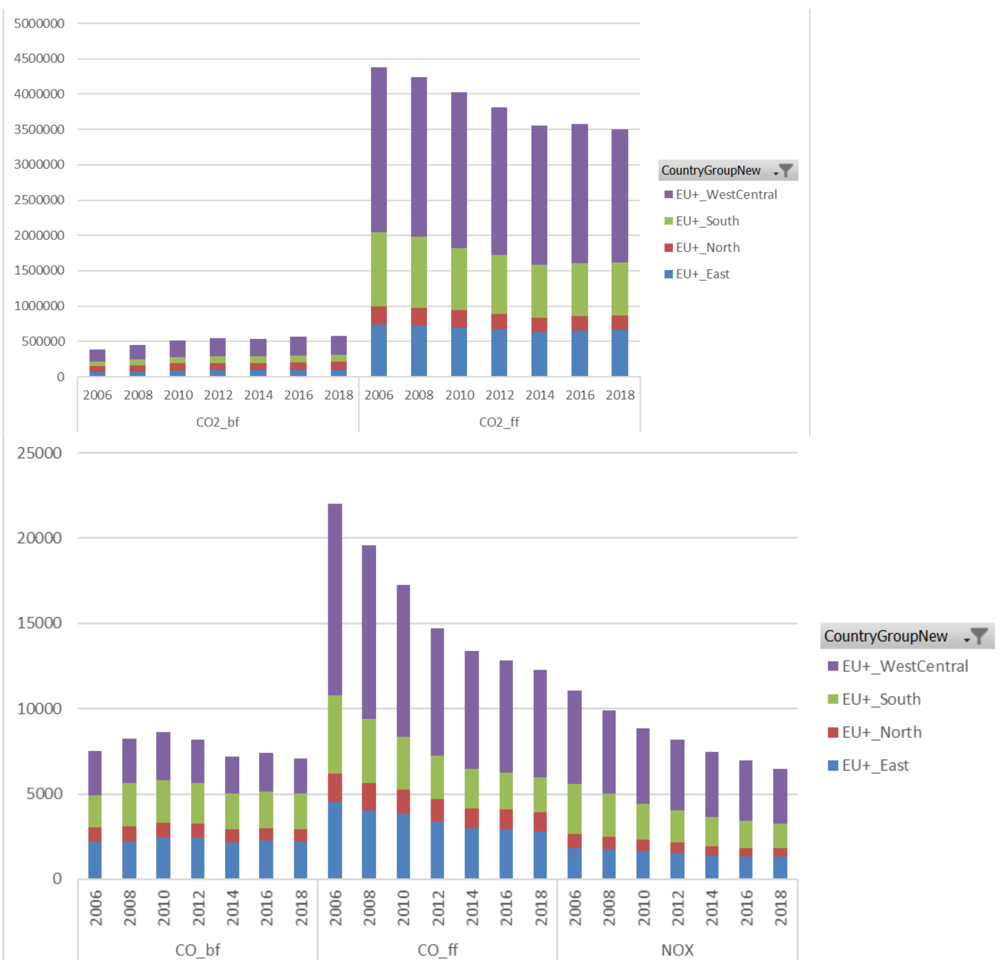

Figure 1: Trends in CO_2 from bio fuel (bf) and fossil fuel (ff) (top) and co-emitted species (bottom) from 2005-2018 for the 4 geographical areas in the EU (see appendix 2 for details).

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The increasing trend in CO_2_bf will make it (even) more complicated to see a clear signal from the reduction in fossil CO_2 emissions in atmospheric CO_2 observations. For the co-emitted species it can be seen that the CO emission from fossil fuel combustion is strongly decreasing, but CO from biofuel and biomass combustion shows no trend (Figure 1). Note that Figure 1 shows only even years but data for all years 2005-2018 are available. The variation for CO from biofuel combustion is mostly due to the climatic variation. These emissions are dominated by wood combustion, in years with colder winters emissions are higher (e.g. year 2010).

The trend in methane emissions is shown in Figure 2. There is modest downward trend visible of approximately ~18% since 2005, but like with CO_2_ff, since 2015 the emission remained more or less stable.

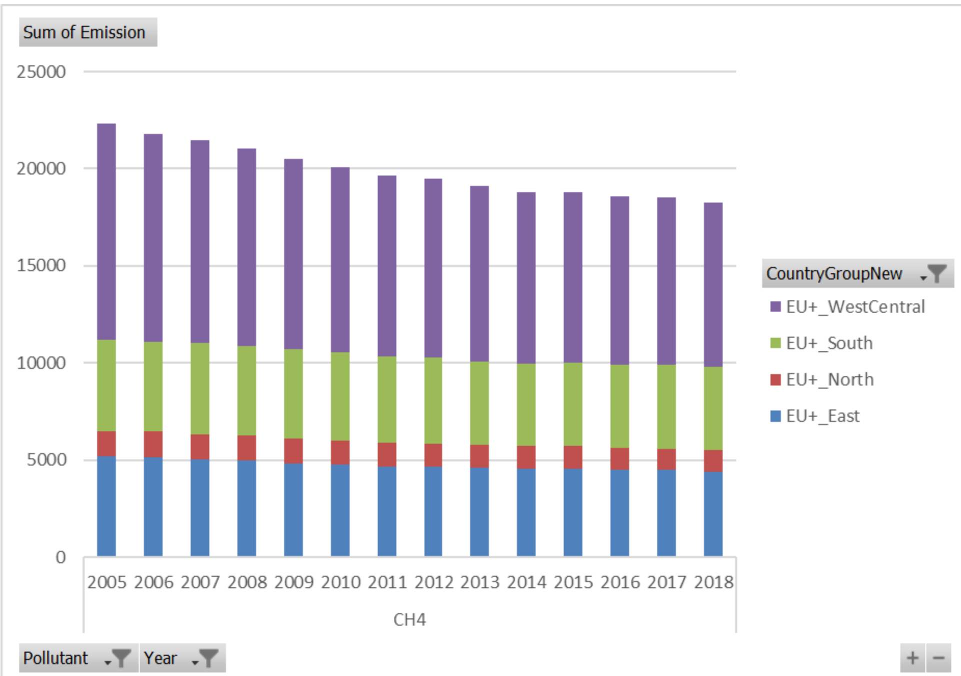

Figure 2: Trends in CH_4 from 2005-2018 for the 4 geographical areas in the EU (see appendix 2 for details).

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1. Methodology for developing the 2005-2018 regional European anthropogenic emissions

The methodology that was used for developing the TNO GHG and co-emitted species regional emissions is shown in Figure 3. The methodology has been further developed and refined since the previous TNO GHGco v.2.0 inventory and is based on the method used for the earlier TNO_MACC, MACC-II and MACC-III emission inventories (Kuenen et al., 2014). The method starts from the reported emissions by European countries to UNFCCC (for greenhouse gases) and to EMEP/CEIP (for air pollutants). The emissions have been aggregated to ~250 different combinations of sectors and fuels. Because of the different level of detail in reporting between air pollutants and greenhouse gases, in specific cases aggregation and/or disaggregation was needed to harmonize the sectors between all pollutants and countries.

The reported data have been checked for gaps, errors and inconsistencies and form the basis for the TNO_GHGco emission inventory for 2005-2018. Where needed, reported data were replaced or completed using other emission data from the GAINS model (Amann et al., 2011). Expert judgement was used to evaluate the quality of each of these data sources and make choices on what to use. International sea shipping emissions were made available from the CAMS emission project (Granier et al., 2019). Shipping emissions were modelled using the Ship Traffic Emission Assessment Model (STEAM, Johansson et al., 2017; Jalkanen et al., 2016), which uses Automatic Identification System (AIS) data to describe ship traffic activity. For inland shipping, AIS data based grids have been used for some countries where coverage was sufficient, while for other countries, the grid is replaced with an TNO estimate since the reporting of inland shipping emissions across countries is not consistent enough. Emissions from agricultural waste burning are based on the GFAS system (Kaiser et al., 2012). GFASv1.2 uses satellite fire radiative power (FRP) detections from MODIS-Aqua and -Terra for calculating emissions from biomass burning at 0.1° x 0.1° spatial resolution. Emission maps from GFAS were overlaid with a new land cover map based on the ESA CCI land cover database (https://www.esa-landcover-cci.org/) to identify the fire emissions from agricultural land use. GFAS has also provided the appropriate spatial and temporal distribution for these emissions. The resulting emissions are then checked in detail with regard to their absolute value, trends, and profiles.

Thereafter, a consistent spatial distribution methodology is applied where each emission source gets a specific proxy assigned which defines how emissions are spatially distributed over the country. For point sources information was collected on the location of power plants, large industrial installations, oil and gas production sites, airports and waste treatment locations (e.g. landfills). For area sources, proxies are collected which are thought to best represent the spatial variability of each specific emission source such as population density,

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different land cover classes (from the EEA CORINE land cover database), or a road transport network (e.g. based on open street map). Automated scripts have been developed to calculate the spatially distributed emissions, which are subsequently aggregated to the GNFR level for the gridded output files in order to limit the total amount of data.

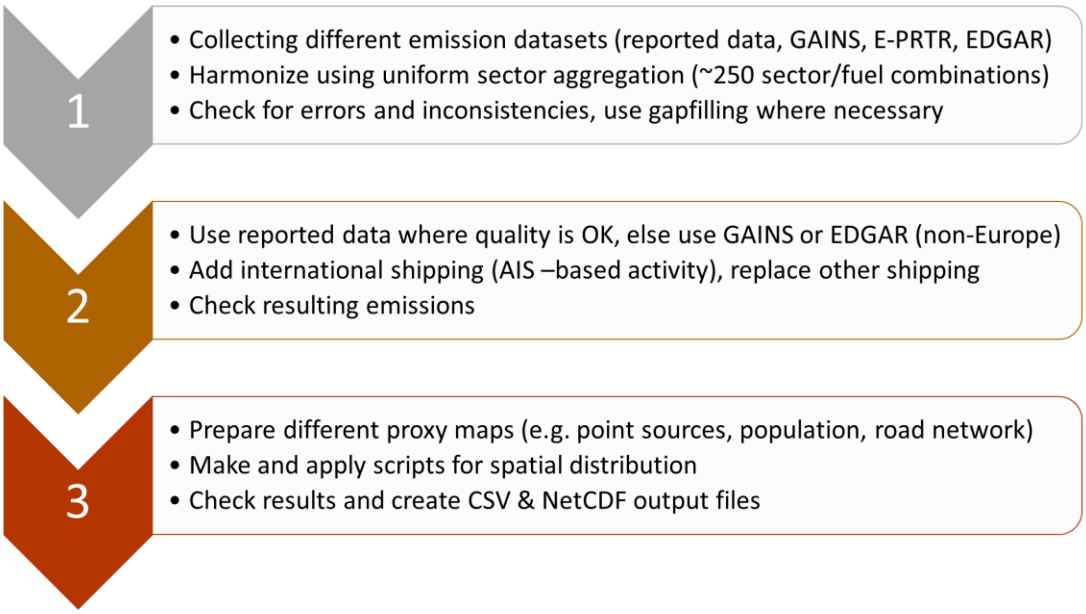

Figure 3: Methodology for developing the anthropogenic global emissions

The European domain for the modelers is larger than the EU27 plus United Kingdom, Norway and Switzerland. Therefore, emissions from other countries within the model domain located in Europe (e.g. Russia) are taken from the GAINS model (Amann et al., 2011) and processed/spatially distributed by TNO. Emissions outside of Europe, but within the model domain (e.g. the North African region along the Mediterranean Sea) are taken from the EDGAR database (Crippa et al., 2018). Further details of the processing of emissions for non-EU countries are given in Kuenen et al. (2014). The main characteristics of the regional European emission dataset are given in Table 1.

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Table 1: Characteristics of the TNO_GHGco_v3 regional European emissions

TNO_GHGco_v3.0 characteristics	
Species	CO_2_ff (fossil fuel), CO_2_bf (biofuel[a]), CO_ff (fossil fuel), CO_bf (biofuel[a]), NO_x (as NO_2), CH_4, NMVOC
Resolution	1/10° x 1/20° (longitude latitude, ~ 6x6 km over central Europe)
Period covered	2005 – 2018 (annual emissions for 14 individual years)
Domain	30° W – 60° E 30° N – 72°N
Sector aggregation	GNFR (A to L), with GNFR F (Road Transport) split in F1 to F4 (total 16 sectors) *(see* Table 2*)*
Emission unit	kg (both in CSV and NetCDF files)
Countries	42 countries + 13 sea regions ***(see Annex)*** ***Note:*** Emissions for other countries within the domain are added based on EDGAR v4.3.2 (Crippa et al., 2018) where it is assumed that emissions remain constant from 2012 onwards.

[a] CO_2 from biofuel in the context of this report comes from a range bioenergy sources, mostly solid biomass (including wood), other biomass and liquid biofuels.

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1.1. Updates and improvements compared to the earlier TNO emissions data sets

1.1.1. Comparison with TNO MACC inventories

The main differences of this dataset compared to the TNO_MACC inventories are:

- A horizontal resolution of 0.1° x 0.05° (lon x lat) to align with other emission inventories such as EDGAR and EMEP which have a resolution of 0.1° x 0.1° (lon x lat). This means that the resolution is around 30% higher compared to earlier TNO emission inventories (such as the TNO_MACC inventories) at 0.125° x 0.0625°.
- The sector classification in the emission grids has been updated from SNAP to GNFR (See Table 2). GNFR is an aggregated version of the NFR (Nomenclature For Reporting) which is used by individual country emission reporting to EMEP and EU.
  More details on the sector classification can be found in Table 2 and at the following link: http://www.ceip.at/ms/ceip_home1/ceip_home/reporting_instructions/.
- Along with the updated grid definition used, the allocation and identification of countries has been updated in accordance with the current countries and borders. Compared to the TNO_MACC emission inventories, ISO3 code YUG (consisting of Serbia and Montenegro) has been replaced by individual codes for Serbia, Montenegro and Kosovo.
- EDGAR data have been used for gapfilling for those countries that are part of the domain, but not part of UNECE Europe (in North Africa and the Middle East). These are based on EDGAR v4.3.2 for all substances, covering years 2000-2012. From 2012 onwards, these emissions are assumed constant since no EDGAR data were readily available at the time when this emission inventory was created.
- Compared to the earlier TNO_MACC inventories, for the TNO_GHGco emission inventory all distribution proxies have been renewed (see next section).

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Table 2: GNFR Sector explanation and link to SNAP nomenclature previously used in TNO-MACC emission inventories

GNFR Category	GNFR Category Name	Link to SNAP
A	A_PublicPower	SNAP 1, only power and heat plants
B	B_Industry	SNAP 1 (non-power and heat plants) + SNAP 34 (or SNAP 3+4)
C	C_OtherStationaryComb	SNAP 2
D	D_Fugitives	SNAP 5
E	E_Solvents	SNAP 6
F	F_RoadTransport	SNAP 7
G	G_Shipping	SNAP 8, only shipping (all types)
H	H_Aviation	SNAP 8, only aviation
I	I_OffRoad	SNAP 8, non-shipping and non-aviation
J	J_Waste	SNAP 9
K	K_AgriLivestock	SNAP 10, livestock only
L	L_AgriOther	SNAP 10, non-livestock only
F1	F_RoadTransport_exhaust_gasoline	SNAP 71
F2	F_RoadTransport_exhaust_diesel	SNAP 72
F3	F_RoadTransport_exhaust_LPG_gas	SNAP 73
F4	F_RoadTransport_non-exhaust	SNAP 74 (only NMVOC emission) + SNAP 75 (only PM emissions)

1.1.2. Comparison with TNO GHGco v.2.0

- Full update of emission data for reported time series (2005-2018).
- Partial update of data from E-PRTR & LCP reporting, processed for the sector public power and heat production.
- The correction of several point source coordinates (power plants & industry).
- An increasing number of countries is reporting NMVOC emissions from agriculture. In TNO_GHGco_v3.0, these emissions have been included for all countries (see Fig. 4). This adds ~1200 kton NMVOC annually to the European emissions, which adds 10-16% to annual emissions with the highest relative contribution in the latest years and the highest contribution in Western and Central Europe. For those countries that have no official reporting of these emissions, a bottom-up calculated estimate was produced and included to improve the consistency of the inventory.
- For the distribution of natural gas transport emissions, a new spatial proxy has been used that is based on the work done in the project 'Methane in the energy sector' for DG Energy. The spatial proxy is compiled by combining data from a GIS database provided by DG Energy, which had been aggregated to grid cell level in the context of the aforementioned project, and the Global Oil and Gas Features database (GOGI

dataset1). The GOGI dataset was mostly used for mapping the gas transport network in Eastern Europe. The new geographic data provides significantly more detail in the location of gas lines than the old proxy.

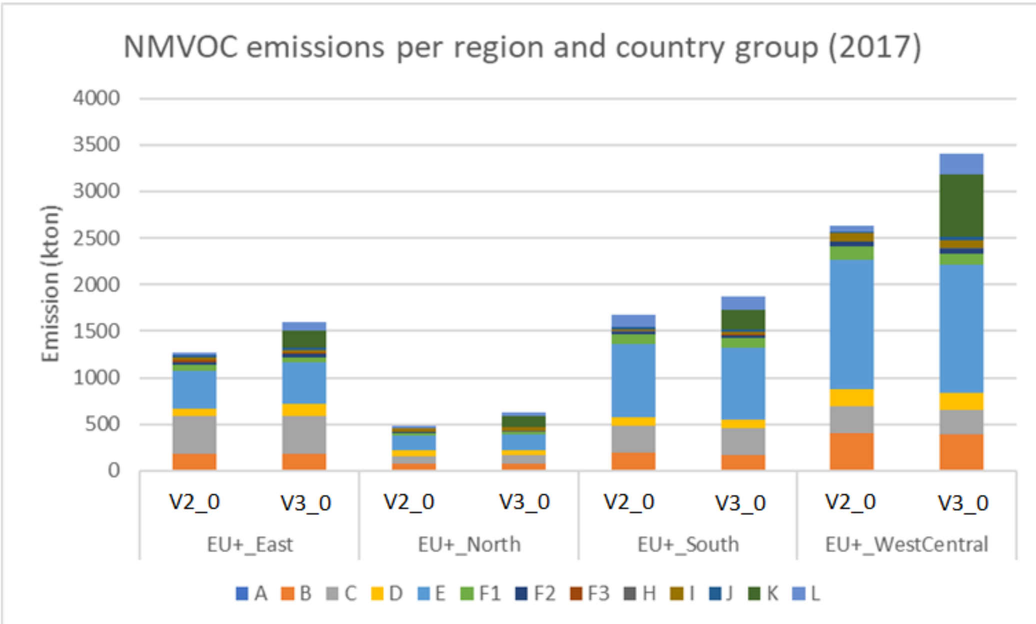

Figure 4: Emissions of NMVOC (kton/yr) in TNO_GHGco_v2.0 and TNO_GHGco_v3.0 for different country groups in Europe (see Section 1.4). As can be seen the difference between the two versions is mostly in the agricultural sectors (K and L).

1.2. Key features of the spatial distribution

- For power plants, the locations and characteristics of each large power plant in Europe have been collected from the combination of various datasets:
    - E-PRTR (European Pollutant and Transfer Register, http://prtr.ec.europa.eu/)
    - CARMA database (Carbon Monitoring for Action, http://carma.org/)
    - Reporting of EU Member States to the Large Combustion Plants Directive
    - Platts-WEPP (World Electric Power Plants database, version December 2015, https://www.platts.com/products/world-electric-power-plants-database)
    - Industrial reporting dataset (successor of E-PRTR and LCP datasets)

  These datasets have been linked together to obtain a full overview of the power plants and to identify gaps and errors, which have been corrected and gapfilled to the extent possible. Since the E-PRTR and LCP datasets have now been replaced by the Industrial Reporting dataset (https://www.eea.europa.eu/data-and-maps/data/industrial-

[1] Rose, K., Bauer, J., Baker, V., Bean, A., DiGiulio, J., Jones, K., Justman, D., Miller, R. M., Romeo, L., Sabbatino, M., Tong, A., 2018. *Development of an Open Global Oil and Gas Infrastructure Inventory and Geodatabase*; NETL-TRS-6-2018; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Albany, OR; DOI: 10.18141/1427573.

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reporting-under-the-industrial-3), this dataset has also been partially linked where possible (based on old ID's, facility name and location). It is expected that EEA will publish a dataset version that also includes historical E-PRTR and LCP data in the coming months. This new dataset will hopefully facilitate a full linking of new and historical data for a consistent time series for power plants and other industrial sources.

- For industrial point sources, E-PRTR has been used. Absolute emissions have been obtained similar to power plants described above, for selected sectors and pollutants only. For year 2018, the distribution of emissions from 2017 was used, since the new data reporting is in the new Industrial Reporting dataset, which could not yet be consistently linked to historical E-PRTR data. For petroleum refineries and integrated primary iron and steel plants, supplementary information (Oil & Gas Journal's Annual Refining Survey, https://www.ogj.com/ogj-survey-downloads/worldwide-refining and World Steel Dynamics Plantfacts Capacity Database, http://gsis.worldsteeldynamics.com/) was used to check for consistency and completeness of E-PRTR data.
- Point sources for both power plants and industrial sources are used in an absolute instead of a relative way. In the earlier TNO_MACC inventories, the point sources were used only to distribute national total emissions for the relevant sector. In this inventory, the exact emissions from point sources are used. Remaining emissions are distributed using industrial area land cover classification from CORINE. Only in case the sum of point source emissions from E-PRTR exceeds the national total for that sector, the point source emissions within that sector are all scaled down to not exceed the national total for the respective sector.
- Population density is used as the default distribution for many sectors when no specific information is available. To reflect changes over time from 2005-2017 three versions of the Landscan population map (https://web.ornl.gov/sci/landscan/) have been used (for the years 2005, 2010 and 2015, respectively). Urban and rural population maps have been created from the population density map by comparing the population density in each cell (inhabitants/km^2).
- For residential wood combustion a unique spatial distribution has been constructed and used based on an overlay of a fuel wood supply function and a fuel wood demand function, derived from population density, degree of urbanisation, local biomass supply and estimated average wood transport distances.
- For airports, the distribution map from TNO_GHGco_v2.0 has been updated based on Eurostat statistics on the passenger and freight flights by airport for all years. The main advantage is that yearly specific maps can be created, reflecting the opening and closure of airports during the time series, as well as growth in air traffic in specific airports.

- For international shipping, absolute emission values are taken from the STEAM model, based on AIS data and developed by FMI. Consistent AIS-based maps are available for the years 2013 - 2018. For earlier years, scaling factors have been calculated for the shipping emissions to estimate emissions for the years prior to 2013 by sea area, taking into account the implementation of environmental control measures in different sea regions, such as the Sulphur Emission Control Areas (SECA).

1.3. Emission profiles

In addition to the grid files, the following additional information is also provided:

- Temporal profiles: default time profiles are provided per GNFR sector code (consisting of a variation between months, between days of the week and hours in the day).
- Effective emission height: a default effective height is provided per GNFR sector code.
- An updated NMVOC speciation table is provided for 2000-2018, distinguishing over 20 different NMVOC compounds. A specific profile has been developed for the newly added NMVOC emissions from agriculture. This new profile has been integrated in this speciation table.

1.4. Country groups

Emission characteristics and trends can differ per country, but are often similar for specific groups of countries that share some characteristics (e.g. level of development or climatology). Therefore, to simplify the analyses, we have grouped countries together in 4 groups based on their geographical location:

- 'EU+ East': eastern EU countries
- 'EU+ North': northern EU countries + Norway + Iceland
- 'EU+ South': southern EU countries
- 'EU+ WestCentral': western EU countries + Switzerland + United Kingdom

All other countries are collected in the group 'non-EU countries'. We show results for the 4 EU+ groups, simply named 'EU+' hereafter. The exact definition of each country group is shown in the Annex to this report.

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2. Results: the TNO_GHGco_v3 emission inventory

2.1. Emissions

Table 3: TNO_GHGco_v3.0 total emissions by country and sea region for the year 2018 (Gg/yr).

Country		CO2_ff	CO2_bf	CO_ff	CO_bf	NOX	CH4	NMVOC
EU+_East	BGR	43,764	7,793	137	146	80	271	79
	CZE	104,559	16,769	391	439	161	526	237
	HUN	49,791	11,078	142	221	97	291	131
	POL	337,585	33,927	1,686	655	686	1,949	763
	ROU	77,114	17,408	264	537	202	1,119	253
	SVK	36,129	6,942	176	125	59	178	88
	SVN	14,508	2,879	36	63	32	77	32
EU+_North	DNK	34,814	19,112	141	91	71	295	130
	EST	17,720	4,957	61	72	30	45	24
	FIN	45,381	41,696	131	198	109	181	82
	ISL	3,170	49	110	0	7	25	6
	LTU	13,716	5,815	55	85	41	123	46
	LVA	7,878	7,041	41	86	29	70	42
	NOR	40,208	4,954	329	99	111	186	168
	SWE	40,869	32,283	225	92	100	175	131
EU+_South	CYP	7,430	293	11	1	14	35	10
	ESP	264,612	30,426	748	463	536	1,576	616
	GRC	69,918	4,766	263	110	197	403	154
	HRV	17,635	6,055	72	162	42	156	74
	ITA	342,968	46,133	774	1,249	538	1,722	899
	MLT	1,489	27	8	0	5	8	3
	PRT	51,067	11,452	143	113	141	364	153
EU+_WestCentral	AUT	67,051	22,656	264	224	141	258	107
	BEL	102,109	12,918	269	76	158	314	127
	CHE	37,187	7,547	124	30	61	194	86
	DEU	756,999	100,786	2,501	441	1,083	2,106	1,201
	FRA	335,036	63,265	1,363	982	719	2,257	710
	GBR	376,053	46,820	1,254	246	717	2,077	797
	IRL	38,813	2,803	72	7	67	560	128
	LUX	5,445	655	12	3	12	23	11
	NLD	161,601	13,345	474	75	208	692	240
Non_EU	ALB	7,498	880	32	45	29	123	33
	BIH	18,338	3,817	77	188	42	126	65
	BLR	39,075	6,810	245	135	149	620	204
	KOS	8,654	1,222	37	62	25	46	22
	MDA	6,319	1,129	60	55	19	128	42
	MKD	8,622	1,673	20	73	22	66	25
	MNE	2,220	464	13	25	6	21	9
	RUS	1,081,089	89,307	4,289	3,234	1,950	14,895	2,256
	SRB	39,150	4,605	157	230	78	241	96
	TUR	317,395	28,661	1,316	1,347	676	2,294	798
	UKR	257,556	22,049	2,386	1,024	564	2,350	594
Sea regions	ATL*	38,239	0	-	0	894	0	7
	BAS	16,714	-	-	-	-	-	-
	BLS	7,343	-	-	-	-	-	-
	MED	61,279	-	-	-	-	-	-
	NOS**	30,271	0	-	0	644	0	6
	OTH***	1,729	0	-	0	1,965	1	16

*ATL includes also Barentz Sea (BAR), Greenland Sea (GRS), Norwegian Sea (NWS)
**NOS includes English Channel (ENC)
***OTH (Other sea regions) includes Caspian Sea (CAS), Kara Sea (KAR), Persian Gulf (PSG)

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2.2. Grid maps

The emissions are provided on an annual basis for the year 2005-2018 for the species listed in Table 1. As an example of the emissions Figure 5 shows the fossil CO_2 emissions from shipping, derived mostly from the AIS based STEAM model (Jalkanen et al. 2016). Figure 6 shows biofuel CO_2 emissions from small combustion installations in 2018.

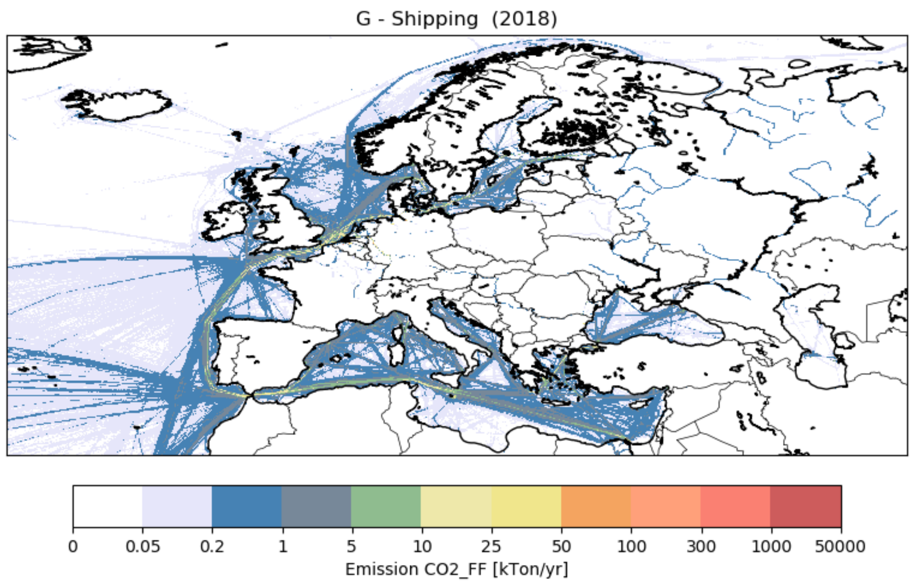

Figure 5: Examples of distributed emissions in TNO_GHGco_v3.0 emission inventory in 2018; fossil CO2 from shipping (unit: Gg/yr/grid cell)

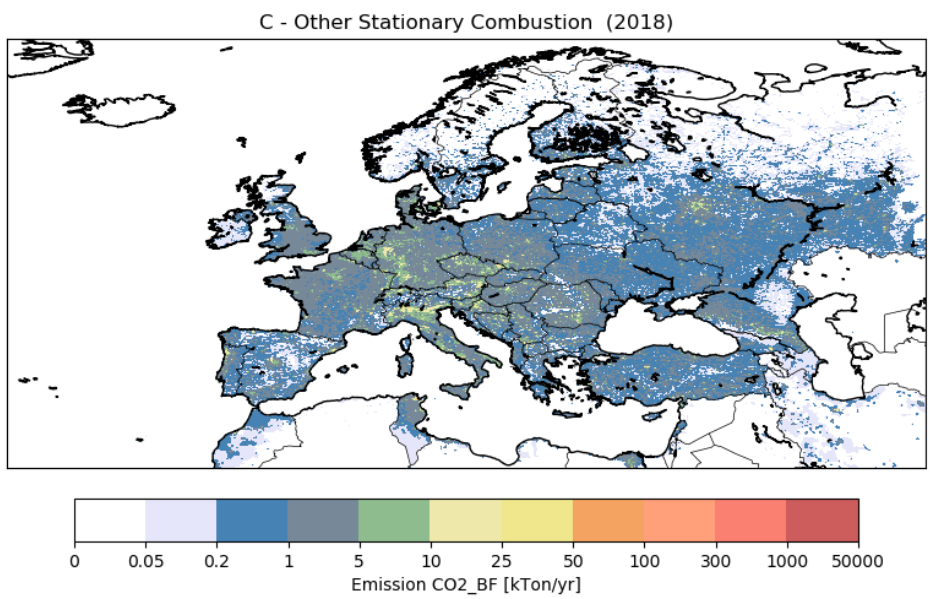

Figure 6: Examples of distributed emissions in TNO_GHGco_v3.0 emission inventory in 2018; biofuel CO2 from other stationary combustion (unit: Gg/yr/grid cell) Note that this is mostly resulting from residential wood combustion

To illustrate the impact that changes in the method and distribution proxy can have, we first show the CH_4 emissions from the fugitives category in Figure 7. As mentioned before, the spatial proxy for natural gas transport has been updated. Differences are especially visible in the eastern part of the domain, where more detail is visible in the pipeline network.

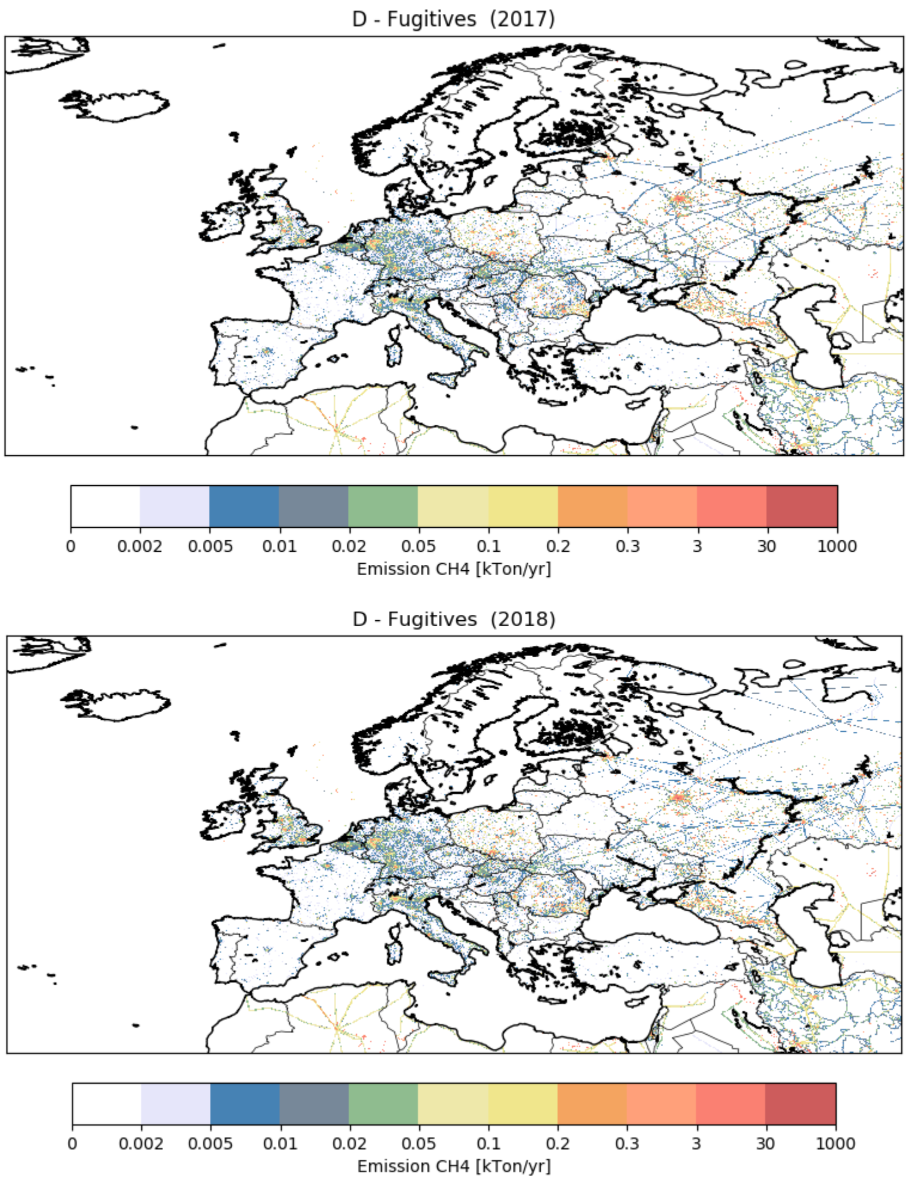

Figure 7: Examples of distributed emissions in TNO_GHGco_v2.0 for 2017 (top) and TNO_GHGco_v3.0 for 2018 (bottom); fossil CO2 from fugitives (unit: Gg/yr/grid cell)

Another important change in the methodology is the inclusion of NMVOC emissions from the agricultural sector (both from livestock and other activities), which is now done consistently for all countries (Figure 8). We clearly see an increase in emissions for most countries, which in some cases didn't have any emissions for the agricultural source sectors in the TNO_GHGco_v2.0.

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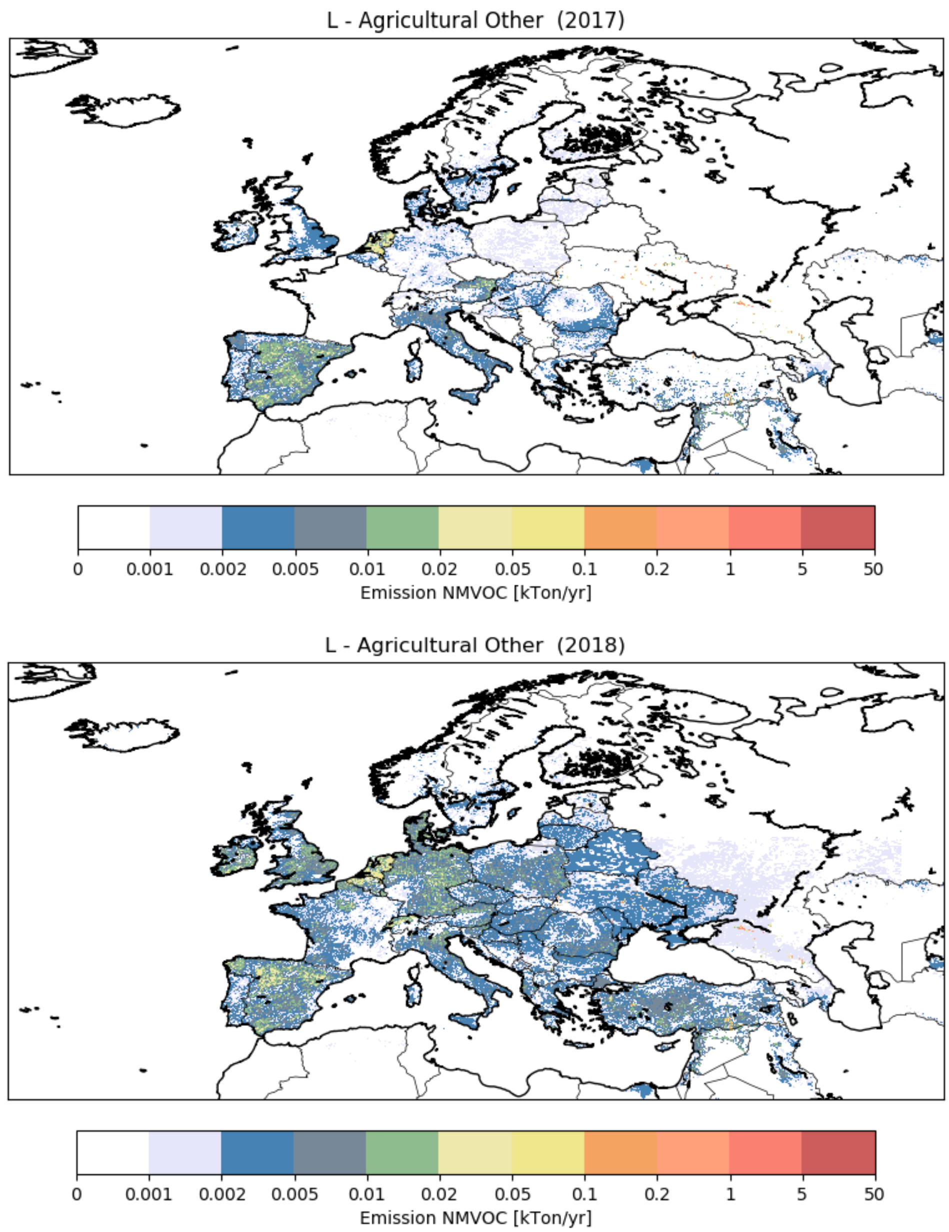

Figure 8: Examples of distributed emissions in TNO_GHGco_v2.0 for 2017 (top) and TNO_GHGco_v3.0 for 2018 (bottom); NMVOC from other agriculture (unit: Gg/yr/grid cell)

2.3. Illustration of emission trends

The trend in emissions of CO_2, CO (both for fossil and biofuel origin), CH_4, NMVOC and NO_X in 2005-2018 for the EU+ is shown in Figure 9. CO_2 emissions from fossil fuels have decreased by ~20%, but biofuel CO_2 has increased in the same time frame, becoming increasingly important and making up about 14% of the total CO_2 emissions in 2018. Emissions of CO from fossil fuels have decreased significantly, while biofuel CO emissions have remained relatively stable. The latter can be explained by the fact that the use of biofuels has increased (hence the increase in biofuel CO_2 emissions), which is compensated for by improved technologies (lower emission factors). Also for CH_4, NMVOC and NO_X emissions have decreased over the time period.

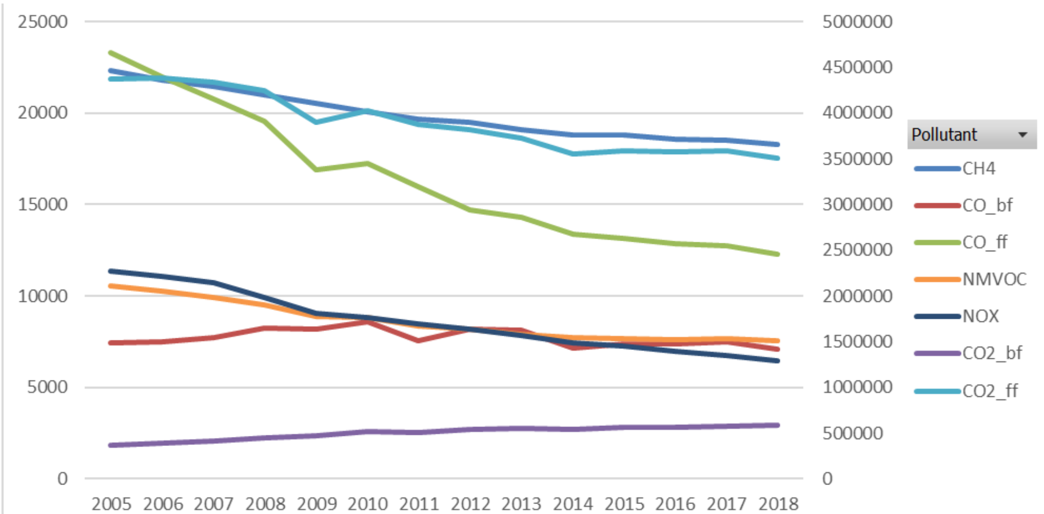

Figure 9: Trend in emissions in 2005-2018 for the EU+ (kton/yr). Note that CO_2 emissions are plotted on the right Y-axis.

Figures 10 and 11 show the emission trends for CO_2 from fossil and biogenic origin, distinguishing the share of each GNFR sector in the total emission. Annual CO_2_ff emissions of sectors A (public power and heat) and B (industry) together have fallen by some 685 Mt over the period 2005 – 2018, while the annual CO_2_bf emissions of these sectors have risen by some 130 Mt. Clearly visible is the increasing use of biomass in power generation (sector A) but also the increasing share of biofuel use in road transport (especially biodiesel, sector F2).

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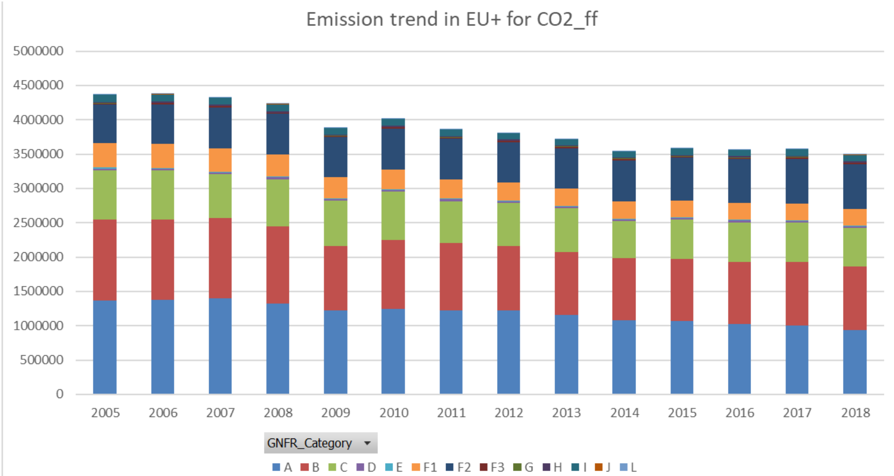

Figure 10: Trend 2005-2018 in the TNO-GHGco-v3.0 regional European emissions for CO2 (Gg/yr) from fossil fuels for the EU+ by source sector (GNFR see Table 2 for sector codes). Note the temporary dip in 2009 due to the financial crisis.

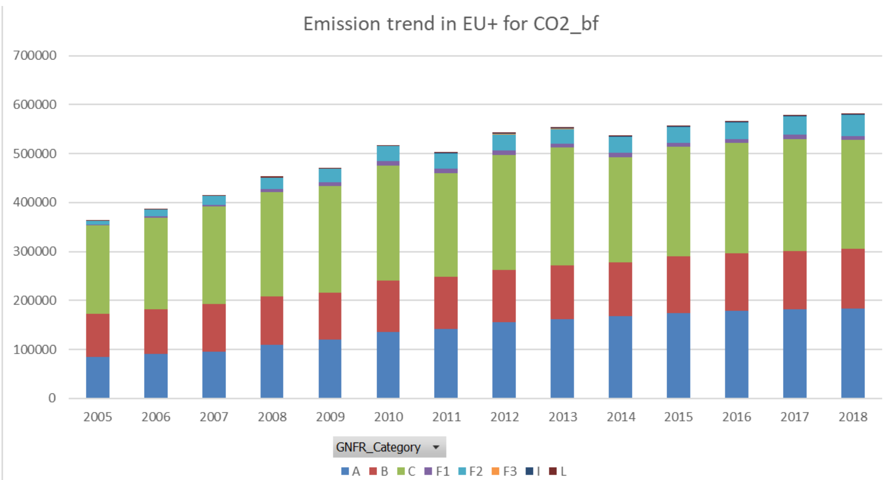

Figure 11: Trend 2005-2018 in the TNO-GHGco-v3.0 regional European emissions for CO2 (Gg/yr) from biofuels (all biomass) for the EU+ by source sector (GNFR see Table 2 for sector codes).

The net decrease in total CO_2 emission despite increasing population numbers (~2.6% for EU-27) and increasing economic activity in the period 2005 – 2018, suggests that this is mostly an effect of improved energy efficiency across sectors and regions. Reductions in other pollutant emissions have been consistently larger than those in CO_2 emissions, indicating that in addition to energy efficiency gains, technologies have become cleaner across sectors and regions.

This is illustrated by the ratio of NOx emissions to total CO_2 emissions (see this ratio graphed for the major NOx releasing sectors in figure 12), which decreased by 34% on average over the period 2005 – 2018. For GNFRs A_PublicPower and F_RoadTransport_exhaust_diesel, which were the largest NOx releasing sectors in 2005, the reduction was even larger at ~45%. At the same time, the ratio stayed roughly constant during this period for GNFR C_OtherStationaryComb.

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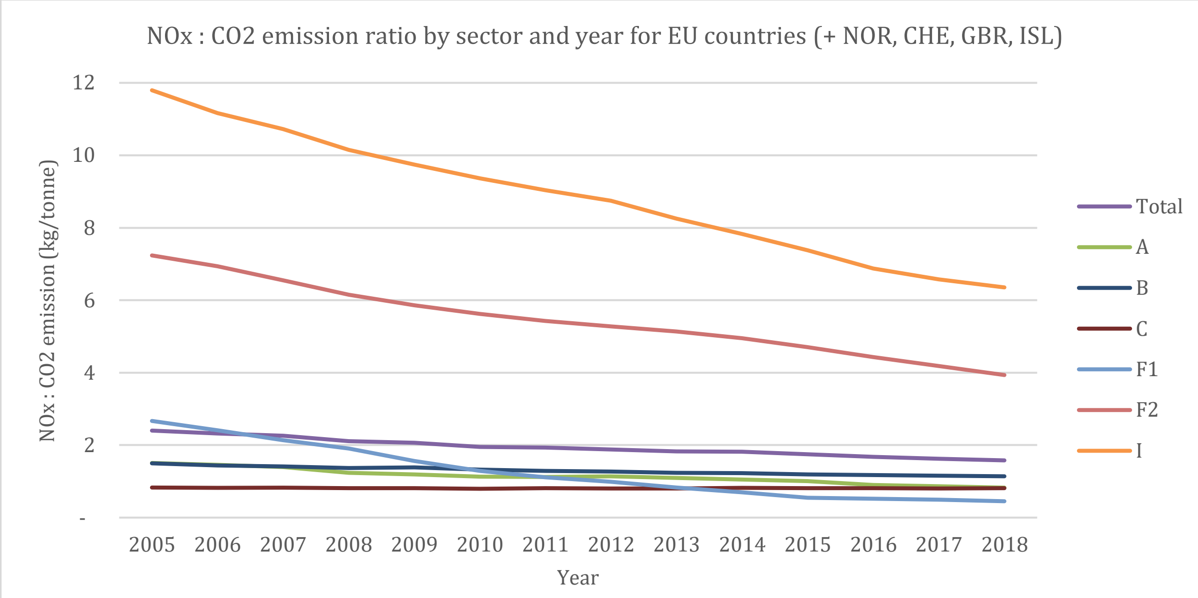

Figure 12: Trend 2005-2018 of emissions ratio between NOx and total CO_2 emissions for the EU+ by source sector (GNFR see Table 2 for sector codes). Only the largest NOx releasing sectors are displayed.

For CO, the pattern is similar, with an average 27% decrease is the ratio CO to total CO_2 emissions emitted across sectors and regions, again indicating technological improvements leading to lower emission intensities. The road transport sectors have the largest relative reduction of ~67% in the CO:CO_2 ratio. GNFR B_Industry has a reduction of 17% in the ratio while both A_PublicPower and C_OtherStationaryComb see an increase in the CO:CO_2 ratio.

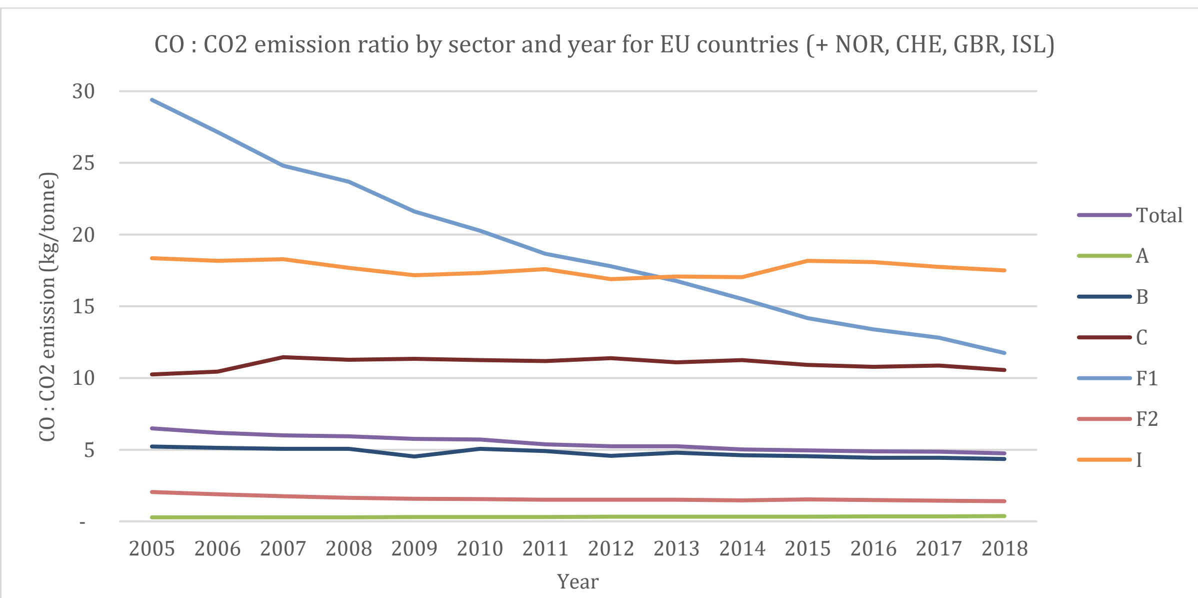

Figure 13: Trend 2005-2018 of emissions ratio between CO and total CO_2 emissions for the EU+ by source sector (GNFR see Table 2 for sector codes). Only the largest CO releasing sectors are displayed.

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3. Conclusions

A updated version of the TNO greenhouse gas and co-emitted species (GHGco) emission database at a resolution of ~ 6x6 km was made to support modelling of CO_2 and its co-emitted species across Europe. It contains annual emissions for the years 2005-2018. To develop the present version, the entire timeseries was reviewed and reporting of countries as of 2020 was used. This implies that at the moment of delivery (June 2021) the dataset is in line with NIR (National Inventory Report) reporting of EU countries to UNFCCC for the year 2020. The dataset covers the entire European domain for main the GHGs: carbon dioxide (distinguishing between fossil fuel CO_2 and biofuel CO_2) and methane (CH_4), as well as key co-emitted species that may be used as tracers for CO_2 from combustion sources: carbon monoxide (CO, also distinguishing between fossil and biofuel) and nitrogen oxides (NOx).

3.1. Evaluation and follow-up

This new dataset includes multiple important improvements compared to the GHGco v2.0 dataset. As a first step, the product will be evaluated in combination with European modelling teams as part of the VERIFY project.

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IIASA (Z. Klimont et al.) for access to GAINS data
JRC (M. Crippa et al.) for access to EDGAR data

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6. Annex

Table 4: Overview of the country grouping. The EU+ indicates that in some cases also a non-EU country is included in a countrygroup due to geographical location and/or similar legislation. These are indicated with a *. NON-EU indicates the countries in the European domain (UNECE Europe) but not within the EU.

Country Group	Country_name	ISO3
EU+_East	Bulgaria	BGR
	Czech Republic	CZE
	Hungary	HUN
	Poland	POL
	Romania	ROU
	Slovakia	SVK
	Slovenia	SVN
EU+_North	Denmark	DNK
	Estonia	EST
	Finland	FIN
	Iceland*	ISL
	Lithuania	LTU
	Latvia	LVA
	Norway*	NOR
	Sweden	SWE
EU+_South	Cyprus	CYP
	Spain	ESP
	Greece	GRC
	Croatia	HRV
	Italy	ITA
	Malta	MLT
	Portugal	PRT
EU+_WestCentral	Austria	AUT
	Belgium	BEL
	Switzerland*	CHE
	Germany	DEU
	France	FRA
	United Kingdom*	GBR
	Ireland	IRL
	Luxembourg	LUX
	Netherlands	NLD
NON_EU	Albania	ALB
	Armenia	ARM
	Azerbaijan	AZE

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	Bosnia and Herzegovina	BIH
	Belarus	BLR
	Georgia	GEO
	Kosovo	KOS
	Moldova	MDA
	Macedonia	MKD
	Montenegro	MNE
	Russian Federation	RUS
	Serbia	SRB
	Turkey	TUR
	Ukraine	UKR
NON_UNECE	Algeria	DZA
	Egypt	EGY
	Greenland	GRL
	Iran	IRN
	Iraq	IRQ
	Israel	ISR
	Jordan	JOR
	Kazakhstan	KAZ
	Kuwait	KWT
	Lebanon	LBN
	Libya	LBY
	Morocco	MAR
	Palestine	PSE
	Saudi Arabia	SAU
	Syria	SYR
	Turkmenistan	TKM
	Tunesia	TUN
	Uzbekistan	UZB
SEA	Atlantic Ocean	ATL
	Barentz Sea	BAR
	Baltic Sea	BAS
	Black Sea	BLS
	Caspian Sea	CAS
	English Channel	ENC
	Greenland Sea	GRS
	Irish Sea	IRC
	Kara Sea	KAR
	Mediterranean Sea	MED

	North Sea	NOS
	Norwegian Sea	NWS
	Persian Gulf	PSG

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