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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)	D2.4
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1. Changes with respect to the DoA

A miscommunication in the original DoA had placed the time for this deliverable a month after delivering the VERIFY 2000-2015 emissions data delivery. However, given that the completion of the 2000-2015 datasets took most of the resources and was scheduled for M12, we could not construct a first version of this deliverable using emission modelling and an in-depth analysis as initially planned. During the VERIFY general Assembly this issue was discussed and the delivery was rescheduled for Month 17 after discussion with and approval of PO/EC considering that this version is a first step and that improvements of the methodology for the emission extrapolation will be performed in the following years (and thus described in the associated deliverables). The gridded data for 2018 were made available on time (see evidence of accomplishment) but the accompanying deliverable report was delayed 3 weeks.

2. Dissemination and uptake

The TNO GHGco_t-1 emission inventory for 2018 will be used in tasks 2.3 and 2.4 as a prior inventory for inversions. The data have been made available to WP2 through the VERIFY directory TNO ftp site and through the VERIFY data base, that is accessible from the VERIFY web-site through a catalogue of data: http://verify.lsce.ipsl.fr/index.php/products.

3. Short Summary of results (<250 words)

Based on the TNO GHGco emission inventory (2000-2015), which was compiled in VERIFY WP2 (See also Deliverable 2.1) an estimation was made for the year t-1 (2018) emissions. Several methods were tested by applying an in-sample approach to the existing inventory. Effectively this means that we tested various regression methods or prediction options based on the emissions data for the years 2008-2012 to predict the year 2015 emissions. The methodologies which provide the best match with the real 2015 emissions were applied to the emissions timeseries 2010-2015 leading to predicted 2018 emissions. Next the 2018 emissions were gridded using a scaling approach by assuming the spatial distribution of the emissions by source sectors in 2018 to be similar as 2015. This results in a high resolution (~6 x 6km over central Europe) gridded inventory for 2018 (t-1), which is consistent with the 11-year timeseries (2005-2015) delivered previously. It includes anthropogenic emissions of CO_2 (fossil fuel and biofuel separately) and the co-emitted species CO (fossil fuel and biofuel separately), NOx, CH_4 and NMVOC. The methodology allows for immediate delivery for intermediate years (t-2, t-3) Although the title of this deliverable is “year -1 inventory”, the objective of this work is to support the pre-operational system of VERIFY. It is therefore necessary is to produce a complete time series from 2005 to year -1 to be used by the inversion. For this first year in the VERIFY cycle, the data for t-2 and t-3 are also produced and will be available on the data base at the end of August 2019.

4. Evidence of accomplishment

The TNO GHGco v.1.1 t-1 inventory (year 2018) has been made available via the FTP server to VERIFY partners through a mail including the login details to the TNO ftp server on July 3, 2019, and it will be available by the end of July 2019 on the data-base of VERIFY (accessible through the VERIFY web-site). Moreover, several tables and figures in this deliverable report show the results in detail and serve as supporting evidence of accomplishment.

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Version	Date	Description	Author (Organisation)
V0	17/07/2019	Creation/Writing	Antoon Visschedijk (TNO), Hugo Denier van der Gon (TNO), Stijn Dellaert (TNO), Jeroen Kuenen (TNO).
V1	22/07/2019	Writing/Formatting/Delivery	Antoon Visschedijk, Hugo Denier van der Gon (TNO)
V1.1	25/07/2019	Revision after review LSCE	Hugo Denier van der Gon (TNO)
V2	25/07/2019	Formatting/Delivery on the Participant Portal	Gregoire Broquet (LSCE) Philippe Peylin (LSCE)

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1. Introduction

Within the VERIFY project it was recognised that it would be beneficial to have a best-guess emission estimation for the most recent historical year (t-1). Official emission data generally lag at least 2 years behind as the necessary statistical data for emission calculation need to be compiled and published first. This deliverable report describes a projection of emission data for the "Current Year – 1" (t-1), which means during the time of writing this report (2019) it describes a projection for the year 2018. However, the same methodology is currently being applied for year t-3 and t-2 in order to have a complete time series for the whole historical period and the data will be delivered on the VERIFY portal before August 30, 2019.

There were some important constraints on this first VERIFY t-1 emission inventory. First of all, it had to be made in a very short amount of time because work on the projection can only commence after the consistent timeseries 2000-2015 is completed. This implies that for this first version of the t-1 there was only little time for any deeper analysis of drivers, policies or emission control measures. Also setting up emission models for specific source sectors would need more time and endanger the delivery time. Therefore the methodology is based on sensibly extrapolating emission trends observed for earlier years in combination with expert knowledge of emission data and their underlying patterns. The methodology will be refined in the subsequent versions of this deliverable.

This report describes the development and results of a methodology to extrapolate pre-2015 trends to 2018. Instead of using simple linear regression and extrapolation, a somewhat more sophisticated and intelligent extrapolation approach has been attempted, which was optimised by in-sample testing for historical years.

The pollutants covered are:
- CH_4
- CO
- CO_2
- NMVOC (non-methane volatile organic compounds)
- NO_x

The area covered are the European countries of the UN-ECE (United Nations Economic Commission for Europe; see annex 1) and the developed methodology has been applied consistently to all countries this domain.

A brief glance at the relative 2000 – 2015 emission trends for all EU countries plus Norway, Switzerland and Iceland (EU(28)+) is provided by Figure 1, which shows mostly steadily decreasing emissions, suggesting that extrapolation will produce reasonable results.

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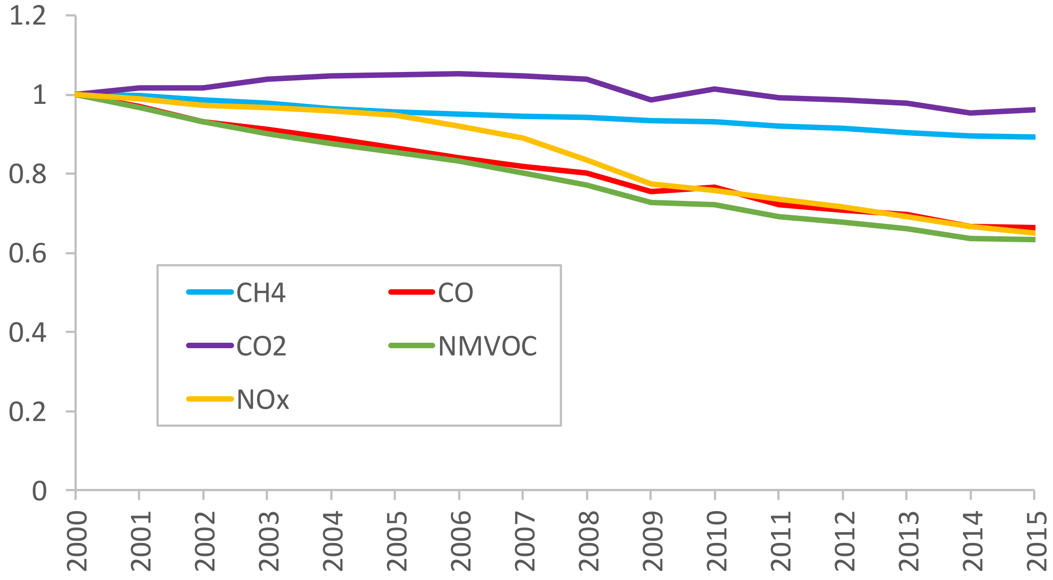

Figure 1 Emission trends for selected pollutants for the entire EU28 normalized for the year 2000 emission level (year 2000 emission = 1)

2. A simple and robust emission trend extrapolation method for "Year – 1"

This section will start with a closer look at observed emission trends in Europe since the year 2000. Although in the meantime also data for 2016 are available these have not been used in this study because we need a consistent time series for extrapolation. Simply adding a new year does not work well as the methodology to estimate certain sectors may have changed. This creates disruption of trends. So that means that if we want to add 2016 first, we have to reanalyse the entire 2000-2016 timeseries before we can start to work on the prediction of the t-1 emissions. This was not feasible in the time available. Hence the timeseries used is 2000-2015.

2.1. Observed emission trends during 2000 to 2015

Trends in regional emission data for the period 2000 to 2015 have been plotted in a series of charts shown below. In each figure two panels are shown distinguishing different regions, each with a different emission data origin. The first region (top panel) is the EU28 plus Norway an Switzerland (EU(28)+), for which emission data is made up of mostly country-supplied data on annual basis. The second region (lower panel) comprises the other countries in Europe, for which emission data are mostly based on interpolation of five year advancing IIASA GAINS estimates, with linear interpolation in between. Emissions are shown by GNFR (gridded nomenclature for reporting) source sector (Table 1) and are expressed in units relative to the emission total in the first year (2000). It must be noted that the quality of the emission data for the EU(28)+ is much higher than for the European countries outside the EU(28)+. The value of the trend analysis for the non-EU(28)+ is therefore limited, as emission time series effectively comprise only four data points (2000, 2005, 2010 and 2015) with linear interpolation in between.

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Table 1. 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 + SNAP 75 [Note that SNAP 74 has only NMVOC and SNAP 75 has only PM emissions]

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CH_4: In the EU(28)+ methane emission is dominated by three sources/sectors:

- fugitive emissions from fossil fuel production and distribution (GNFR D), which initially show a downward trend but seem to stabilise in recent years
- emission from waste disposal (GNFR J, mostly landfills) that shows a steady and consistent downward trend
- emission from livestock GNFR K) which shows a weak fluctuation but no consistent trend

These same sectors also dominate methane emissions outside the EU(28)+, with the most important contribution coming from GNFR D, fugitive emission from fossil fuel production and distribution, which have been increasing since 2000. This is likely due to increases in natural gas and oil production.

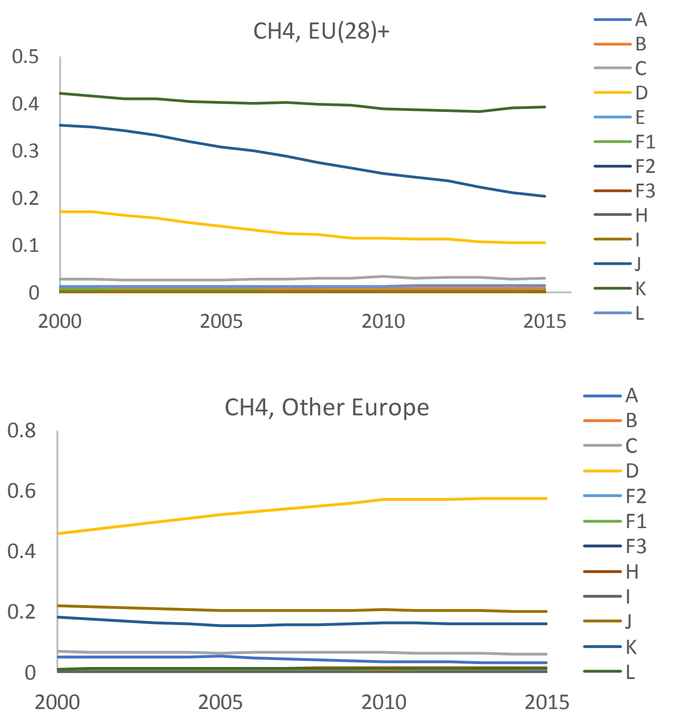

Figure 2 Trends in CH_4 emissions by source sector (GNFR, Table 1) for the EU28+ and other European countries in 2000-2015. Y-axis presents the share of each sector relative to the total emission in 2000 (2000 = 1)

CO: CO emission in the EU(28)+ is caused primarily by:

- small combustion sources (GNFR C, for CO mainly from wood and some coal combustion), which are likely influenced by weather/heating degree days, show a stable emission level with at first sight erratic variations (most likely caused by meteo variations) and no long term downward trend
- industrial sources (GNFR B, for CO mainly from metallurgy), which seem to depend primarily on the business cycle/economy but may also show a weak downward trend

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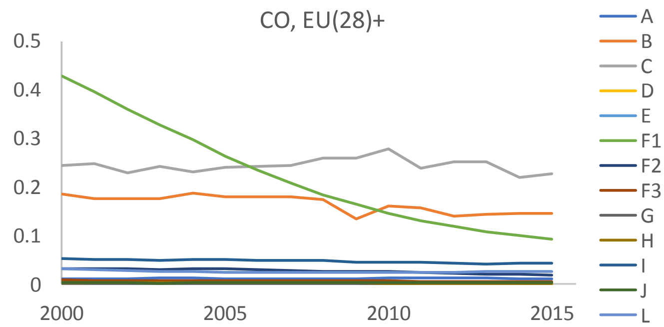
- road transport (GNFR F1, mostly gasoline-fuelled vehicles), from which emission has decreased considerably as a result of the Euro standards; some further reduction can be expected as older vehicles continue to be phased out



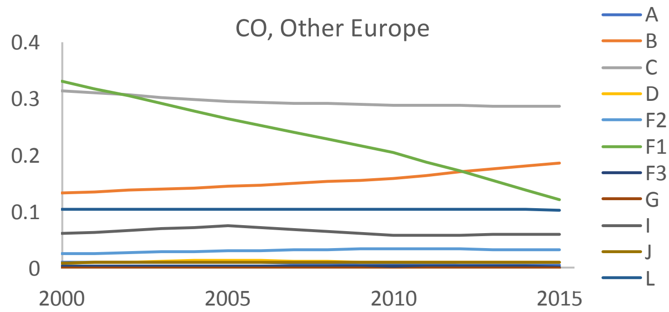


Figure 3 Trends in CO emissions by source sector (GNFR, Table 1) for the EU28+ and other European countries in 2000-2015. Y-axis presents the share of each sector relative to the total emission in 2000 (2000 = 1)

For the non-EU(28)+ the main change in CO emission is road transport where emission shows a strong and consistent downward trend as a result of car fleet modernisation and the Euro standards. It should be noted that especially CO emission data for the non-EU countries are of far lesser quality than the EU(28)+ data.

CO_2: In the EU(28)+ there are four important CO_2 sources (sum of CO_2 from biofuels and fossil fuels):

- Power plants (GNFR A) that show no real consistent trend besides perhaps some business cycle influence and a small downward trend since 2007; however from 2014 to 2015 this trend seems to reverse yet again, likely as a result of sustained economic growth starting around 2013 according to Eurostat's real GDP growth rate – volume data
- Industry (GNFR B) that principally follows the business cycle (note the dip during the 2009 economic crisis)
- Households (GNFR C) that correlate with heating degree days but shows no trend over time.
- Road transport (GNFR F1 and F2, gasoline and diesel-fuelled vehicles respectively) of which the total seems to remain constant (not shown) but diesel use seems to increase at the cost of gasoline use (fuel shift)

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Outside of the EU(28)+ power plant emissions (GNFR A) dominate emissions, which do not show a consistent trend. Industry (GNFR B) comes in second and shows a consistent increase over the period 2000 to 2015. Third important CO2 source outside the EU(28)+ are households (GNFR C) that show a weak downward trend.

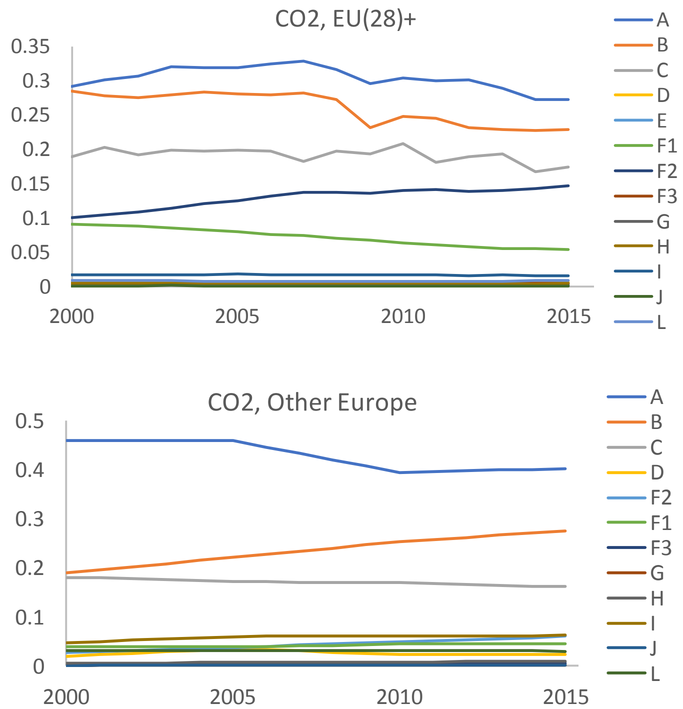

Figure 4 Trends in carbon dioxide (CO_2) emissions by source sector (GNFR, Table 1) for the EU28+ and other European countries in 2000-2015. Y-axis presents the share of each sector relative to the total emission in 2000 (2000 = 1)

NMVOC:

- In the EU(28)+ solvent use (GNFR E) dominates NMVOC emission, which shows a downward trend, mostly due to reduction of industrial solvent use.
- Gasoline vehicles (GNFR F1 and F4) used to be another important source but emission has come down considerably.
- Fugitive emission from oil and gas production and distribution (GNFR D) has also decreased considerably until 2010 but seem to have stabilised since then.
- Industry (GNFR B) and households (GNFR C) do not show a clear consistent trend.

Outside the EU(28)+ only transport emissions (GNFR F1, F4 and I) seem to decrease while other sources remain approximately constant.

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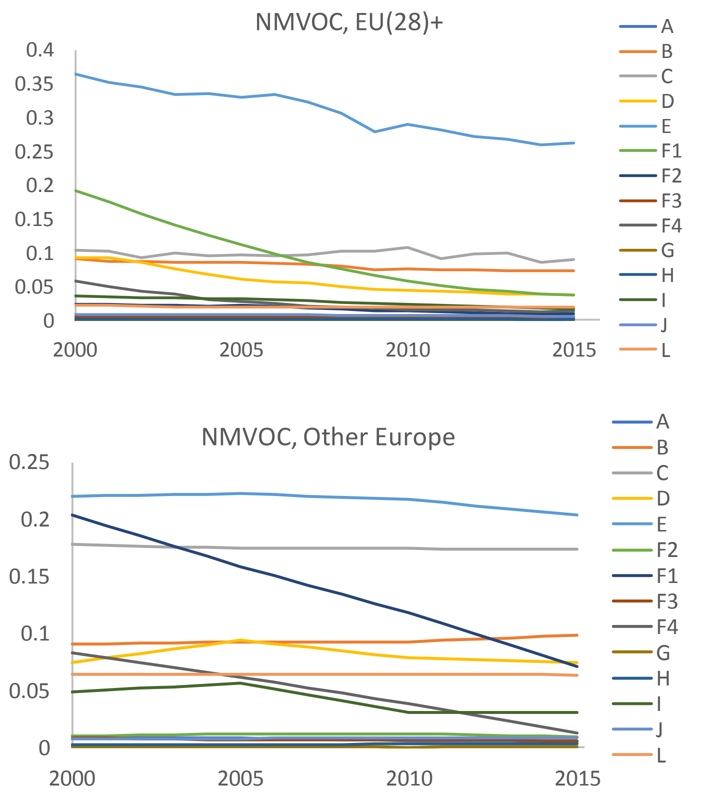

Figure 5 Trends in NMVOC emissions by source sector (GNFR, Table 1) for the EU28+ and other European countries in 2000-2015. Y-axis presents the share of each sector relative to the total emission in 2000 (2000 = 1)

NO_x: In the EU(28)+ NO_x emission is primarily determined by

- Diesel-fuelled road vehicles (GNFR F2) that since 2005 show a downward trend as a result of the Euro standards
- Power plant emissions (GNFR A) that show a somewhat erratic but overall downward trend, also from emission reduction measures and power plant decommissioning
- Industry (GNFR B) with also some overall downward trend
- Non-road vehicles (GNFR I) that are also decreasing as a result of emission standards
- Gasoline-fuelled road vehicles (GNFR F1) that have strongly decreased due the Euro standards
- Small combustion sources (GNFR C) that have remained constant

Outside the EU(28)+ power plant emissions (GNFR A) are decreasing and so are gasoline-fuelled road vehicles (GNFR F1) as a result of car fleet modernisation and the Euro standards. Industrial emission (GNFR B) is increasing while other sources remained approximately constant.

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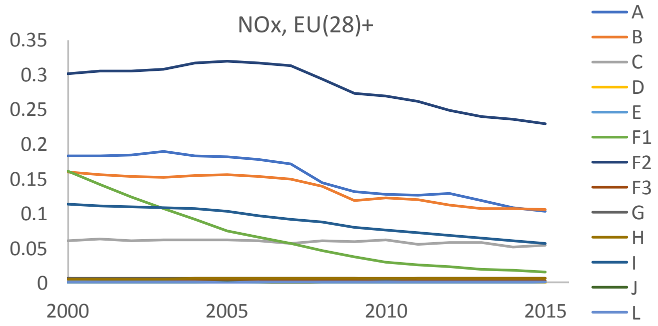

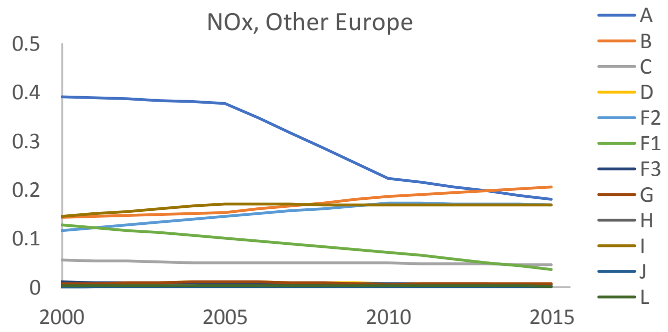

Figure 6 Trends in NO_x emissions by source sector (GNFR, Table 1) for the EU28+ and other European countries in 2000-2015. Y-axis presents the share of each sector relative to the total emission in 2000 (2000 = 1)

2.1.1. Summary of observed emission trends

Summarising the trend analysis for the EU(28)+, the following sector – pollutants combinations show a robust and consistent trend on a regional scale.

Emission source	GNFR	Affected pollutants
Road transport exhaust emission reduction	F1, F2, F3	CO_2, CO, NMVOC, and NO_x
Evaporative losses from road vehicles	F4	NMVOC
Other (non-road) mobile sources	I	NO_x
Fugitive emissions fuel production and distribution	D	CH_4
Waste disposal	J	CH_4
Solvent use	E	NMVOC
Large combustion plants	A, B	NO_x

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Without exception these emission trends are the result of well documented emission control and prevention measures, implemented in the EU(28)+ during the past decades. Outside the EU(28)+ the benefits of the Euro emission standards for road vehicles can be clearly observed as well. Economic growth and production increases allegedly result in some increasing emissions as well but the robustness of these observations may be limited as emission data quality is limited.

2.2. Methodology for testing extrapolation algorithms with in-sample forecasting

To optimise the methodology used for the t-1 forecast we test the results of an in-sample forecast. This implies that various approaches are used to predict the emission for a year for which the emission is already known. Whatever approach that most closely reproduces the observation is selected for t-1.

2.2.1. Level of sector details in regression/trend extrapolation

To estimate T-1 emission data, two fundamentally different approaches exist a) observed trends may be extrapolated or b) data for the last available year may be assumed to be most representative. For the EU(28)+ as a whole, emission data seem reasonably predictable, as observed trends can usually be explained by the known implementation of emission reduction policies which go rather gradual for example because of fleet replacement.. From country to country, the time path or speed of implementation of emission control measures may however not line up. The total and remaining reduction potential of control measures may also differ from country to country. Therefore, regionally observed trends may not be representative for individual countries and trend extrapolation should preferably be undertaken on a country by country basis.

In addition it may be beneficial to disaggregate sector contributions in case several types of control measures may be implemented concurrently. Further sector disaggregation can in that case increase accuracy, but in practice there is a limit to this. On a highly disaggregated source sector level there are for instance occasional shifts in sector categorization over the years and the chance of missing data for one or more years also increases. The uncertainty of the emission data also increases when source sector specification gets ever more detailed. As a result of this we choose to consider trends at GNFR sector level, believing that this level of sector detail is an acceptable compromise between accuracy and robustness. Several pragmatic choices were made along the way to predict the 2018 emissions using the 2000-2015 timeseries. These are briefly discussed in the following sections.

2.2.2. Time period considered in regression analysis

The period included in trend analysis can vary from only the last two years to the entire available timeseries. Considering a long period may lead to more robust and stable results (as artifacts and interannual variations are cancelled out) but may also fail to capture recent developments and/or could lead to overestimations as in reality the trend may be leveling off (or go faster). For effective regression it is preferable to limit the time period considered to a period of monotonic in- or decrease.

Another consideration is that for the present t-1 forecasts three years have to be bridged (i.e. 2018 is estimated based on data from 2015 at the latest). Note that often the gap to be bridged in Europe will be 2 years but for extrapolation a complete consistent time series is needed. Creating this timeseries is a considerable task, hence occasionally it will occur that the gap to be bridged is 3 years because the time series has not yet been updated. Three years is a substantial jump in time which necessitates stable and perhaps somewhat conservative trend extrapolation. It is also important that, if present, longer term trends are captured. Loosely based on trend observations made in the previous chapter it was assumed that sector-wide implementation of emission control measures may have a typical average timescale of about 5 to 10 years. Hence it was decided to include a five-year period in the regression analysis. The influence of including different time intervals in the regression analysis has not further been investigated.

2.2.3. Regression algorithms

When considering annual emission data over a certain period, emissions may appear either stable or changing at a constant rate, or a varying rate. Besides a “true” trend (for instance as a result of gradual implementation of an emission reduction measure), an emission timeseries may include some seemingly random year to year fluctuation as well. A regression algorithm preferably captures the true trends that have predictive value, and cancels out random artefacts.

Most available computer software that can be used for automated trend analysis offers the possibility for linear, as well as exponential regression, producing either a linear or exponential trend equation. Both methods have their pro’s and con’s.

Which method will produce the best results for short term emission forecasts is difficult to predict beforehand. When zooming in on the level of individual countries and sectors data may become more erratic than any consistent trends observed on a regional level, so robustness and stability seems important. Both regression algorithms have been tested by in-sample forecasting (section 2.3), and it was decided to select the algorithm for the t-1 forecast based on the outcome of this test.

2.2.4. Trend extrapolation versus assuming last available year data

As mentioned before, the alternative to extrapolating trends to predict emissions is assuming the last available year as the best approximation for the forecast year. However, it is expected that if the year to be predicted is further away, the performance of the last available year will decrease. For example we expect that predicting future emissions by assuming them equal to 2015 works better for 2016 than for 2018.

When emission estimation methodologies are updated, countries are required to recalculate and resubmit the entire historic time series, not just the latest year. In practice, timeseries recalculation is sometimes omitted or overlooked and jumps in emission timeseries may appear. In such cases the last available year will be a better approximation for t-1 than any trend extrapolation (because a change in methodology cannot be predicted). Assuming the last available year may therefore be included in the forecast methodology as a fall-back approach.

2.2.5. Time series consistency

Countries aim to continuously improve estimation methodologies. If a new improved methodology or emission factor is adopted all historic years are adjusted. This is why emission reported for the same year (e.g. 2005) may be quite different in subsequent annual emission submissions (e.g. 2015, 2016 and 2017). Data updates are frequent and the changes may be quite considerable, especially for air pollutants. It is essential that the emission timeseries on which the t-1 forecast is based must be limited to data reported in one specific reporting year only. A combination of different reporting years will likely introduce discontinuities that are artefacts and will obscure “true” trends. When data for a new year become available this data cannot be added to improve the t-1 forecast, unless a whole new consistent emission timeseries is used.

2.3. Results of in-sample forecasts

The in-sample forecasts we use to test the various prediction options consist of predicting 2015 emissions based on 2008 – 2012 emission reporting. Since the 2015 emissions are known, we can judge the performance of the prediction three years in the future). Three approaches to predict 2015 are compared to the actual 2015 emissions:

- Assuming the last available year data (2012) for 2015 (= no trend)
- Linear regression of 2008 – 2012 data and subsequent extrapolation to 2015
- Exponential regression of 2008 – 2012 and subsequent extrapolation to 2015

On individual country - pollutant – GNFR level, the residual sum of squares (ΣRSS) for these three projections is calculated by summing the squared differences between the projected and the actual known 2015 data, over all GNFR sectors. This information is used to decide which prediction method provided the best results because we do not want, for reasons of transparency, to select different approaches for each individual country - pollutant – GNFR level.

2.3.1. First regression/extrapolation approach

In our first round of testing we have tested if regression/trend extrapolation (linear or exponential) is indeed superior to simply assuming no trend (2012 data). The same extrapolation/regression approach has been used for all individual combinations of country, substance and sector, with no exceptions. Table 2 shows the interpreted ΣRSS comparisons per substance for the EU(28)+ as a whole (2^{nd} and 3^{rd} columns).

A rather unexpected but important conclusion from Table 2 is that only for CH_4 regression and extrapolation leads to a more accurate prediction for t-1. For all other substances assuming no trend (the last available year) is a better predictor for t-1 than both types of extrapolation. A second conclusion is that exponential regression and extrapolation performs relatively better than linear regression/extrapolation.

For countries outside the EU(28)+ this picture is roughly confirmed but the quality and completeness of the emission data does not actually allow such a detailed analysis, so the data are not shown.

A remark here is that, since we needed a 5-year time period, we had to include the years 2008-09 which are exceptional due to the economic crisis. As we move forward in time, this specific disruption will no longer be in our time series.

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Table 2: Regression and extrapolation (linear and exponential) compared to assuming constant (last available) emission, when all sector substance combinations are included regression/extrapolation

Substance	All GNFR – substance combinations	
	Linear	Exponential
CH_4	Worse	Better
CO	Much worse	Worse
CO_2	Much worse	Much worse
NMVOC	Much worse	Worse
NO_x	Much worse	Much worse

2.3.2. Reasons for inaccuracy introduced by linear or exponential extrapolation

It has been investigated in detail what the reasons are for the seemingly low predictive value of the regression/extrapolation for t-1 in the first in-sample forecast. It turns out that there is no single reason for this. It is important to realize that after a long period of decrease, emissions of many previously dominating sources seem to have stabilized somewhat after 2010, thereafter showing less strong trends (see Section 2.1). Low remaining emissions may then also be more difficult to reduce any further. This will be even more the case in preparing the actual t-1 estimate, which is three years later. Secondly several sources (or source sectors) are primarily governed by unpredictable factors such as the weather or closure of a large facility (Note that the use of weather data to predict for example residential combustion is foreseen in the next cycle of t-1 prediction) . Thirdly and perhaps most importantly, if there are any major inconsistencies in estimation methodology within a certain timeseries, this will derange any attempt at modelling an emission trend, and in that case data for the last available year will often give a much better t-1 estimate.

There are also a few situations where linear and exponential regression principally fails to produce a satisfiable result, in spite of a clear present trend. With linear regression emissions can even become negative, especially when the target year is relatively far from the last available year with emission data. Trends also have to be monotonic to be captured by linear or exponential regression. An initial decrease followed by a straight line or slight increase cannot be sufficiently described by a linear or exponential trendline. Extrapolation will for instance give an estimate that is far too low in that case. Situations like this may be limited by choosing the right timeseries interval in the regression analysis.

2.3.3. Second improved regression/extrapolation approach

In spite of the fact that when applied to all country – substance – sector combinations, trend extrapolation gives an overall worse approximation of t-1 emission than assuming no trend at all, in Section 2.1.1 some

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clear and explainable medium and long term overall emission trends were identified. The second round of in-sample forecasting, regression and extrapolation has therefore been limited to the sector – substance combinations identified in Section 2.1.1. For all other sector - substance combinations, the reasons discussed in Section **Erreur ! Source du renvoi introuvable.** apparently cause too much false trends to be introduced in he t-1 projection. Again all countries are still treated the same way.

In the in-sample forecast this new approach greatly improves the accuracy of the t-1 projection. Table 3 again compares the regression/extrapolation approximation, to only assuming the last available year data. This time however only the trends identified in Section 2.1.1 have been included in the regression/extrapolation. For other substance – sector combinations the last available year data are used in both cases. For all substances except CO_2 and NMVOC the t-1 estimate more closely approaches the actual (in-sample 2015) emission than simply assuming last available year data everywhere. For CO_2 and NMVOC it does not seem to make much difference which method is used. Again exponential regression/extrapolation generally performs better than linear extrapolation.

Table 3: Regression and extrapolation (linear and exponential) of robust trends only compared to assuming constant (last available) emission.

Substance	Selected robust trends only	
	Linear	Exponential
CH_4	Better	Much better
CO	Worse	Better
CO_2	Better	Identical
NMVOC	Worse	Identical
NO_x	Better	Much better

One substance that proves particularly hard to predict is CO_2. Except for shifts in sector contributions (e.g. gasoline/diesel use in transport, see Section 2.1) there are no clear trends observed for CO_2 in the EU(28)+. Year to year variation in total emission seems to be largely determined by unpredictable factors. The reason why linear regression/interpolation seems to give slightly better results than exponential extrapolation may in this case well be circumstantial for CO_2. However, it should be noted that CO_2 overall is relatively stable with no major strong decrease, despite considerable emission reductions scheduled for 2030. The main point here is that if no or hardly any changes occur it is nearly impossible to predict a better value than the last available year.

Also NMVOC emission turns out difficult to predict. Transport activities used to be a big NMVOC source with a clear downward trend but not so much in recent years. Now solvent use is the major NMVOC source and a slow overall decrease of emission is observed for the EU(28)+ during 2000 – 2012. However for solvent use in particular there can be large inconsistencies in methodologies used for the different years. Once solvent emission is estimated for a certain year, countries seem less enthusiast to recalculate emission after a methodology update for this source. This likely has to do with the relatively complex estimation methodologies that this source sector often requires.

3. Results for t-1 (2018) and gridded data

In this study the results of the in-sample forecast are taken as leading for the approach used for the actual t-1 (2018) projection. A robust and conservative approach has appeared to be the best way to predict t-1 emission. This approach involves exponential regression and extrapolation only for sector – substance combinations that show robust and well understood trends and no attempting to extrapolate/predict other trends.

Table 2 presents the projected t-1 (2018) emission, using the methodology derived in Section 2. Emissions are calculated at the level of country – sector - substances but are summarized over two regions in Table 2. The projected emissions relative to the 2015 emission are shown in Figure 7. In both the EU(28)+ and the non-EU a slight decrease of emission is predicted for most substances. For CO_2 t-1 projection is almost identical to 2015 (last available year data). It should be noted that the lack of a trend here in fact implies a different sort of trend. The economy has been growing and traditionally that means an increase in energy use, hence in CO_2 emissions. Now we see a growth in economy but no change in CO_2. Hence energy intensity of production is reduced.

Table 4: Projected 2018 (t-1) emissions (kton)

Substance	EU(28)+		Non-EU	
	2015	2018	2015	2018
CH4	18807	18086	22445	22503
CO	21454	20572	17666	16947
CO2	4152543	4147399	2007909	2025553
NMVOC	6271	5935	3891	3723
NOX	7200	6455	4024	3927

VERIFY is a research project funded by the European Commission under the H2020 program. Grant Agreement number 776810.

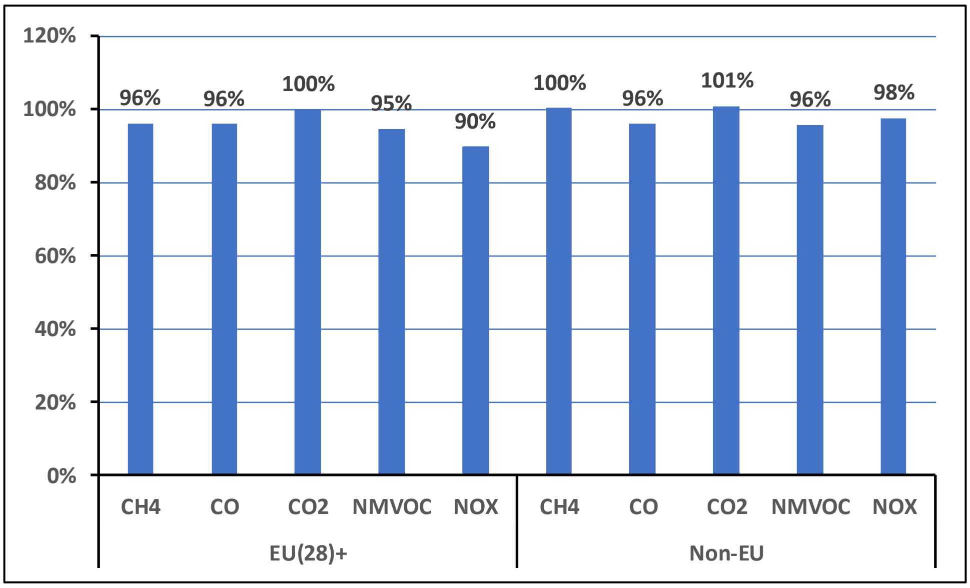

Figure 7: Projected t-1 (2018) emissions, relative to the 2015 emission

The following set of figures show 2015 and 2018 emissions per sector, for five selected countries: Germany (DEU), Spain (ESP), France (FRA), Poland (POL) and Romania (ROU). Sector coding is provided in Table 1.

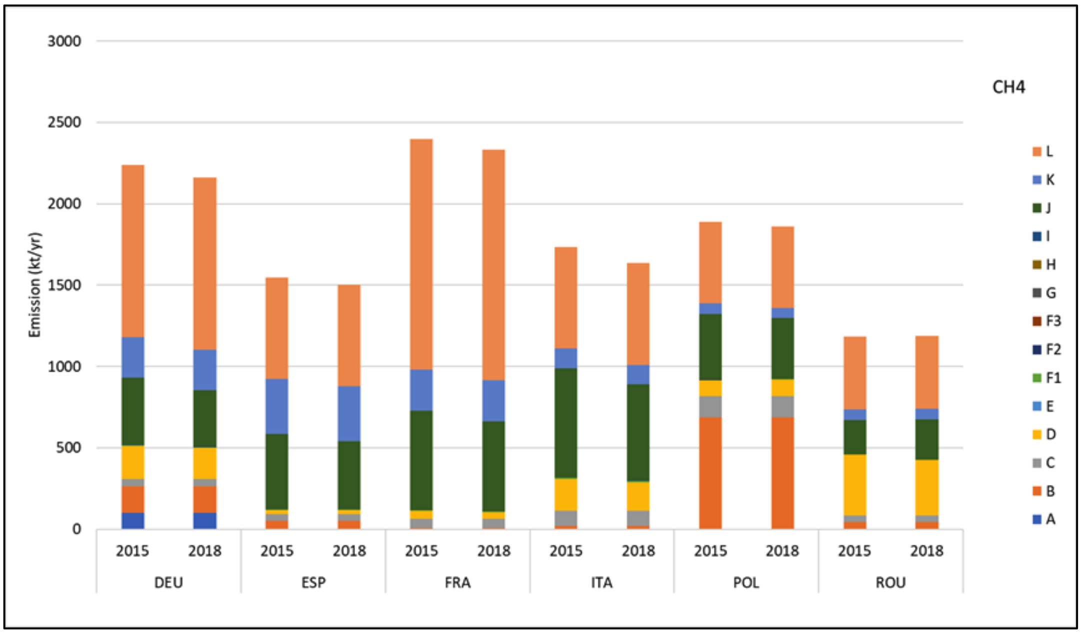

Figure 8: CH_4 emissions for selected countries in the EU28 by source sector for 2015 and 2018 (t-1).

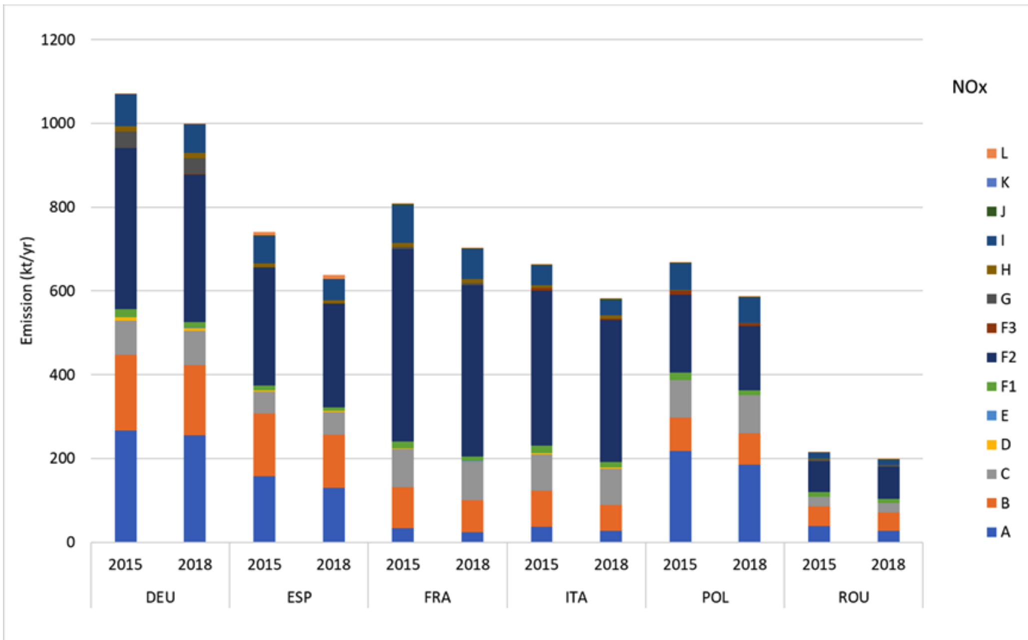

Figure 9: NO_x emissions for selected countries in the EU28 by source sector for 2015 and 2018 (t-1)

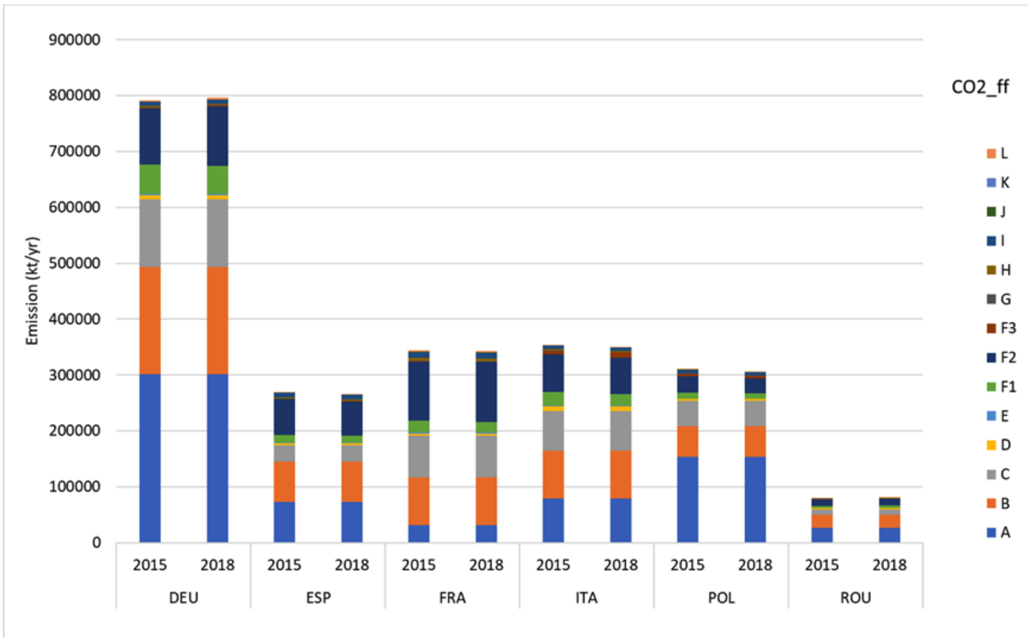

Figure 10: CO_2 emissions for fossil fuel combustion for selected countries in the EU28 by source sector for 2015 and 2018 (t-1).

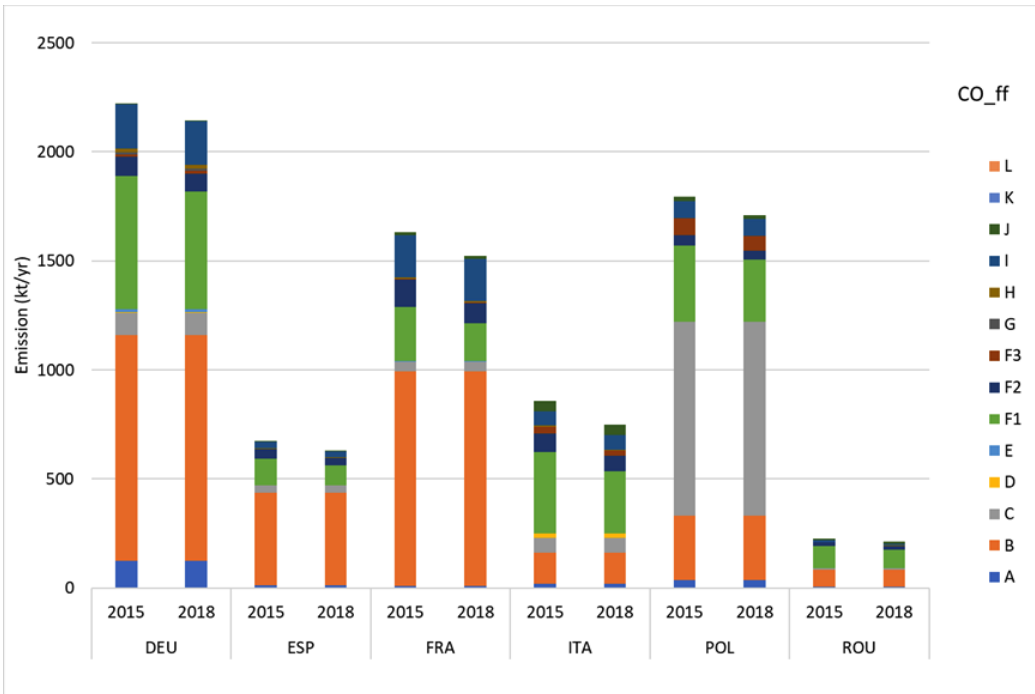

Figure 11: CO emissions from fossil fuel combustion for selected countries in the EU28 by source sector for 2015 and 2018 (t-1)

3.1. Emission grids for 2018 and access to the data

The t-1 (2018) emission data have been gridded on a 0.1 x 0.05° lon-lat resolution. This has been done by scaling the existing TNO-GHGco 2015 gridded data to the 2018, on a country - substance – sector basis. The TNO GHGco v.1.1 t-1 inventory (year 2018) has been made available via the TNO FTP server to VERIFY partners (July 3, 2019) and will also be available on the VERIFY database at the end of July 2019 (see "products" page of the VERIFY website). For further information please contact hugo.deniervandergon@tno.nl

4. Outlook/recommendations

In this deliverable report the methodology and the resulting t-1 emission (2018) are described. However, the overall VERIFY inversion set-up will need not only the t-1 but also the other years between the latest available emission data year and the t-1. In the current example that implies that next to t-1 (=2018) under this task also the years 2016 and 2017 should be delivered. This does not provide any obstacles or delays, since we have the methodology in place. For this first year in the VERIFY cycle, the data for t-2 and t-3 are being produced and will be available on through VERIFY data base at the end of August 2019.

VERIFY WP2 task 2.1 will provide year t-1 emissions data in an annual cycle, meaning that in 2020 we will produce 2019 emissions under this task. Moreover, aalthough the title of this deliverable in the DoA is "year -1 inventory", the objective of this work is to support the pre-operational system of VERIFY. It is therefore necessary is to produce a complete time series from 2005 to year -1 to be used by the inversion. For the next cycle in 2020 the year -1 and -2 (and if needed -3) will be delivered together as one product.

It is our ambition to improve the quality of the t-1 emissions estimation methodology every year. Possibilities to further improve the developed t-1 extrapolation method exist. The current "first version" methodology is solely based on analysis of existing emission data. Emission data usually become available with a two to three year time delay. Several other types data which may represent important drivers for emissions become available sooner, such as meteorological and macroeconomic data. We will aim to increasingly use such data to improve the prediction. Such data represent drivers of emissions and they can be used to model emissions to further improve the accuracy of t-1 emission estimations. For next year the use of a heating degree day function to predict residential combustion emissions is foreseen to further improve the t-1 emission projection methodology. Moreover, we will make intercomparisons with other products such as the Global Carbon Project forecasts and consider the use of statistics. Nevertheless, the current exercise and resulting methodology is important because inventories need to be, above all, complete. We now have an approach that deliveries complete inventories and we can start to stepwise improve the accuracy and predictive value.

As indicated, our belief is that over time (within the VERIFY project) the quality of the t-1 predictions will improve because 1) for certain sectors we intend to introduce emission modelling using year-specific data and 2) the next full time series will most likely be 2000-2017. This implies that to use the 5 years data for an in-sample forecast, analysis will start from 2010. This will remove the exceptional economic crisis years from our regressions, possibly leading to a better performance.

Annex 1. List of European countries included in the year-1 inventory.

Country Group	ISO3	Country Name
EU 15	AUT	Austria
	BEL	Belgium
	CHE	Switzerland
	DEU	Germany
	DNK	Denmark
	ESP	Spain
	FIN	Finland
	FRA	France
	GBR	United Kingdom
	GRC	Greece
	IRL	Ireland
	ITA	Italy
	LUX	Luxembourg
	NLD	Netherlands
	NOR	Norway
	PRT	Portugal
	SWE	Sweden
EU New Member States	BGR	Bulgaria
	CYP	Cyprus
	CZE	Czech Republic
	EST	Estonia
	HRV	Croatia
	HUN	Hungary
	LTU	Lithuania
	LVA	Latvia
	MLT	Malta
	POL	Poland
	ROU	Romania
	SVK	Slovakia
	SVN	Slovenia

Country Group	ISO3	Country Name
Non EU countries	ALB	Albania
	BIH	Bosnia and Herzegovina
	BLR	Belarus
	ISL	Iceland
	KOS	Kosovo
	MDA	Moldova
	MKD	Macedonia
	MNE	Montenegro
	RUS	Russian Federation
	SRB	Serbia
	TUR	Turkey
	UKR	Ukraine
Sea regions	ATL	Atlantic Ocean
	BAR	Barentz Sea
	BAS	Baltic Sea
	BLS	Black Sea
	CAS	Caspian Sea
	ENC	English Channel
	GRS	Greenland Sea
	IRC	Irish Sea
	KAR	Kara Sea
	MED	Mediterranean Sea
	NOS	North Sea
	NWS	Norwegian Sea
	PSG	Persian Gulf

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