VERIFY GA

April 28-29

WP2 Verification methods for fossil fuel CO_2 emissions

April 28th, 2021

Online

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WP2 team
(TNO, UEDIN, KIT, UHEI, JRC, LSCE, WU, ULund)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776810

WP2 VERIFICATION METHODS FOR CO2_FF EMISSIONS

Overall objective WP2:

Construct FFDAS to estimate ffCO2 emissions at sub-national resolution (25-50 km) by combining new anthropogenic emissions, natural fluxes (WP3) with in situ and satellite atmospheric data.

WP leader	**5 –TNO / UEDIN**
Participants	TNO, CEA, JRC, KIT, UHEI, UEDIN, ULUND, WU

Teams in WP2 – who is doing what?

- **T2.1 Emission inventories – global / regional (TNO / JRC)**
- **T2.2 Case study region; in situ + data analysis & new measurements (UHEI + KIT)**
- **T2.1&2&4 Uncertainty calculation and emission model set-up for test cases (WU / TNO)**
- **T2.3 Inversion system set-up for budgets/trends of CO_2 using satellite measurements (CEA-LSCE)**
- **T2.4 CCDAS and FFDAS set up in combination with WP3 (ULUND / WU)**
- **T2.4 Model systems and configuration document (UEDIN)**

FFDAS to estimate ffCO2 emissions at sub-national resolution

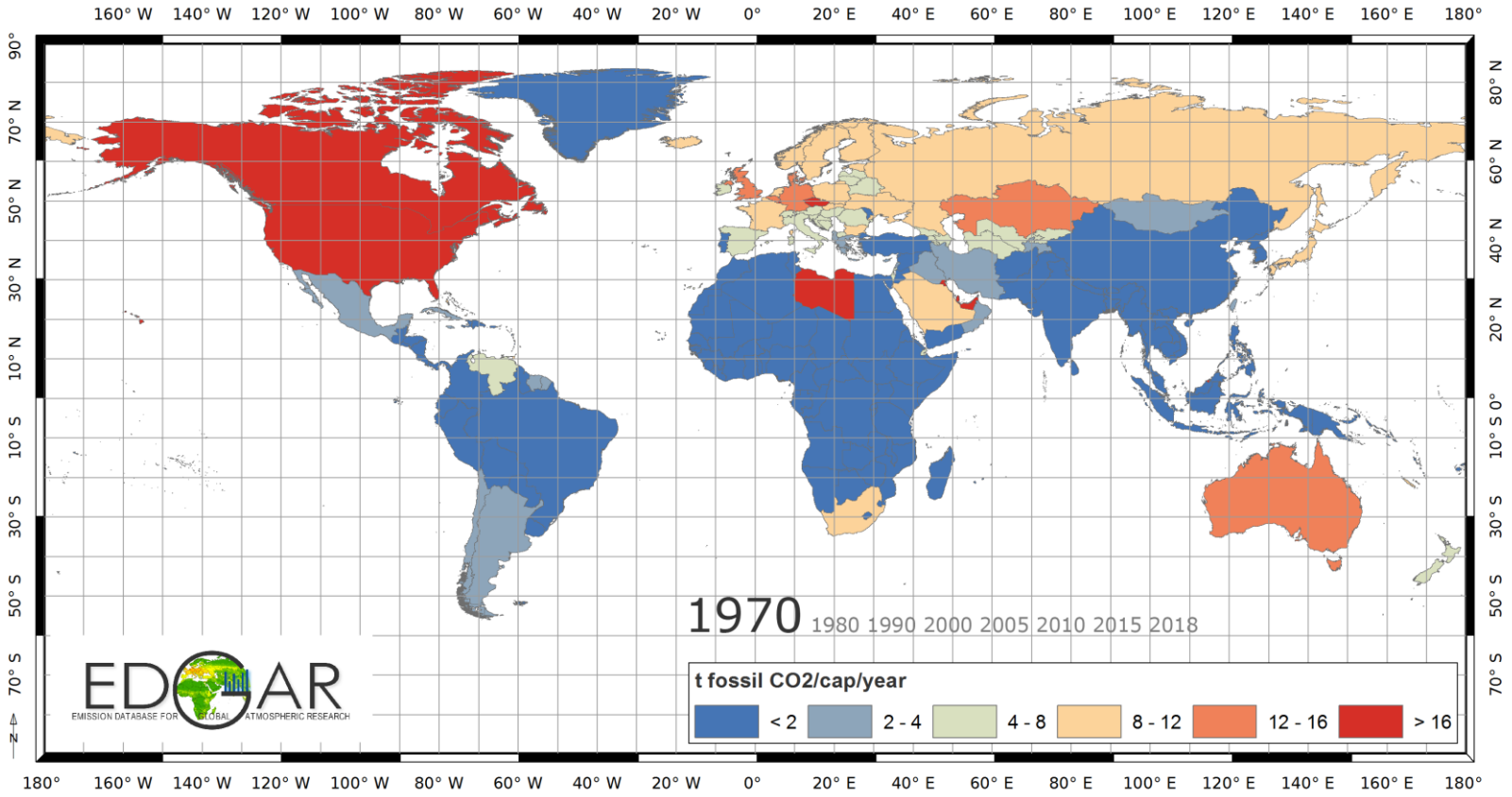
T2.1 – Bottom-up emission estimates for anthropogenic CO2 and co-emitted tracers (TNO, JRC, WU; M01 M48)

Specific objective: Deliver high-res emission of ffCO2, bfCO2 & co-emitted tracers (CO, NOx, NMVOC) for Europe, 2005-present

Progress & **achievements** M19-M36

- Fast-track global CO_2 emissions from JRC / EDGAR up to year -2. (2017)
- Updated 1x1 km for case study domain (2015 -> 2017) with most recent point source emissions (see also figures T2.2)
- System/method in place to deliver yr-1 and yr-2 for European domain (cyclic improvement)
- Timely delivery of European regional (~6x6 km) inventory 2005-2019 for VERIFY synthesis.

T2.1 CONTINUOUS UPDATES OF EDGAR FAST TRACK CO_2 EMISSIONS (JRC)

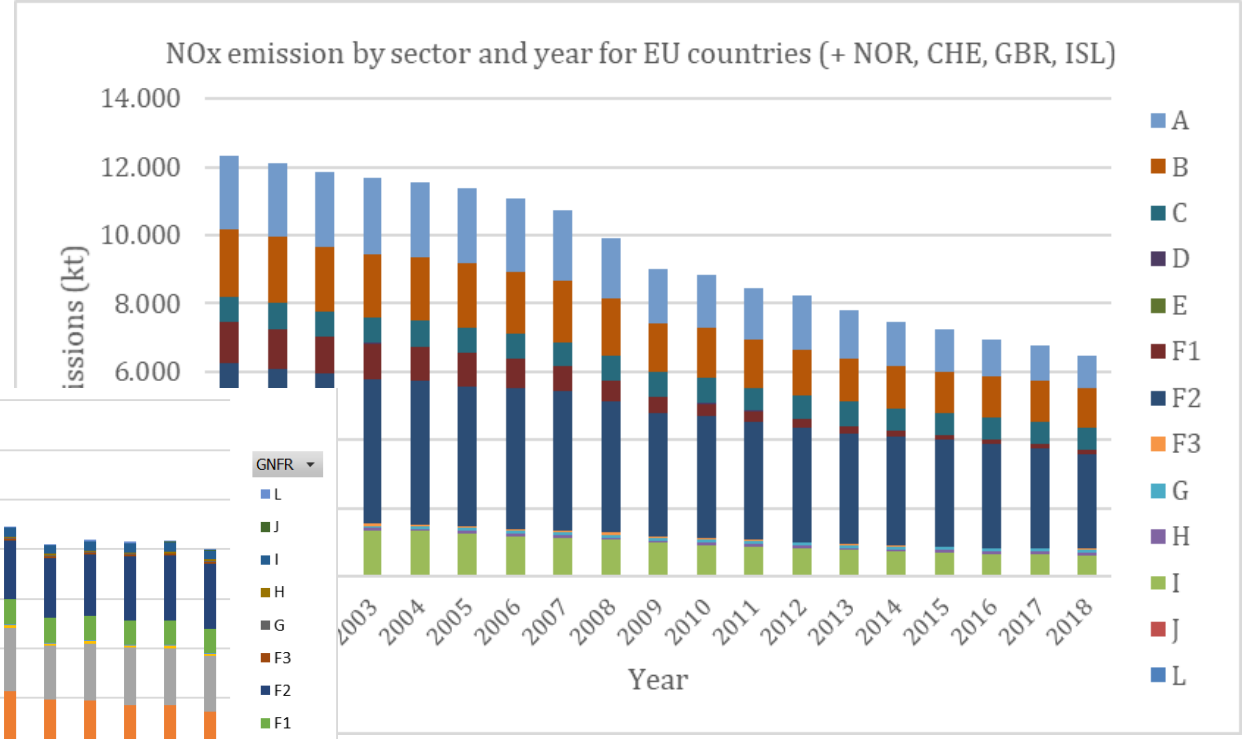


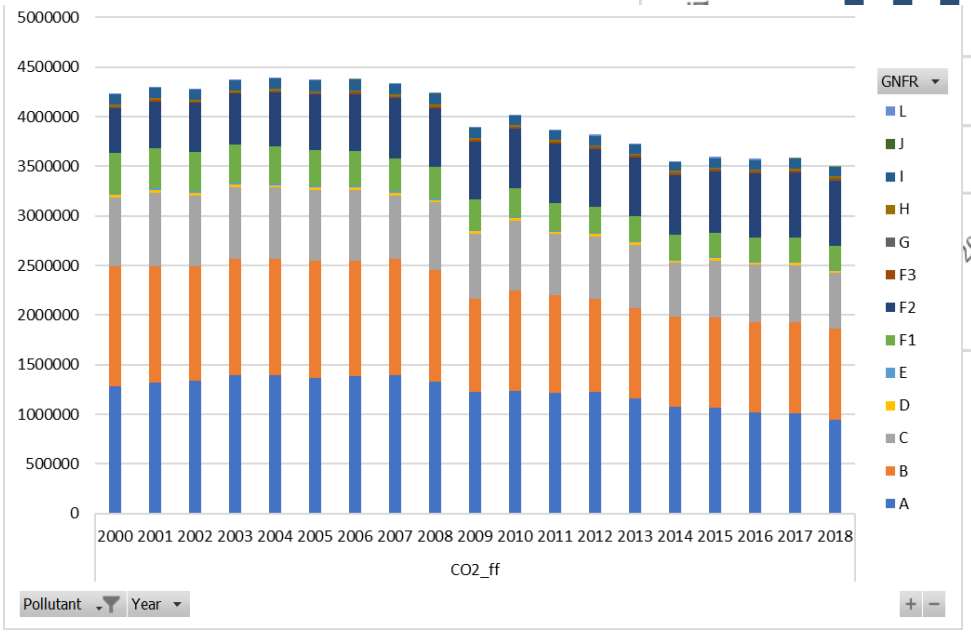
Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J.G.J., Vignati, E., Fossil CO2 emissions of all world countries - 2020 Report, EUR 30358 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21515-8, doi:10.2760/143674, JRC121460.

T2.1 – D2.5 FINAL PRESENT YEAR-1 EMISSION INVENTORY AND GRIDS

Past months working on updating the timeseries 2005-**2018**.

Data are ready –delivery in 1-2 weeks.



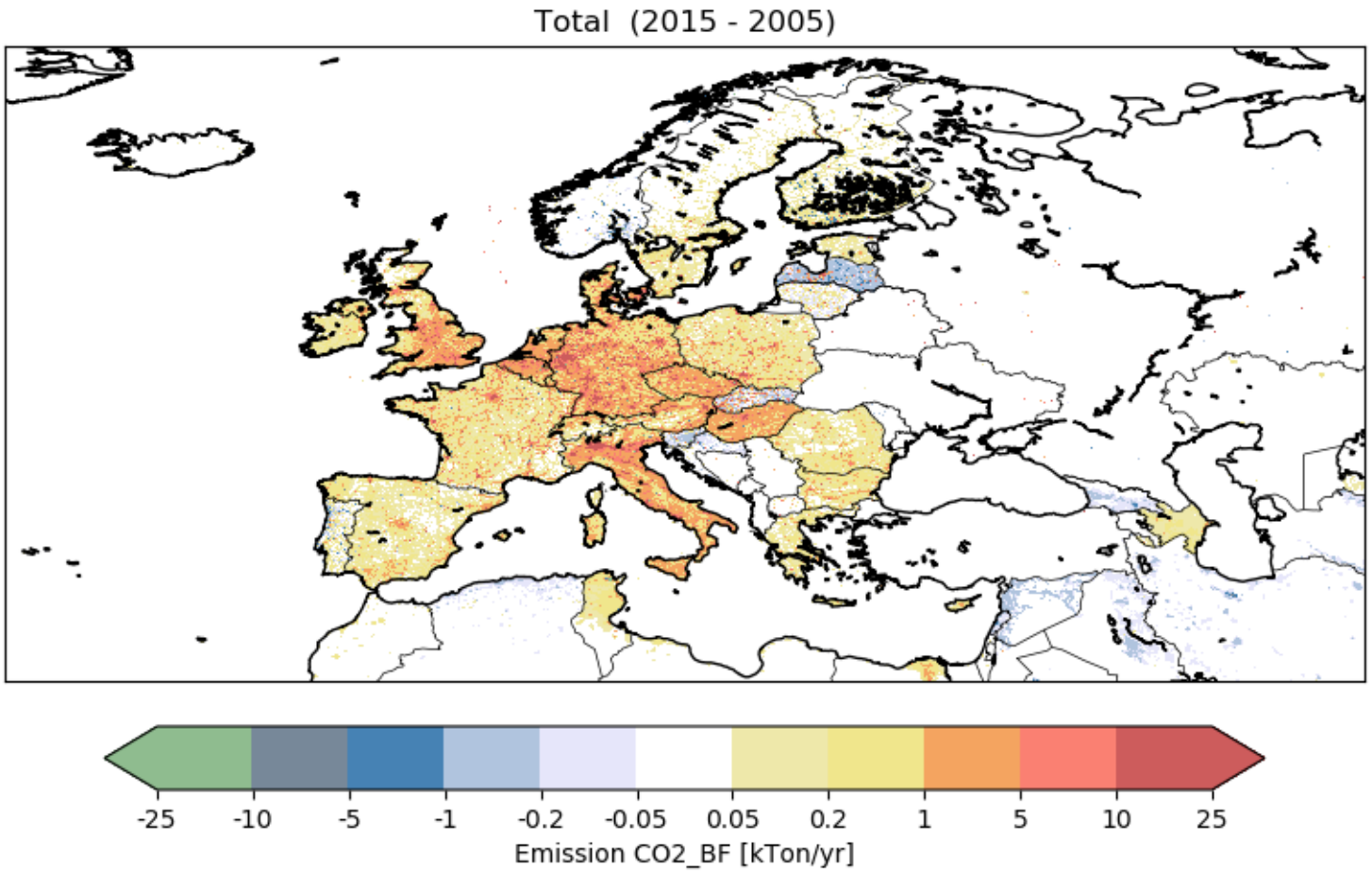


CO_2 trend very different, important to have a good grip on co-emitted species by year

T2.1 – D2.5 FINAL PRESENT YEAR-1 EMISSION INVENTORY AND GRIDS

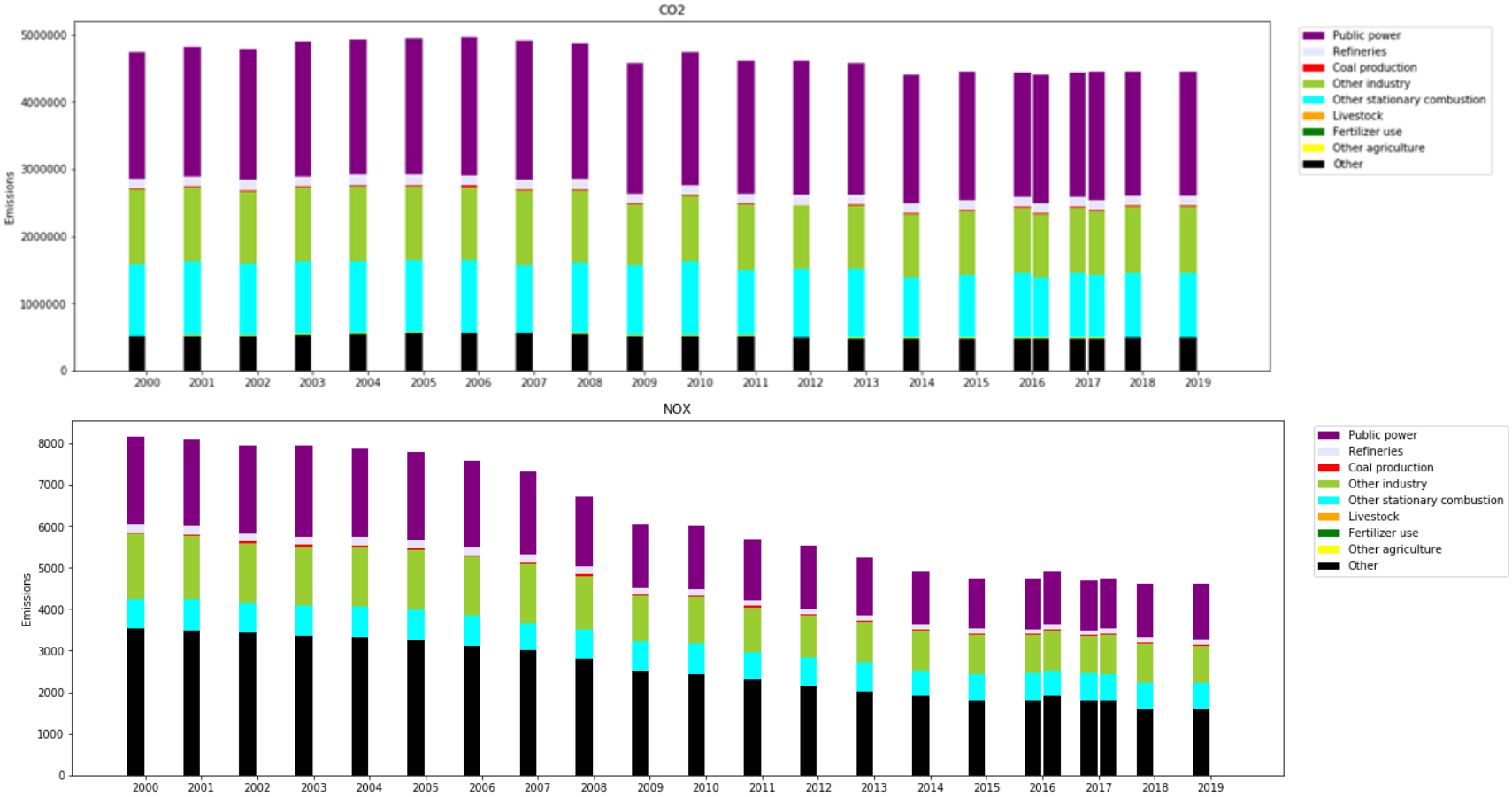
Past months working on updating the timeseries 2005-**2018**.

Data are ready –delivery in 1-2 weeks.



In 2020 we produced 2018 & 2019 to supplement 2005-2017 timeseries

T2.1 – D2.5 SECOND PRESENT YEAR-1 EMISSION INVENTORY AND GRIDS



Time series of emissions of CO_2 and NOx per source sector summed for the whole domain.

For years before 2016 emissions are reported; for 2016 and 2017 both the reported (right bars) and estimated (left bars) emissions are given; for 2018 and 2019 emissions are estimated.

Crucial for providing the VERIFY synthesis time series upto yr-1

T2.1 – D2.6 FINAL PRESENT YEAR-1 & -2 EMISSION INVENTORY AND GRIDS

Contribution (%) of each source sector in Europe to the total emissions of a gas in 2017. Last year only the yellow sectors were considered. This year the analysis is extended with the red sectors.

	CO_2 ff	CO_2 bf	CH_4	CO	NO_x	NMVOC
Public power	32	23	2	2	18	1
Industry	25	16	8	18	14	10
Other stat. Comb.	15	44	4	29	6	12
Fugitives	3	0	35	1	1	15
Solvents	0	0	0	0	0	30
Road transport - gasoline	6	1	0	26	3	14
Road transport - diesel	13	4	0	9	29	3
Road transport - LPG	1	0	0	2	1	4
Road transport - non-exhaust	0	0	0	0	0	5
Shipping	2	0	0	1	18	0
Aviation	1	0	0	0	1	0
Off-road	3	0	0	5	8	2
Waste	0	0	24	1	0	1
Agriculture-livestock	0	0	23	0	0	0
Agriculture-other	0	11	5	7	1	3

Overview of activity and proxy data used for each source sector

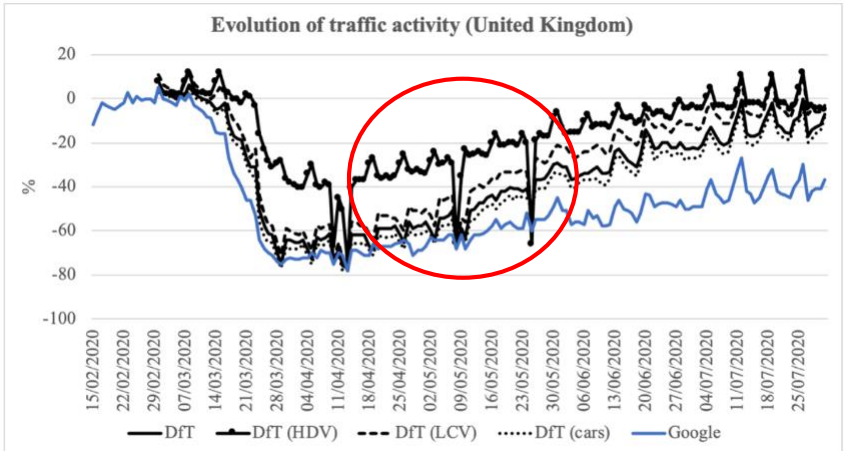
	Activity data	Period	Proxy data	Period
Public power	Electricity generation (non-renewable)[1]	2010-2020	GDP	Up to 2020
Industry: Refineries	Refinery througput[1]	2008-2019	GDP	Up to 2020
Industry: Coal mining	Coal production[1]	2008-2019	GDP	Up to 2020
Industry: Other	Industrial production index (manufacturing)[2]	2000-2020	GDP	Up to 2020
Other stat. Comb.	Yearly degree day sum[3]	2005-2020		
Road transport	Energy consumption in transport sector[4]	2008-2019	GDP	Up to 2020
Shipping	CO_2 emissions from inland shipping[5]	2013-2019	GDP	Up to 2020
Agriculture-livestock	Animal numbers (cattle, swine, sheep, other)[6]	2010-2019		
Agriculture-other: Application of manure and fertilizer	Total nutrient N from agricultural fertilizer use[7]	2010-2018	Utilised agr. area	2007-2019
Agriculture-other: Other	Utilised agriculture area[8]	2007-2019		

[1] Source: ENTSO-E; [2] Source: Eurostat; [3] Source: ERA5 hourly data, converted to yearly degree day sum using the approach described by Mues et al. (2004); [4] Source: Eurostat; [5] Source: FMI; [6] Source: FAO; [7] Source: FAO; [8] Source: Eurostat

There are two ways to describe the activity:

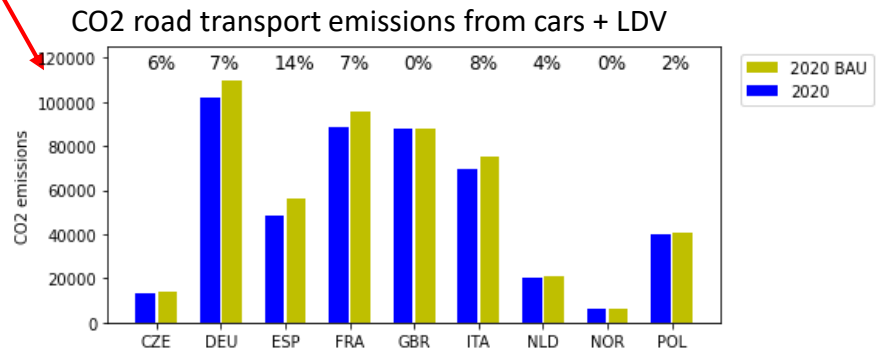
1. Preferred: Using activity data that can be directly linked to the source sector.
2. Back-up: Using a generic proxy not directly linked to the source sector to estimate the activity, such as gross domestic product (GDP).

When 1) is not covering the full period it can be extended using 2)



Courtesy of Marc Guevara and team (CAMS/COP-066 deliverable report)

Passenger cars and HDV responds differently to COVID-lockdowns, while we use the same proxy for both… GDP is not good enough as proxy! Emission reductions are underestimated.



Two challenges for 2020:

1. Proxy data is lacking for 2020 and a trend analysis will not capture COVID lockdown
2. Proxy data does not capture effect of COVID lockdowns sufficiently

Workplan for 2020:

1. Construct a 2020 emission inventory using the same approach as for 2019.
2. Develop 2020 BAU (without COVID effect) and apply country- and sector-specific daily emission reduction factors provided by Marc Guevara and team

We will compare both approaches to see how this works out!

Lockdowns also affect temporal variability in emissions… how to deal with that?

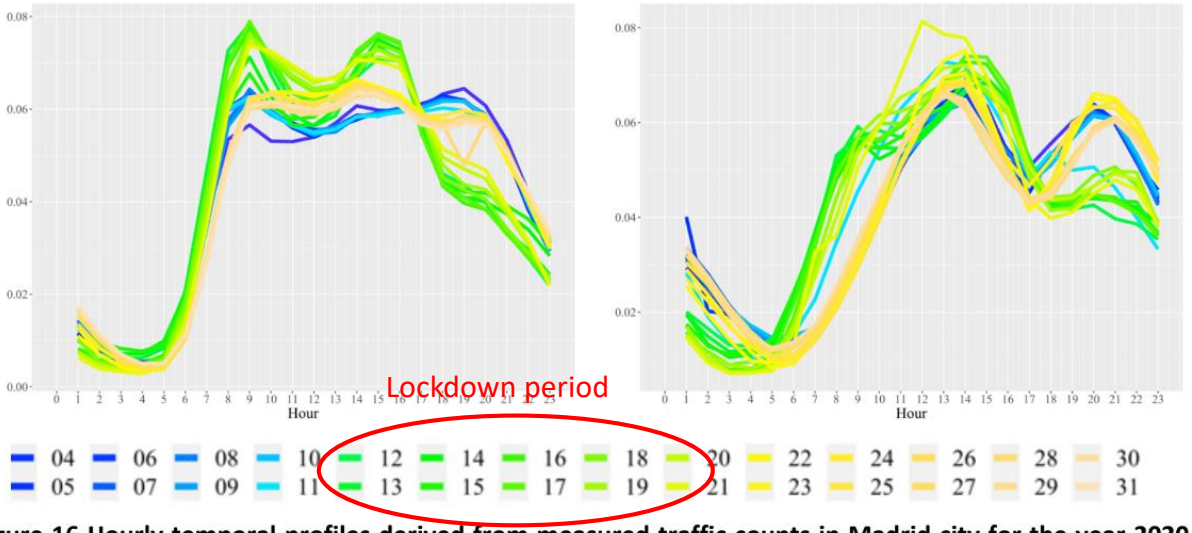


Figure 16 Hourly temporal profiles derived from measured-traffic counts in Madrid city for the year 2020 (AM, 2020) for weekdays (left) and Saturdays (right) discriminated by week of the year.

Courtesy of Marc Guevara and team (CAMS/COP-066 deliverable report)

Food for thought:

1. The standard monthly/daily files do not capture the 2020 dynamic – is this important for the VERIFY synthesis (&inversion)?
2. Should we make new temporal profiles for 2020?
3. Should we provide daily emissions for 2020? (using the emission reduction factors from Marc Guevara and team)

T2.1 – Bottom-up emission estimates for anthropogenic CO2 and co-emitted tracers (TNO, JRC, WU; M01 M48)

Specific objective: Deliver high-res emission of ffCO2, bfCO2 & co-emitted tracers (CO, NOx, NMVOC) for Europe, 2005-present

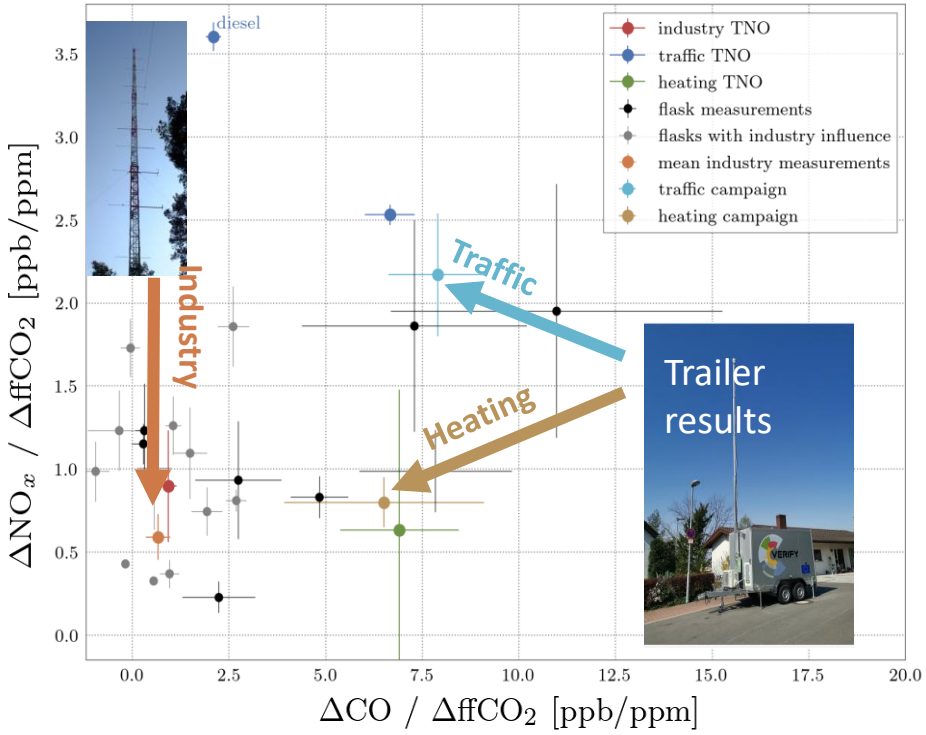
Workplan M36-M48

- Fast-track global CO_2 emissions from JRC / EDGAR up to year -2. (2019/2020)
- Construction & delivery of European regional (~6x6 km) inventory 2005-2018 for VERIFY synthesis. (CO_2 and co-emitted species)
- Construction yr-1 and yr-2 for European domain (2019, 2020)
  - Note mentioned complications for 2020 (absolute emissions and timing of emissions)
- Deliver 2005-2020 for VERIFY synthesis.
- Evaluate 2005-2020 dataset & publish result.

T2.2 Assessment of atmospheric proxy/ffCO$_2$ ratios and independent $^{14}CO_2$-based ffCO$_2$ emission estimates

Specific objective: Evaluate proxy/ffCO2 ratios near emission hotspot; validate using 14C data in a test-bed experiment

Time	Topic	Presenter
9:30 - 10:00	Atmospheric proxy/ffCO2 ratios - potentials and limitations for regional ffCO2 estimation	Samuel Hammer (UHEI)



VERIFY GA Day 2 - Thursday 29 April 2021 ;
* 09:30 - 12:10 : Specific science talks linked to VERIFY activities

T2.2 Assessment of atmospheric proxy/ffCO$_2$ ratios and independent ^{14}CO$_2$-based ffCO$_2$ emission estimates (UHEI/KIT)

- **Specific objective**: Evaluate proxy/ffCO2 ratios near emission hotspot; validate using 14C data in a test-bed experiment

Workplan M36-M48

- Observations are finished.
- Evaluated proxy- and ^{14}CO$_2$ -based ffCO$_2$ estimates within the test-bed region using high-res. modelling.
  - Thus, 2019 and 2020 emission estimates for the test-bed region are NEEDED!

T2.3 – Annual to monthly budgets of fossil CO2 emissions at the national scale across Europe using CO and NOx satellite measurements

Objectives, progress and achievements M19-M36 (LSCE)

→ See **D2.11** with the **10-year re-analysis of the national scale CO_2 anthropogenic emissions, 2008-2017**

→ Use of co-emitted species: currently NO_2 spaceborne data only, adding CO spaceborne data soon

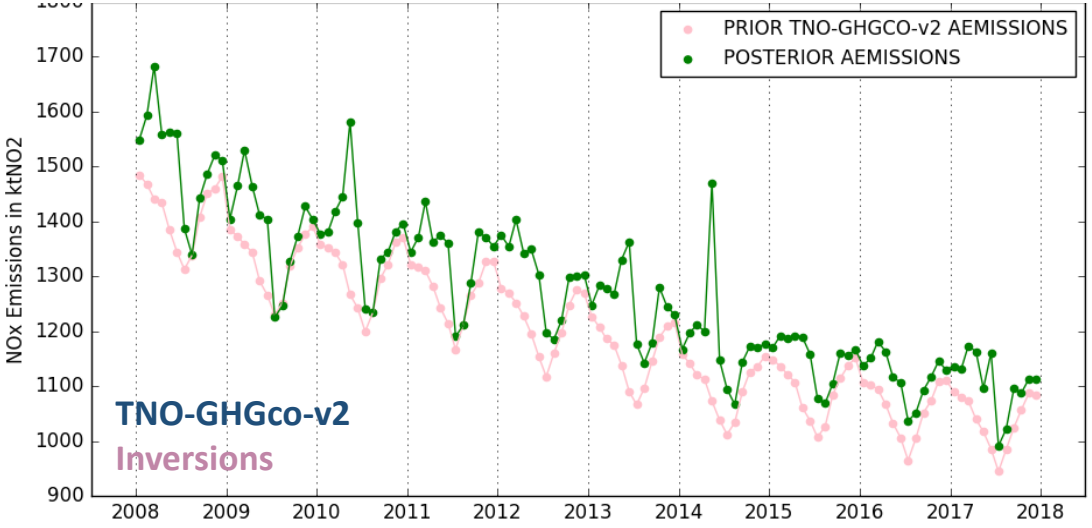
→ Current set-up of the atmospheric inversions: 2-step approach

→ **Target = developing a fully integrated joint CO-NO_x-CO_2 inversion framework**

I. Variational regional inversions of the NO_x emissions

Estimates of daily European NO_x emissions at 0.5° horizontal resolution, using the TNO-GHGco-v2 inventory as prior knowledge, the NO_2 OMI data, the CIF inversion platform, and the CHIMERE regional CTM.

Monthly budgets of NO_x emissions in Europe



Main results

→ Increase of the estimates of NO_x anthropogenic emissions by the inversion compared to the TNO-GHGco-v2 inventory, mainly due to positive corrections during spring and summer

→ Annual budgets of national NO_x anthropogenic emissions are increased by about 5-10% compared to the TNO-GHGco-v2 inventory.

T2.3 – Annual to monthly budgets of fossil CO2 emissions at the national scale across Europe using CO and NOx satellite measurements

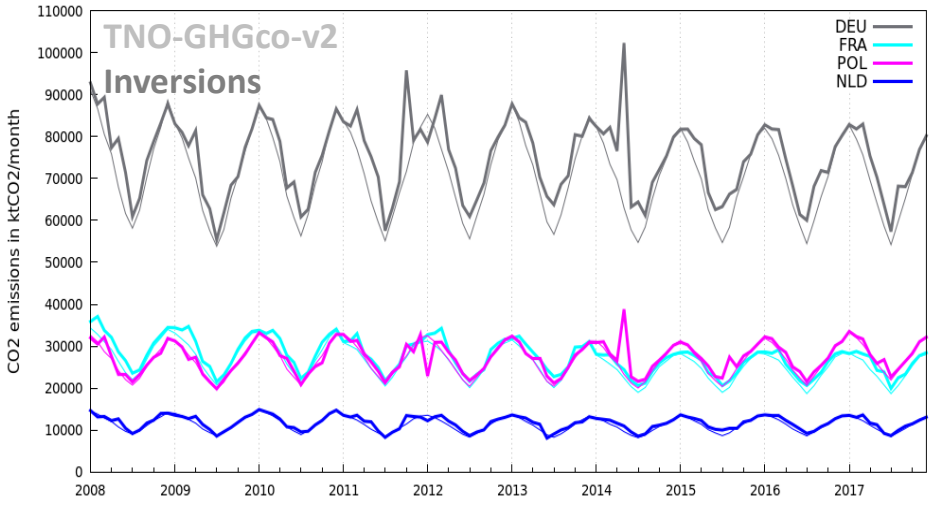
Objectives, progress and achievements M19-M36 (LSCE)

- → See **D2.11** with the **10-year re-analysis of the national scale CO_2 anthropogenic emissions over 2008-2017**
- → Use of co-emitted species: currently NO_2 spaceborne data only, adding CO spaceborne data soon
- → Current set-up of the atmospheric inversions: 2-step approach
- → Target = developing a fully integrated joint CO-NO_x-CO_2 inversion framework

II. Conversion into $FFCO_2$ emissions at 1-month / national scale

1) NO_x maps converted into of 1-month / national budgets of NOx emissions for 5 large sectors of activity based on a fit to sectorial maps of emissions from the TNO-GHGco-v2 inventory

2) Conversion into 1-month / national budgets of NOx emissions for the 5 large sectors of activity based on emission ratios from the TNO-GHGco-v2 inventory



Main results

→General consistency between our $FFCO_2$ estimates based on NO_2 satellite data and the TNO-GHGco-v2 inventory

→ Positive indication regarding the potential of the atmospheric inversion approach and co-emitted species to support the estimate $FFCO_2$ emissions at the national scale

Monthly budgets of $FFCO_2$ emissions in Germany, France, Poland and Netherlands

Specific objective: Develop framework to support monitoring ffCO2 from different sectors at the national scale using satellite measurements of CO and NO

Workplan M36-M48

- Extension of the NOx European emission inversions, and of the corresponding national scale FFCO2 emission estimates to cover 2005-2020 (Spring 2021)
- CO European emission inversions, and conversion into national scale FFCO2 emission estimates for 2005-2020 using the same 2-step scheme as in D2.11 (Summer 2021)
- Statistical synthesis of the two FFCO2 national scale emission estimates over 2005-2020 ("final re-analysis") – D2.12 (M42)
- Potential update of the prior uncertainties in the inversion and of the NOx/CO-> FFCO2 conversion protocol and based on the uncertainty analysis on the dynamical inventory model (M48)
- **First tests of co-assimilation of NO2, CO and CO2 satellite data in a fully integrated joint CO/NOx/CO2 inversion framework** (M48)
- New publications: at least one by M48

T2.4 – Exploring the potential of new data, upcoming instruments, and new methods to improve the pre-operational ffCO2 estimation system

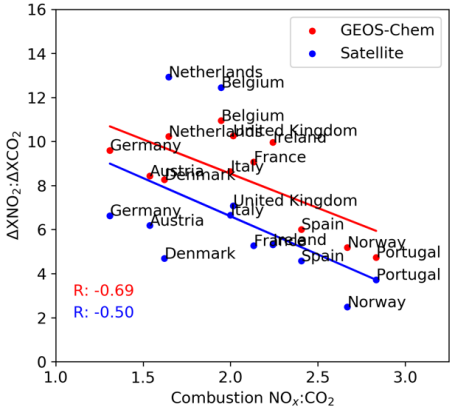
Objectives, progress and achievements M19-M36 (UEDIN)

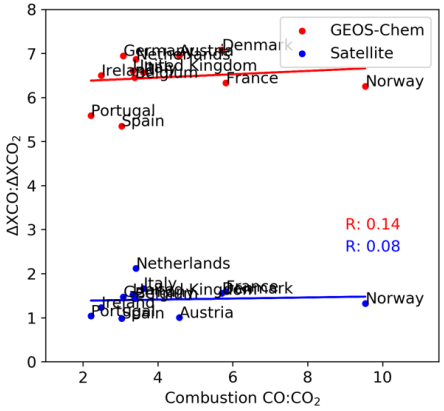
Reactive trace gases (observable from satellites) are co-emitted with CO_2 during combustion.

Challenge: how do we use that information to determine <u>combustion</u> CO_2?

D2.14 explores this using two approaches.

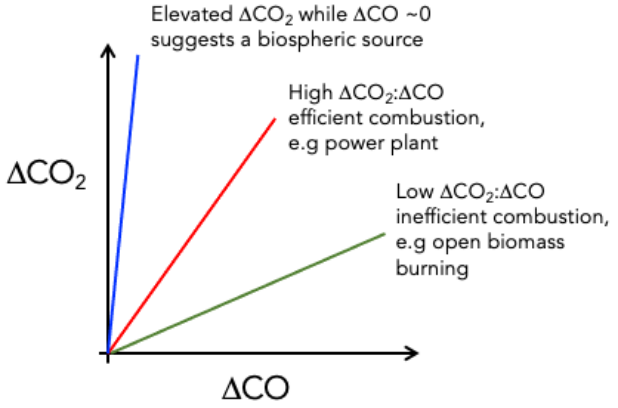
1) use observed and model CO and NO_2 as proxies for combustion CO_2 to test inventories





We use GEOS-Chem driven by TNO inventories over Europe and UK

2) Inversion: use CO to constrain combustion CO_2 [results shown for in situ data but can be extended]

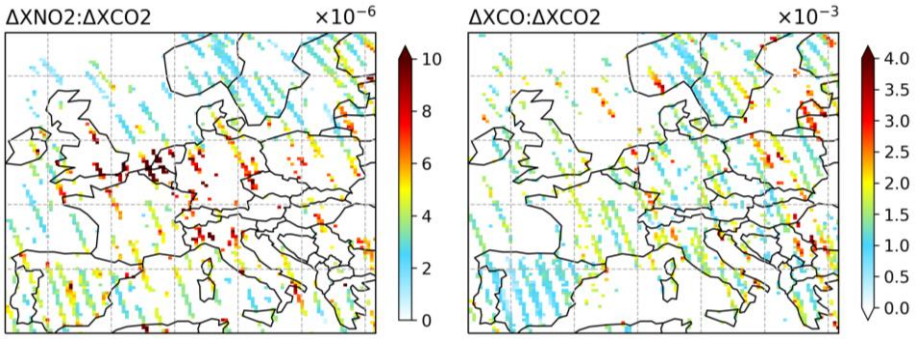


CO_2:CO correlations (and their uncertainties) due to the combustion process & atmospheric transport

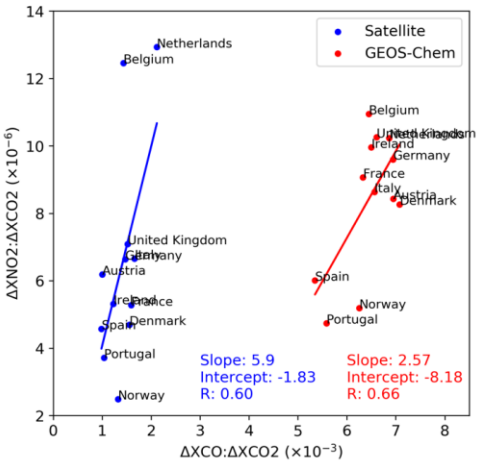
T2.4 – Exploring the potential of new data, upcoming instruments, and new methods to improve the pre-operational ffCO2 estimation system

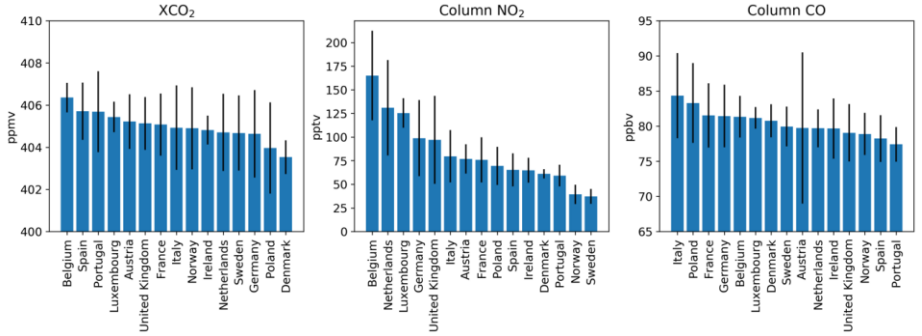
Objectives, progress and achievements M19-M36 (UEDIN)

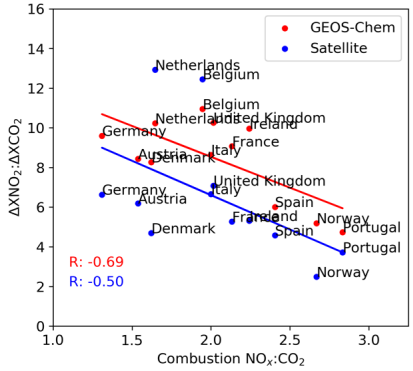
2018

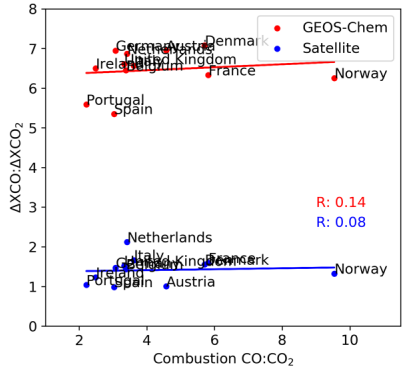


- Model overestimates $\Delta CO:\Delta CO_2$
- Stronger correlation in atmospheric space than emissions.









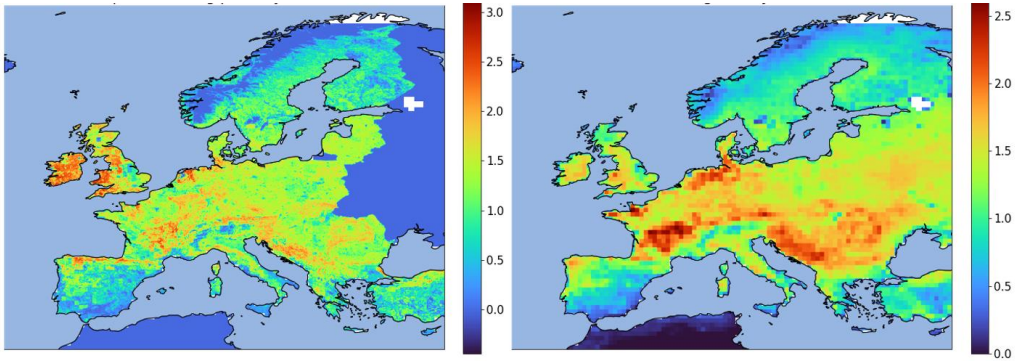
Different sector contributions to CO_2 from different countries also responsible for national variations in $\Delta CO:\Delta CO_2$ and $\Delta NO_2:\Delta CO_2$

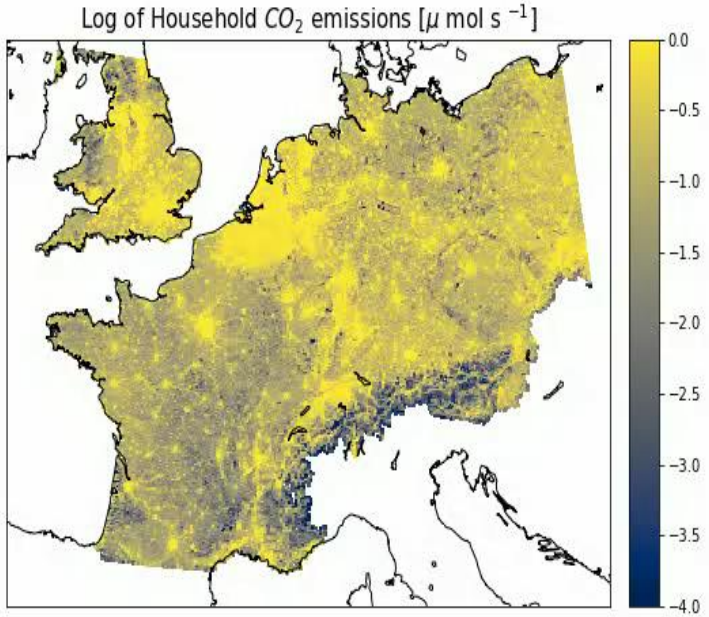
- Using this approach, NO_2 appears to be the better proxy for combustion CO_2 emissions.
- Negative slope suggests strong non-linearity between NOx emissions and NO_2 columns. Likely due to photochemistry.

T2.4 – Exploring the potential of new data, upcoming instruments, and new methods to improve the pre-operational ffCO2 estimation system

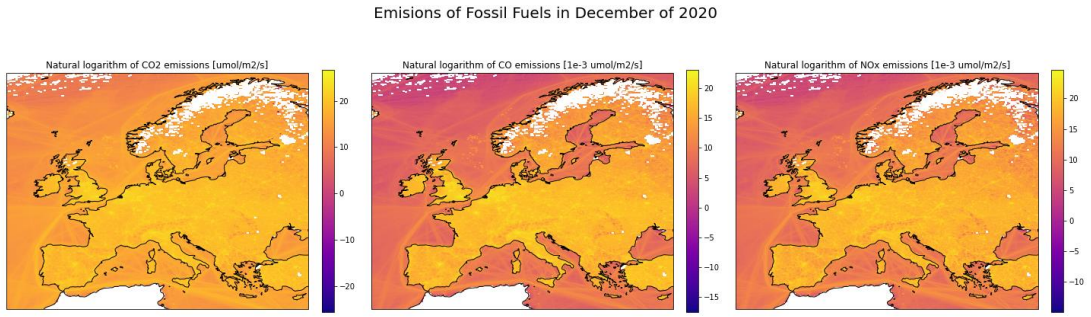
Objectives, progress and achievements M19-M36 (WU)

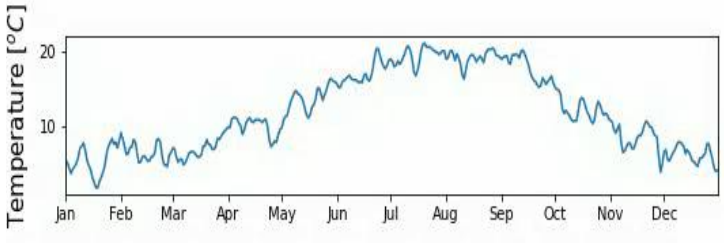
Dec-2018 SiB4 biosphere flux (NEE) at 2x2km (Corinne) and at 0.5x0.5 degrees (native)





Dec-2020 Fossil fuel emissions (CO_2, CO, NO_x) at 0.1x0.2 degrees





ENTSO-E (hourly), EuroStat (monthly), T, u,v, SSRD (hourly), ...

T2.4 – Exploring the potential of new data, upcoming instruments, and new methods to improve the pre-operational ffCO2 estimation system

Objectives, progress and achievements M19-M36

PhD research Auke van der Woude (WU)

FF error

BIO error

Only CO_2 used

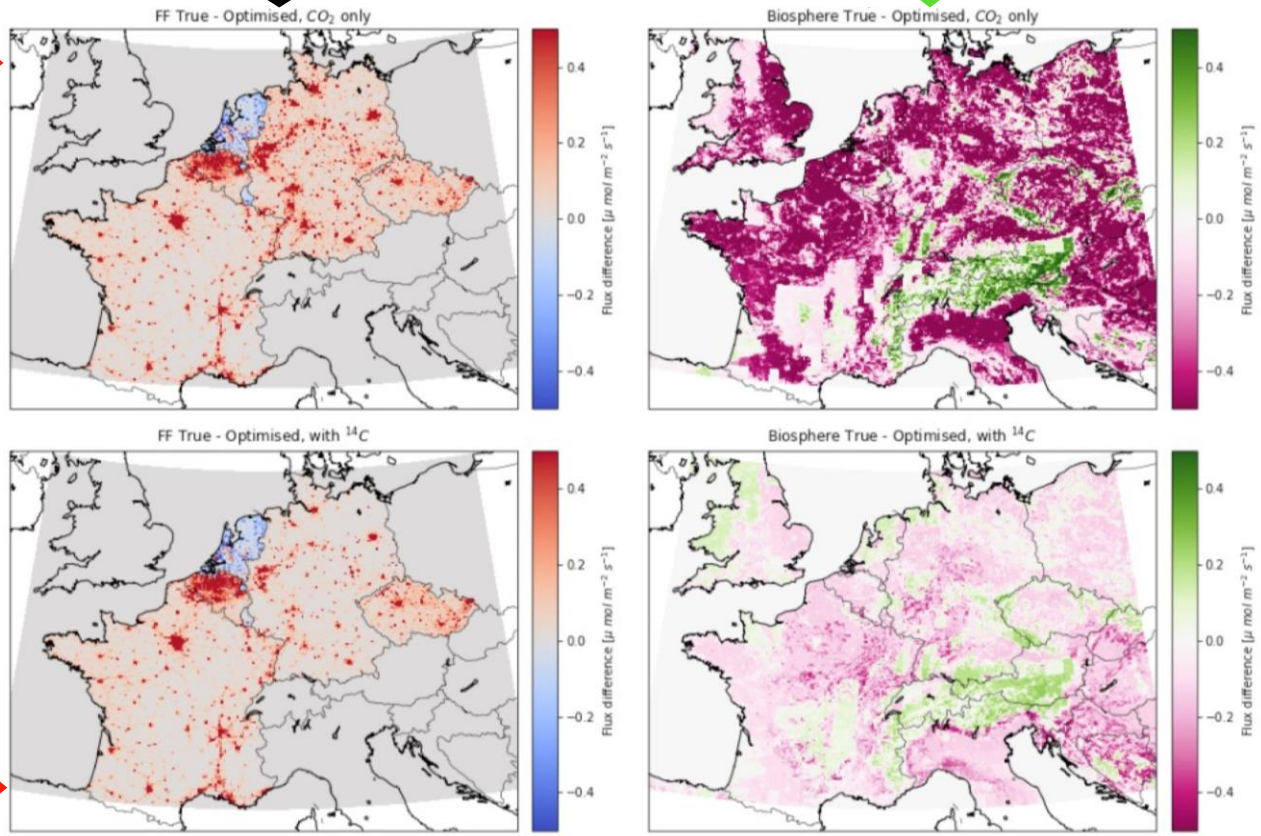
Data assimilation of CO_2 and radiocarbon (Δ14C) to constrain the sources and sinks of CO_2 in Western Europe.

-> Simulations of hourly varying FF emissions (households, traffic, industry, power production, renewables).

-> Simulations of hourly photosynthesis and respiration by biosphere (2x2km)

-> Simulations of atmospheric transport (CO_2, Δ14C, CO, NOx) and weather (renewables and biosphere)

Δ14C and CO_2 used



assimilation of $\Delta^{14}C$ helps separate local sources (**fossil**) from diffuse sinks (**bio**)

WORK PLAN TO M48

- The remaining developments are focused on modelling tasks T2.3 and T2.4:
  - Final analysis of national CO2 anthropogenic emissions, 2005-2020 (contributing to VERIFY synthesis)
  - Assessing the impact of future space-borne sensors to infer combustion CO2 emissions from Europe.
    - The OSSE system is being developed, building on an existing inversion framework.
- Both these tasks are progressing on time.

Conclusions and critical/open issues

Supporting the development of a pre-operational system

- Providing high—resolution emission inventories up to yr -1 (=2020 in 2021)
- Ground-truthing inventories using in-situ data and ground based remote sensing
- Developing methods to use reactive trace gases as proxies for combustion CO2 in 10+ yrs inversions

Critical issues:

- How do we use all available observational data in a single modelling framework?
- We need the “handshake” at sector level to connect with (official) inventories

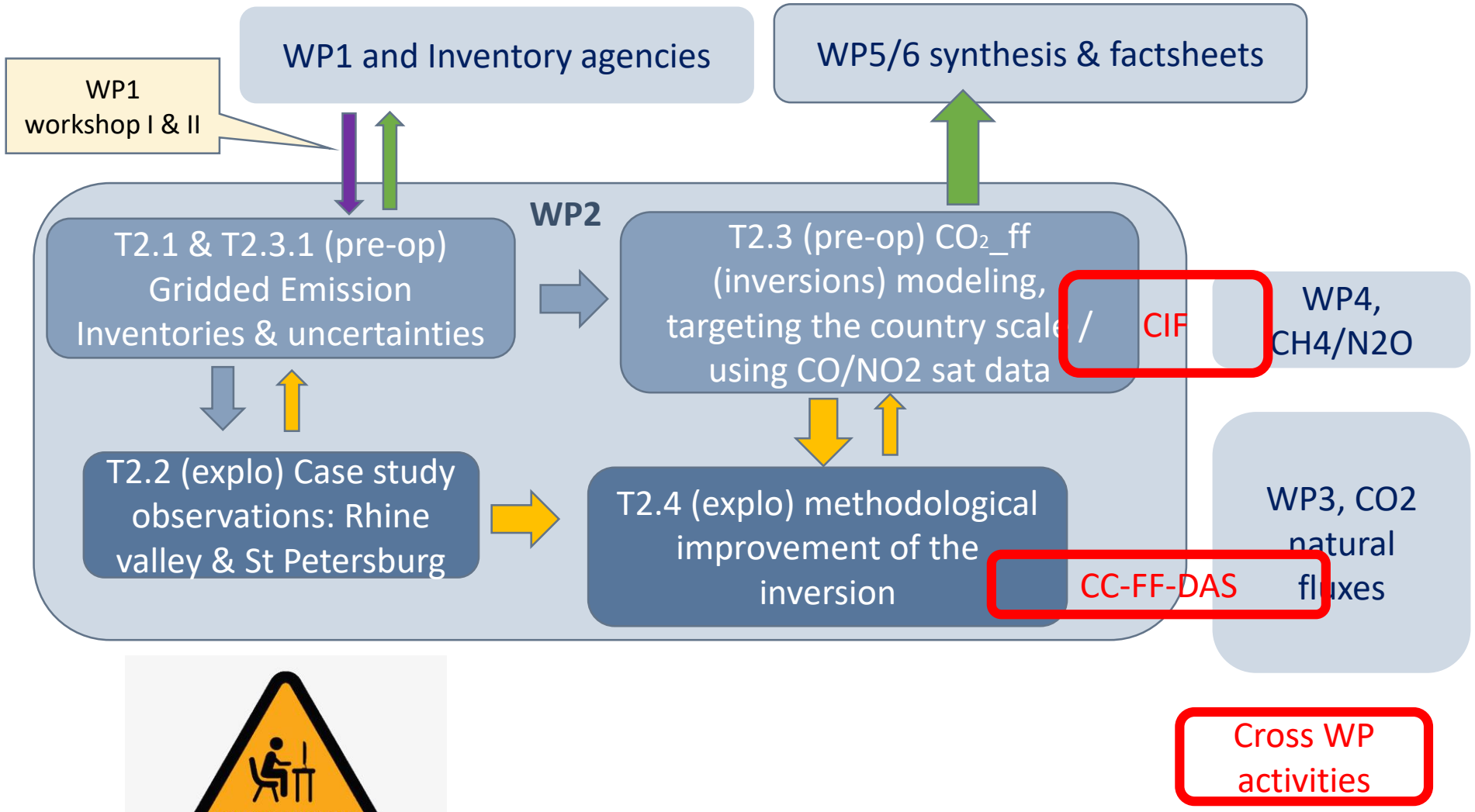
Explore next generation approaches

- NRT emission inventories that are driven by changes in weather, energy and economic statistics.
- Using CO2:CO inversions to estimate combustion and natural net fluxes of CO2 and emissions of CO within a Bayesian framework.

Thank you for your attention.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776810

VERIFY WP2 VERIFICATION METHODS FOR CO_2_FF EMISSIONS – INFORMATION FLOW CHART



WP2 – Main Achievements to date

- System in place for providing annual high-resolution emission data 2005 to yr-1 (final will be 2020)
- Inversion system using CO & NO2 observations to provide CO2 fluxes for VERIFY synthesis
- Both are going through cyclic (annual) further improvement: every year results are better
- Challenging measurement campaigns in St Petersburg and Rhine valley completed
- Developing the pre-operation system to infer combustion CO_2 from reactive trace gases has started
- Publications are coming from all tasks.

CHALLENGES AND DEVIATIONS FROM PLAN

- Risks were mainly coming from the Covid-19 pandemic – difficult to do experimental work – often not allowed: Deliverables delayed but within acceptable limits
- Challenging to fully use in modelling approaches before end of project. New insights from observations include importance of accurate representation of local sources with more detail than generally available
- No major deviations from the Description of Action anticipated

WP2 – STATUS OF DELIVERABLES M19-M36

DEL n°	M	DEL Title	Lead	Due date	Status	Comments
D2.2	24	Second High Resolution emission data 2005-2016	TNO	31-1-2021	V	
D2.5	29	Second Present year-1 emission inventory and grids	TNO	30-6-2020	V	
D2.7	24	Temporal variations of proxy/ffCO2 ratios	UHEI/KIT	31-1-2020	V	Delayed due to Covid delivered Feb 2021
D2.8	36	Source sector dominated proxy/ffCO2 ratios	KIT/UHEI	30-4-2021		due Jan 2021; draft February 2021 delays in the campaigns (Covid issues). Final version April 2021
D2.11	30	Second, fast-track, Re-analysis of the national scale CO2 anthropogenic emissions over 2005-2015	LSCE	31-7-2020	V	Draft provided Jan 2021; final version provided Feb 28, 2021
D2.13	36	Strategy for joint optimization CO2 emissions and natural CO2 exchange in one self-consistent system	ULUND	30-6-2021		Draft Jan 2021 due to greater difficulties than expected for such joint-optimization and slightly covid issues. A final version will be end of submitted in June 2021.
D2.14	36	Value of reactive trace gases observed by TROPOMI to improve quantitative analysis of ffCO2	UEDIN	31-1-2021	V	

- All deliverables pre M19 are done & approved

DELIVERABLES M36-48

Del#	M	Deliverable title	Lead	Due date	Comments
D2.3	39	Final High Resolution emission data 2005-2017	TNO	30-4-2021	Rescheduled & approved by PO/EC to include an extra year (2005-2017 + 2018)
D2.6	41	Final Present year-1 emission inventory and grids	TNO	30 -6-2021	Rescheduled for Month 41 approved by PO/EC. : cannot start until D.2.3 is ready
D2.12	42	Final Re-analysis of the national scale CO2 anthropogenic emissions over 2005-2020	LSCE	31 – 7- 2021	Currently no delay foreseen
D2.15	45	Assessment of the impact of the future space-borne observations of CO2_CO-HCHO on ffCO2 emission estimates	UEDIN	31 -10-2021	Currently no delay foreseen

EXTRA SLIDES WP2 IN TASK ORDER