,
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

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Changes with respect to the DoA

The deliverable was initially planned at month 24 (M24) of the project. Because M24 was close to the planned General Assemblée, it was decided to shift the meeting towards late spring/early summer. Because of the Corona19 outbreak, it was further shifted towards autumn 2020 and has been organized in videoconference.

Dissemination and uptake

(Who will/could use this deliverable, within the project or outside the project?)

This report will be uploaded to the internal web-page of the VERIFY project (SharePoint platform), primarily as a means to disseminate the results of the second stakeholder meeting within VERIFY. Part of the workshop results will also be made publicly available (**http://verify.lsce.ipsl.fr/**) to inventory compilers and scientists, as to help shape up discussions on prioritization of the development of methodologies for improving independent verification of greenhouse gas emissions at several scales. The focus of the project is primarily the European scale, but there may be clear interests on other scales such as the global scale and the regional/local scale.

Short Summary of results (<250 words)

The aim of the network meetings is to bring together experts from National GHG inventory (NGHGI) Agencies and the climate and emission scientists/modelers (CES/M), to contribute to achieving the overall objectives of the project. The ultimate aim of the project is to use the improved knowledge of GHG budgets from VERIFY to improve national inventories, in collaboration with national inventory agencies. Based on the presentations and discussion during this meeting, we can summarize the main differences between both "worlds" (emission inventorying and modelling/measurements) as follows:

	NGHGI	***CES/M***
Temporal scale	Low resolution: Yearly, until t-2 (t-1)	High resolution: Monthly, hourly
Spatial scale	Low resolution: Territorial, country specific (per Member State)	High resolution of spatially disaggregated data, applicable for - regional/global coverage without political border - local scale for verification of e.g. large point sources
Activity link	Fine granularity:	Course granularity: Larger groups of activities for which spatial and

	Disaggregated by source, subsector, human activity specific	temporal data are available, of interest for near real time emission assessment
Challenges	Direct/indirect emissions, uncertainties, increased complexity	Modeling of processes, biofuel/biomass, Carbon Capture and Storage.

Inventory experts operate in the context of- and within the boundaries of the UNFCCC reporting guidelines and IPCC emission inventory guidelines. Reporting at a higher spatial/temporal resolution would be beneficial for independent verification, but is as yet outside the scope of formal/legal requirements. However, this meeting shows there is scope for better collaboration between emission inventory experts and modelling& measurement experts.

Scientists have made progress over the past few years in developing methodologies that may help in both comparison of- and verifying the inventories. Tools are made available through the LSCE VERIFY website. There is a huge potential e.g. in developing and applying Earth Observation tools; but also inverse modelling. An extension of the measurement network over Europe might be beneficial in this context.

Evidence of accomplishment
(report, manuscript, web-link, other)

This report is the deliverable D1.6 for VERIFY. The slides of the different presentations given during the workshop are accessible under: **http://verify.lsce.ipsl.fr/index.php/events/verify-second-networking-meeting**

Version	Date	Description	Author (Organisation)
V0	08/12/2020	Writing/Formatting/Delivery	Paul Ruyssenaars (RIVM), with contributions of the presenters from the meeting
V0.1	11/12/2020	Review/Writing	Lucia Perugini (CMCC)/ Dirk Guenther (UBA Dessua) Philippe Peylin (CEA/LSCE)
V1	14/01/2021	Formatting/Delivery on the Participant Portal	Aurélie Paquirissimy (CEA/LSCE)

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

1. Glossary

Abbreviation / Acronym	Description/meaning
TD/BU	Top Down / Bottom Up
EO	Earth Observation
NGHGI	National Green House Gas Inventory
MRV	Monitoring, Reporting and Verification
ffCO_2	CO2 emission form fossil fuel
LULUCF	Land Use, Land Use Change and Forestry
NFI	National Forest Inventory
CO_2	Carbon dioxide
N_2O	Nitrous oxide
CH_4	Methane
CO	Carbon monoxide
NO_2	Nitrogen dioxide
URD	User Requirement Document
CES/M	climate and emission scientists/modelers

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2. Executive Summary

This report summarizes the results of the second network meeting of the VERIFY project.
Aim of these network meetings is to bring together experts from National GHG inventory (NGHGI) Agencies and the climate and emission scientists/modelers (CES/M), to contribute to achieving the overall objectives of the project. The ultimate aim of the project is to use the improved knowledge of GHG budgets from VERIFY to improve national inventories, in collaboration with national inventory agencies.

Based on the presentations and discussion during this meeting, we can summarize the main differences between both "worlds" (emission inventorying and modelling/measurements) as follows:

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Inventory experts operate in the context of- and within the boundaries of the UNFCCC reporting guidelines and IPCC emission inventory guidelines. Reporting at a higher spatial/temporal resolution would be beneficial for independent verification, but is as yet outside the scope of formal/legal requirements. However, this meeting shows there is scope for better collaboration between emission inventory experts and modelling & measurement experts; for instance in creating science based emission datasets at higher spatial- and temporal resolution.

As shown in several synthesis studies in the context of VERIFY, comparisons between datasets may be hampered by differences caused by the application of different tiers and methods used in calculating emissions, and allocation of emissions to different sectors.

Scientists have made progress over the past few years in developing methodologies that may help in both comparison of- and verifying the inventories. Tools are made available through the LSCE VERIFY website **https://verify.lsce.ipsl.fr/**. There is a huge potential e.g. in developing and applying Earth Observation tools; but also inverse modelling. An extension of the measurement network over Europe might be beneficial in this context.

3. Introduction

VERIFY proposes to quantify more accurately carbon stocks and the fluxes of CO2, CH4, and N2O across the EU based on independent observations in support of GHG inventories that rely on statistical data. Accurate characterization of the space-time variations of GHG fluxes, separating their anthropogenic and natural components and their drivers, will be based on advanced modelling approaches using atmospheric GHG measurements, tracer transport inversions and various arrays of land observations, in-situ and from space. Ultimate aim is to use the improved knowledge of GHG budgets from VERIFY to improve national inventories, in collaboration with national inventory agencies. The VERIFY approach will be basically developed for EU, but will also be tested for some countries outside EU, in collaboration with foreign partners.

The main objective of VERIFY's Work Package 1 (WP1) is to assess the current and future needs of inventory institutions and of the international climate process, and to help design the framework of the project's subsequent work packages based on the identified Monitoring Reporting and Verification (MRV) requirements.

To this end, WP 1 has developed a user requirement document (URD, D 1.1.) for a monitoring and verification system of GHGs to be developed by the Work Packages 2, 3 and 4. WP1 has also provided an overview of approaches used in GHG inventories at the national scale (D1.3), and of available methods for verification and their gaps and obstacles (D 1.4.).

Apart from this, there is a strong need for interaction between inventory agencies and the scientific community working on carbon-, methane- and nitrogen cycles. To respond to this need, the task develops short and long-term interactions and networking between inventory agencies and the scientific community. In that perspective, one of the aims of WP1 under VERIFY, is to guarantee a regular interaction between the inventory agencies and the other Work Packages in the project (see figure 1). To this end, the LSCE VERIFY website includes a portal where experts can find emission factsheets for European countries, building on the EU NGHGIs http://webportals.ipsl.jussieu.fr/VERIFY/FactSheets/.

In a series of network meetings, WP1 will especially seek for the interaction with those work packages that are involved in data provision (WP2-4); but also with the work packages 5 and 6 that aim at integrating knowledge into an integrated system that is applicable for EU (and other countries), involving also relevant external experts and scientists. WP1 aims at organising an exchange of knowledge between the partners involved in the consortium as well as scientific and inventory communities beyond the project, with the aim to discuss alternative methods for inventory verification and exploring their opportunities and limits.

To this end, a second network meeting was organized 10-13 November 2020; as a result of the COVID-19 pandemic held as an electronic meeting. This meeting consisted of three sessions, organised with other WPs, and aimed for providing feedback and enhancing information flows

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each on a specific theme, as to facilitate the participation of inventory experts dedicated to the respective topic:

- CO_2 from fossil fuels – 10 November 2020 – 77 Participants
- CO_2 from land sector – 12 November 2020 –70 Participants
- N_2O&CH_4 emissions– 13 November 2020 - 60 Participants

This document reports on these meetings. It summarises the presentations, the key messages and discussion items. All presentations can be found on:
https://verify.lsce.ipsl.fr/index.php/events/verify-second-networking-meeting.

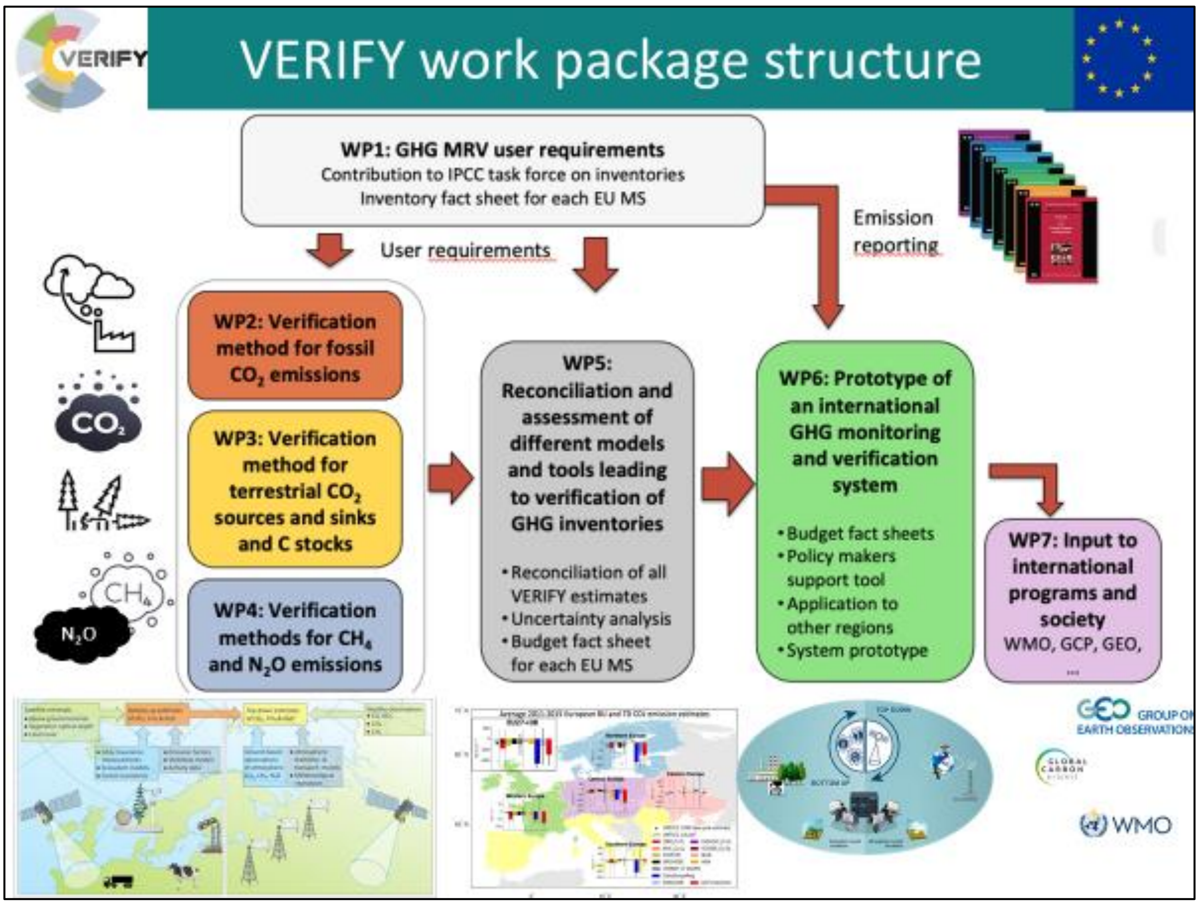

Figure 1: schematic overview of VERIFY structure

4. Report of the Sessions

Each workshop was introduced by an opening speech on the VERIFY project, followed by a presentation held by an inventory expert, outlining the methodologies needs and gaps for the inventory category related to the specific sector/gas in each session, then three/four presentations on the VERIFY results, followed by a discussion slot and a presentation from a WP6 representative, to wrap up and summarize the exchanges during the workshop. During the last session, on N_2O /CH_4 emissions, presentations from the Metoffice (UK) and EMPA (CH) showed the experience of the use of inversion model approaches for verification purposes within the UK and Swiss UNFCCC inventory reports, as to provide concrete examples on opportunities and limits of the application of inversion approach in the inventories.

4.1. Session 1 – CO_2 from fossil fuel (WP2), 10 November 2020

13:00	Opening	Chair: Dirk Günther, UBA Dessau
13:05	Introduction: emission inventory bottom-up data/model requirements	Bernd Gugele, UBA Vienna
13:20	VERIFY latest synthesis results	Robbie Andrew (CICERO, Norway)
13:35	Why use verification tools for CO_2	Hugo Denier van der Gon, TNO
13:50	Tools for independent verification of CO_2	Paul Palmer, University of Edinburgh
14:05	Discussion	All
14:45	Wrap up	Greet Janssens-Maenhout, JRC
15:00	End of meeting	

4.1.1. Emission inventory: bottom up requirements (Bernd Gugele, UBA Vienna)

Bernd Gugele presented the basic principles of GHG inventory reporting under the UNFCCC and addressed basic requirements from the inventory perspective regarding data availability from inverse modelling.

The most important conclusions were:

1. GHG inventories include data at sectoral and category level. Therefore, estimates based on measurements should also be available at level of source/sink category or sector. This can be

obtained by using for example proxy variables. If this is not possible, consultation with GHG inventory experts of the geographic area/sector of interest could be helpful.

2. GHG inventories include data at country level and on a yearly basis. Therefore, top-down approaches of climate research should try to provide the results expressed in a format that can, at least, be aggregated on both national and yearly scales.
3. It would be useful if top-down approaches could use clear and transparent definitions, taking into consideration as far as possible the terminology as defined by IPCC.
4. CO_2 emissions from combustion of fossil fuels shows the lowest uncertainty ranges. Therefore, the scientific community could focus on measurements of N_2O and CH_4 as these GHG emission estimates show much higher uncertainties (at least EU wide). At global level measurements of CO_2 may be more relevant because quality and availability of energy statistics may be more difficult than in the EU.

4.1.2. Verify: latest synthesis results (Robbie Andrew, CICERO)

Robbie Andrew presented a summary of the analysis within the project of the structural uncertainties in fossil CO_2 datasets. This group of uncertainties includes differences in system boundaries, biases, assumptions, and parameter choices, rather than measurement errors.
He showed the relationships between the datasets, and showed that the range of estimates at the global level is a poor indication of uncertainty since datasets do not attempt to estimate the same things. In particular, some datasets explicitly exclude some sources of fossil CO_2 emissions. Using the example of the EU, Robbie broke down specifically why eight datasets report different fossil CO_2 emissions. The talk concluded with the presentation of new, real-time estimates of global emissions, which are largely based on proxies rather than comprehensive bottom-up data, but nevertheless meet a significant demand for information.

Generally, uncertainties in fossil CO2 emissions estimates are low for the EU27+UK, in the order of 1 to 4%. Differences are mainly due to the allocation of fossil types between components such as solid, liquid and gas, but also the inclusion/exclusion of bunker fuels and carbonates from cement production. The single fast track inversions product (based on satellite CO and NO_2 and BU EDGAR v4.3.2 and CDIAC estimates) yields at the moment credible numbers with larger uncertainty (~17%) compared to the BU one. However, such estimate was still “quoted” as a preliminary one that will likely be refined with more complex method under development in WP2.

4.1.3. Why use verification tools for CO2 (Hugo Denier van der Gon (TNO)

Hugo Denier van der Gon started off by explaining that the atmospheric verification methods for fossil fuel CO_2 emissions are less mature and developed than the bottom-up calculation methods using statistics and emission factors. Moreover, the uncertainty in the EU for the latter is currently very small. This is however not the case everywhere and in due time even EU countries may face increasing challenges for good inventories. For example due to the growing use of biofuel/biomass to replace fossil fuels. To understand (and mitigate) climate change we need a good grip on all CO_2 emitted in the atmosphere and new techniques using atmospheric

observations may play an important role. We need to develop these methods now to be able to have them operational when needed.
An example of a new technique was shown where the upwind-downwind flux of the city of St Petersburg was measured. This highlighted that the domain of study often differs from the national scale that is leading in UNFCCC reporting. To be able to intercompare estimates based on atmospheric observations and from inventory agencies, spatial distribution and localisation of sources is crucial.
VERIFY WP2 made considerable progress on this as was illustrated with a map showing improved point source locations and emissions for CO_2 but also co-emitted species like NO_x and CO, which are important to identify anthropogenic CO_2 sources. This led to the conclusion that especially on harmonized reporting of CO_2 and air pollutants to e.g. UNFCCC, EMEP, E-PRTR, LPS directive, spatial distributions and understanding the fossil and biofuel component, a collaboration with national experts from inventory agencies will be of high added value for all communities.

4.1.4. Tools for independent verification of CO2 (Paul Palmer, University of Edinburgh)

Paul Palmer showcased some ongoing work from WP2 that is focused on estimating $ffCO_2$. In the first project, led by U. Heidelberg, radiocarbon measurements ($\Delta 14CO_2$) are used to determine observed ratios of $CO/ffCO_2$ and $NO_x/ffCO_2$ in and around Karlsruhe to identify characteristic values from fossil fuel sectors, e.g. coal power plant, domestic heating, and transport. These ratios were compared with inventory estimates from TNO. Some observed ratios were consistent with inventory estimates while others were between sector-specific values, partly reflecting that observed air masses represent a mix of different sources. Work at the U. Edinburgh has used self-consistent coarse and high-resolution atmospheric chemistry transport models to link TNO inventory estimates for CO and NO_2, commonly used as proxies for fossil fuel combustion, to column measurements of CO and NO_2 from the TROPOMI satellite.
Better agreement is found for the higher-resolution model but with some disagreement on the magnitude and spatial distribution of CO and NO_2 columns that is due to measurement errors and inventory estimate errors.
In the final piece of work, a collaboration between TNO and U. Edinburgh, we explored how to estimate correlations between CO and CO_2 emission uncertainties (via national-scale sector-based activity rates and emission factors across Europe) to help provide constraints on combustion source of CO_2 via CO, thereby allowing the CO_2 observations to provide more information on natural fluxes. National-scale correlations are generally negative (via combustion efficiency) and should be sufficiently large to provide some modest constraint on $ffCO_2$. All three projects are ongoing studies. Nevertheless, it is clear that there is a need for inventory, modelling and measurements groups to work ever more closely together, and **there is an urgency to develop self-consistent GHG and air quality inventories** so that reactive gases produced by combustion can be used to help estimate CO_2 from combustion sources.

4.1.5. Discussion session; Mentimeter survey results; wrap up

The presentations of the National GHG inventory (NGHGI) Agencies and of the climate and emission scientists/modelers (CES/M) with different approaches to the atmospheric emission fluxes are summarised in the table below.

	NGHGI	CES/M
Temporal scale	Low resolution: Yearly, till t-2 (t-1)	High resolution Monthly, hourly
Spatial scale	Low resolution: Territorial, country specific (1MS)	High resolution of spatially disaggregated data, applicable for - regional/global coverage without political border - local scale for verification of e.g. large point sources
Activity link	Fine granularity: Disaggregated by source, subsector, human activity specific	Course granularity: Larger groups of activities for which spatial and temporal data are available, of interest for near real time emission assessment
Challenges	Direct/indirect emissions, uncertainties, increased complexity	Modeling of processes, biofuel/biomass, Carbon Capture and Storage

With the mentimeter web tool, we polled the following opinions on:

1. **The National GHG inventory reports and data tables of the EU Member States are a huge source of information. In case you would have the resources to do more, which information you would like to see further enriched?**
   Spatial distribution was considered as an important topic to invest more effort, followed by uncertainty. It is noticed that a higher spatial resolution goes together with a higher temporal resolution.

2. **Climate change is a global problem. How do you think national inventory agencies and European research communities should contribute?**
   Outreach to developing countries was considered definitely as a very important step to tackle the global problem of climate change. Reference was made to the Parternships in support of the Paris Agreement that DG CLIMA is fostering.

3. **To visualise the urgence of the emission reductions, what do you recommend to communicate to policymakers?**
   The emphasis was put on the trends. These are the most important, in particular when also linking to the targets where we need to evolve to.

4. **Emissions and atmosphere/climate science are still facing huge challenges. What are common challenges?**
   Challenges are numerous: biofuel, inconsistencies in the inventories (to be tackled maybe with the multilateral facilitative dialogue under the Paris Agreement), measurements (in situ as well as space borne, with better coverage of all activities at all different places), uncertainties (of the inventories, the measurements, the models).

4.2. Session 2 – Terrestrial CO_2 sources and sinks and carbon stocks (WP3), 12 November 2020

13:00	Opening	Chair: Lucia Perugini, CMCC
13:05	Introduction : emission inventory bottom-up data/model requirements	Marina Vitullo, ISPRA
13:20	VERIFY latest synthesis results	Han Dolman, VU Amsterdam
13:35	Synthesis of bottom-up and top-down methods for terrestrial carbon fluxes related to land use, land use change, and forestry	Matthew McGrath, LSCE
13:50	What open data tells us: Reconstructing six decades of global land use change	Karina Winkler, Wageningen University
14:05	Groundbased forest inventory data in European LULUCF reporting; the role of synchronized data across countries	Gert-Jan Nabuurs, Wageningen Env. Research
14:20	Introduction survey	Martin Herold, Wageningen University
14:35	Discussion	All
15:05	Wrap up	Giacomo Grassi, JRC
15:15	End of meeting	

4.2.1. Emission inventory: bottom up data/model requirements (Marina Vitullo, ISPRA)

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Marina Vitullo focused on the key steps of the emissions and removals estimates, for LULUCF sector, in the framework of GHG inventory, as submitted annually to UNFCCC/Kyoto Protocol.
The presentation highlighted the LULUCF sector peculiarity, dealing with 6 different IPCC land uses, each of them subdivided in land remaining in the same land use category and land converted to other land use categories.
Three GHG gases (i.e. CO_2, CH_4 and N_2O) have to be reported for the 6 carbon pools (aboveground biomass, belowground biomass, dead mass, litter, soil organic matter and harvested wood products) in each land use category.
In this estimation process, land representation and classification is key to provide a reliable data source for the carbon stock changes estimate. The land representation is a key element where Earth Observation (EO) data could provide useful and high quality data, ensuring consistency with national definitions. The key messages were:

1) Rules, definitions and data availability are key elements to deal with in the GHG inventory process.
2) IPCC guidelines provides each country methods and factors to assess emissions/removals; consequently large variety of approaches/methods/factors results in the reported estimates.
3) Inventory agencies are open to detail the estimation process and to update/modify data and methods used as long as consistency with IPCC guidelines and UNFCCC decisions is ensured.
4) Any proposal by the EO community in relation to novel approaches/methods to be applied in the verification of the GHG estimates is welcome.

4.2.2. Verify: latest synthesis results (Han Dolman, VU Amsterdam)

Han Dolman recalled the aim of WP5 is to understand and reconcile differences between the NGHGI data submitted every year to UNFCCC and several bottom-up and top-down estimates of a.o. CO_2 emissions that are more science and observationally based.

The CO_2 emissions from land can be estimated from activity data and emission factors such as recommended by the IPCC guidelines. Several sector specific models are used in VERIFY to provide similar estimates for forest, grassland and cropland, all including land use change/conversion. These bottom-up methods agree in general on average well with the NGHGI estimates. Differences occur when vegetation models that are driven by daily/hourly weather produce much more inter-annual variability than traditional stock change methods (which are inherently based on multi-year assessments).

Inversion methods for CO_2 land show much more variability in estimates, but e.g. EUROCOM ensemble of European inversions shows good agreement on average with UNFCCC NGHGI data, albeit with a very large variability linked to uncertainties in atmospheric transport modeling and uncertainty inherent to the limitation of the observation network. These models are mainly designed for large scale flux estimates and are still developing their lateral boundary regional conditions.

While there is progress in understanding the differences between top-down and bottom-up sector specific methods in defining which processes are included and excluded, overall they show larger variability than the NGHGI estimates. Several countries have started to include more bottom-up (Tier 3) methods in their reporting. Using top-down inversions for CO_2 is still under development, but few European countries (e.g. UK and Switzerland) use atmospheric observations on a voluntary basis to complement their national inventory data with top-down estimates in an annex to their NGHGI reports.

4.2.3. Synthesis of bottom-up and top-down methods for terrestrial carbon fluxes related to land-use, land-use change and forestry (Matthew McGrath, LSCE)

Matthew McGrath focused in his presentation on the results for the same style of plots for individual countries in Europe, building on the introduction to synthesis plots for CO_2 emissions from the land surface given by Han Dolman. Such work was made possible by the infrastructure created in VERIFY to process files and create plots, which automates the procedure for 79 countries and groups of countries within Europe.
Six different example plots were shown, highlighting the different kinds of questions that the project faces when comparing results from such disparate data sources as national GHG inventories, bottom-up models (both general and ecosystem-specific), and top-down atmospheric inversions. The work of the researchers is to try to understand if apparent agreement is real, and if there are valid scientific reasons for disagreement between approaches, or if they are due to random chance or fundamental differences in what the datasets report/measure.

After discussion of the plots, several collaboration efforts between WP1 and WP3 were highlighted, including biomass density maps, land use/land use change maps, forestry models which are used heavily in the policy arena, and an attempt to calculate LULUCF emission factors using the scientific research model ORCHIDEE for forest land remaining forest land in France.
Matthew McGrath finished his presentation by highlighting one possible complementary source of information that WP3 could provide to WP1: increased spatial and temporal resolution in fluxes.

The key messages from the presentation were:

- The WP3 experts welcome all comments by inventory agencies on plots for their specific country to help understand differences between reported inventories and research models.
- Further collaboration between WP1 and WP3 is encouraged.

4.2.4. What open data tells us: reconstructing six decades of global land use change (Karina Winkler, Wageningen University)

Karina Winkler presented HiLDA+ (Historic Land Dynamics Assessment+), a global land use change reconstruction from multiple Open Data streams, that has been constructed mainly through the support of VERIFY.
With bringing both long-term statistical inventories (FAO land use and population) together with high-resolution spatial information from Earth Observation-based land use/cover classifications (e.g. ESA CCI, MODIS LC, Hansen GFC, Copernicus LC), we build an annual global time series of harmonised land use/cover (Urban, Cropland, Pasture/rangelands, Forest, Grass/shrubs, Sparse/no vegetation) and its transitions at 1 km spatial resolution between 1960 and 2019. This approach contributes to our understanding of land use change extent and processes of the past. This is highly needed to run future climate and environmental models and projections. Since greenhouse gas inventories deeply rely on land use/cover information, improving the quality of datasets on land use change as an input to models is crucial. Using a purely data-driven harmonisation approach, HiLDA+ adds more detail to the assessment of extent, speed and patterns of global land use change and could fill the gap of providing consistent information of land use change for climate and ecosystem models.

The key messages from the presentation were:

- Datasets on land use change are fragmented and differ in spatial, temporal and thematic detail.
- HiLDA+ Global Land Use Change: Combination of multiple observational and inventory data adds more detail to our understanding of global land use change processes (extent, speed, patterns).
- We find that land use change is four times greater than previously estimated from state-of-the-art land use reconstructions (LUH2, HYDE, SAGE). This has an impact on GHG inventories.

4.2.5. Groundbased forest inventory data in European LULUCF reporting: the role of synchronized data across countries (Gert-Jan Nabuurs, Wageningen Environmental Research)

Gert-Jan Nabuurs focussed in his presentation on the CO_2 balance of forest land. He portrayed how countries now use national forest inventories in their reporting to UNFCCC, and how one synchronised modelling approach (EFISCEN) can serve as an independent verification method.
EFISCEN uses partly the same data as the countries do, but applies then one set of additional parameters (distinguished by country, species, region, etc) and model assumptions. It also employs one model approach (YASSO) for soils.

For some countries results match very well the UNFCCC reporting, for others there are significant differences. These can often be explained by the assumptions and the parameter details.

The latest is a higher resolution modelling approach directly running on raw NFI plot data (200,000 plots). This allows incorporation of mixed forests, better routines for local management and has climate sensitive growth functions as well.

4.2.6. "Spatial explicit data for forest GHG" survey, Martin Herold (Wageningen University)

Martin Herold explained that WP1/WP3 are conducting a dedicated survey to assess gaps and needs towards spatially-explicit estimations of forest-related GHG emissions and carbon removals. There is an evolving set of spatially-explicit dataset and estimates that are becoming available, i.e. as part of VERIFY WP3 (land change, biomass, various models).
At the same time there is an increasing requirement and interest by countries with a particular focus on the LULUCF sector and forest-related categories (ref. Regulation (EU) 2018/841). The survey is open and conducted online: https://forms.gle/rrSH5cUTEEk3LEzA6. So far there have been seven replies from national agencies in VERIFY (Ireland, Norway, Austria Netherlands, Germany, Italy & France).

The main findings from the current survey replies:

- There are needs and plans by countries towards spatially-explicit estimations of forest-related GHG emissions and removals.
- Prominent motivations: better understand spatio-temporal patterns and for tracking of mitigation activities and related planning/management.
- Current use and awareness is mostly for land use change; less so for biomass maps and forest/carbon models.
- Most need is for "high-resolution" (i.e. 10-30 m, annual).
- Consistency is key: long-term, national definitions.
- Sense of limited availability/accuracy/consistency of data sources and approaches ... at the same time limited awareness for some new development.

Looking forward, the survey is still open and we will stimulate more GHG inventory agencies to complete it. There is a need for further exchange on current practices, evolving requirements and novel (technical) opportunities. Aim should be to raise joint understanding and awareness and scope priorities and activities for collaborative efforts.

4.2.7. Discussion session and wrap up (Giacomo Grassi, JRC)

The inclusion of LULUCF in the climate targets largely followed the confidence on its numbers: completeness of reporting has increased over time, and so the accounting. Independent verification is still insufficient in most NGHGIs. Looking ahead to 2050, the latest proposal by the Commission suggests that, to track progress towards climate neutrality, the full net LULUCF sink needs to be included. In this context, the main challenges ahead are:

- Further increase confidence in numbers.
- Stop & reverse the current decline of LULUCF sink.

On the basis of the LULUCF EU regulation agreed in 2018, estimates are expected to improve both in terms of Tiers and in terms of spatial representation. Aims of Verify on Land-based CO_2 fits very well in this narrative. Understanding of the drivers is also very important, because they are essential in designing effective policies.

Where are we?

- Good steps have been made in bridging models and GHGI compilers, and in combining empirical/process based approaches (e.g. ORCHIDEE)
- BU results look very promising but we need a closer look to details. Results might look good when aggregated also because of compensating factors across different land uses, AD and EF. More disaggregated data are important to understand the agreement is for good reason or by chance, and also to understand better the drivers.
- There is a great potential from Earth Observation (EO).
- TD show large variability and uncertainty: Beyond the known uncertainties, reported in NGHGIs, LULUCF can probably be seen as the sector with the greatest unknow uncertainties. Can TD help to unravel unknow uncertainties?

Where models and EO may help most

Independent verification, greater spatial and temporal resolution of AD (e.g. forest cover change) and EFs (e.g. biomass maps may be very useful – MS show an increasing interest) and natural disturbances, completeness (soils?), understand better the drivers.

Next challenges

System boundaries and definitions: what process are included (direct vs indirect effects), managed land, etc. To find common grounds:

- Greater transparency by countries (what process is included, maps); WG1 work
- Inventory and science/modelling communities speak different languages. What we need is not necessarily a single language – that would require many years of work – but at least a translator; a “Rosetta stone”. Rosetta stone solutions imply that results from models are used in a flexible/modular way. These are not the ultimate solutions, but can be effective and pragmatic fixes, e.g. under the Global Stock Take.

4.3. Session 3 – CH_4/N_2O (WP4), 13 November 2020

13:00	Opening	Chair: Lucia Perugini, CMCC
13:05	Introduction: emission inventory bottom-up data/model requirements for CH_4 and N_2O	Jean-Pierre Chang/ Anaïs Durand, CITEPA France
13:25	Experience on using inversions for UNFCCC reporting requirements	Alistair Manning, MetOffice UK
13:40	VERIFY latest synthesis results	Roxana Petrescu, VU Amsterdam
13:55	Top-down CH_4 approaches	Dominik Brunner, Empa

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14:10	Top-down N_2O approaches	Rona Thompson, NILU
14:25	Discussion	Jean-Pierre Chang, CITEPA France, Dirk Günther, UBA Dessau
15:00	Wrap up	Greet Janssens-Maenhout
15:15	End of meeting	

4.3.1. Emission inventory: bottom up data/model requirements (Jean-Pierre Chang and Anaïs Durand, CITEPA)

Jean-Pierre Chang and Anaïs Durand recalled the emission inventory bottom-up MRV requirements and specificities for these 2 gases related to the most important sectors: waste and agriculture. Concerning requirements on emission monitoring, waste and agriculture emissions relate to complex processes that can be more or less precisely reflected according to the tier methodologies implemented from the IPCC Guidelines.

For agriculture, the main activity data that are needed, can easily be found on existing websites (FAO, IFA). This ensures the capability to produce at least basic emission estimates for most countries. For more accurate estimations, detailed knowledge and data related to the national agricultural production systems is necessary but not always available.

For the waste sector, countries are facing more or less lack of data (even basic data), to produce accurate emission estimates. This relates especially to the need to implement degradation kinetics over a very long time period for solid waste disposal.

For these 2 sectors uncertainties are large, because of the complexity and possible great variability of the emission processes (e.g. N_2O from agricultural soils, CH_4 from waste sector). Nevertheless, considering especially EU Member States, the national inventory approaches are quite solid, ensure comparability between countries, require a real knowledge of reality of the countries, but solutions are needed to help reducing the high uncertainties of these emissions.

The VERIFY project can help on this issue. Especially the IPCC 2006 Guidelines note that such top down inverse modelling approach based on atmospheric measurements can be used as possible complementary verification of national GHG inventories, but easier to implement at regional or group of countries level for resource and complexity reasons.

4.3.2. Experience on using inversions for UNFCCC reporting requirements (Alistair Manning, UK MetOffice)

Alistair Manning briefly introduced the UK National Verification Programme. Results are used to compare with the UK National Inventory Report to UNFCCC. The UK was the first country (2003) to compare reported emissions to estimates derived from atmospheric observations. The UK developed the InTEM framework for inverse modelling. This system is building on three main elements: (1) observations from an observation network; (2) atmospheric transport modelling to link sources to receptors and (3) prior knowledge – basically the UK inventory gridded on a 1*1 km scale, but also taking into account the transport of gases in the northern hemisphere.

For the result of the inversion it's very important to connect the proper uncertainties to these three elements. As modelling is the most uncertain element, working towards improvements of the atmospheric transport model is key. Other important aspects are: representativeness of the observations (atmosphere well mixed) and the model time: there are different uncertainties for day and night but also weather circumstances such as (strong) winds. But also the comparability of circumstances for different measurement stations is an important aspect.

For CH_4, the UK reported estimates compare rather well with recent atmospheric estimates. There is a year to year variability but no strong seasonal cycle. For N_2O, the UK reported estimates are about 10-15% lower than atmospheric estimates. Besides, there is a very strong seasonal cycle.

UK is working on further improvements of the system, such as better understand the differences between N_2O observations and inventory; precision of the observation instruments; models and finally CO_2 which is the most challenging component

Note that the success of the UK in terms of comparing its reported emissions to the estimates from atmospheric inversion, was probably favoured by close initial links between the two communities

4.3.3. VERIFY latest synthesis results (Roxana Petrescu, VU Amsterdam)

Roxana Petrescu started her presentation by explaining that the aim of WP5 is to understand and reconcile differences between the NGHGI data submitted every year to UNFCCC and several bottom-up and top-down estimates of CH_4 and N_2O emissions that are based more on science and observations. She focused on the EU27+UK and regional results, highlighting the differences observed between UNFCCC NGHGI (2019) data, observation based BU anthropogenic and TD total emissions.

Regarding CH_4, at European and regional scale there is, in general, a good agreement between BU sources, as well as between regional and global inversion ensembles. At the moment, the NGHGI data shows decreasing trends, with Energy and Waste having the highest reduction shares. From the sectoral totals, Agriculture shows the best fit between the BU estimates, all within the 10% uncertainty reported by NGHGI. Overall, the main differences are caused by the application of different tiers and methods used in calculating emissions (e.g. the use of AD and EFs as discussed in Petrescu et al., 2020 AFOLU publication) and the allocation of emissions to different sectors. As NGHGI do not report natural emissions, to use TD as verification and complementarity tools[1], we advocate the need of better quantification of these estimates. We found that, at both global and regional level, this might be the missing link when explaining the differences between anthropogenic BU and total TD estimates.

Regarding the N_2O emissions, for all UNFCCC sectors, the BU anthropogenic estimates show consistent trends and values with the NGHGI (best fit for agriculture, IPPU). Overall, in EU27+UK

[1] IPCC 2019 Refinement advices the MS to actively try to annex total TD estimates in their country reporting

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the highest uncertainty in the UNFCCC NGHGI reporting (2018) comes from the waste sector (626 %), followed by agriculture (soils) (107%). When comparing the BU with TD estimates, the gap between these two is not explained by the natural emissions. For TD it is impossible to separate the N_2O natural from anthropogenic sources (uncertainty introduced by definitions[2]). Natural soils (unmanaged) can have both natural and anthropogenic emissions while anthropogenic (managed) agricultural soils can also have a level of natural emissions. Further improvement of inverse methods for N_2O is needed to determine the total level of emissions and, most importantly, the trends and investigate as well the seasonality variations in the agriculture sector (e.g. N-fertilizer application).

4.3.4. Top-down N_2O approaches (Rona Thompson, NILU)

N_2O emissions for Europe (EU27+UK) were estimated for 2005-2017 using a top-down approach, namely, atmospheric inversion. This approach uses atmospheric observations of N_2O in a statistical optimization to adjust prior (and independent) estimates of the emissions. In the approach, an atmospheric transport model is used to relate the emissions to changes in N_2O concentration. The calculated model-observation difference is related, through the inverted atmospheric transport, to a correction to the prior emission estimate. The atmospheric inversion approach is sensitive to errors in the modelled transport, in the uncertainties assigned to the prior emissions and observations, as well as to assumptions about the initial conditions and atmospheric chemistry (these are the systematic errors). An estimate of the random uncertainty on the inversion estimate was calculated, and showed a considerable uncertainty reduction relative to that of the prior estimate. Atmospheric inversions resolve the emission spatio-temporally (for EU27+UK this was at 0.5 degrees and monthly) but cannot resolve emission sectors, i.e. they calculate the total emission.

For the years estimated, the top-down emissions were on average 0.29 Tg N/y (51%) higher than that reported to the UNFCCC. This can in part be explained by the natural (or background) emissions, which are included in the top-down approach, and are estimated to be about 0.073 Tg N/y (25% of the difference). The remaining discrepancy, may be due to one or more of:

i) an underestimate of the natural emissions,
ii) UNFCCC underreporting of one or more emission sources,
iii) the uncertainty in the top-down approach, estimated to be about 0.14 Tg N/y.

More atmospheric observations would help to reduce the uncertainty in the top-down estimate and better pin-point where the discrepancy is.

The top-down approach indicates a decreasing trend in the emissions from 2013, whereas UNFCCC suggests that the emissions were stable from 2011. Lastly, the top-down estimates include the seasonal and inter-annual variability in the emissions, due to e.g. meteorology and agricultural management, and finds large year-to-year variations, which are not accounted for in the UNFCCC estimates.

[2] natural N_2O is defined as level of emissions in the pre-industrial period

4.3.5. Top-down CH4 approaches (Dominik Brunner, EMPA)

Dominik Brunner presented an overview of top-down methods in the context of CH_4 emission estimation. He argued that CH_4 is a very attractive compound to address for several reasons: It is the second most important long-lived GHG after CO_2, its sources have large uncertainties, it is measured at many stations in Europe and worldwide with high accuracy, and its anthropogenic sources can be more easily separated from biospheric fluxes compared to CO_2. He presented two examples of top-down CH_4 emission studies.

The first one is the study conducted in VERIFY, where measurements from the European ICOS network and other monitoring sites are used to estimate CH_4 emissions over Europe. The emissions estimated for Europe obtained with his model were found to be largely consistent with the bottom-up emissions reported to UNFCCC, both showing a small downward trend since 2005.

The second example focused on Switzerland, where a well-established top-down emission estimation system supported by the Swiss Federal Office for the Environment is already in place since 2016. The top-down CH_4 estimates obtained with this system closely match the numbers officially reported to UNFCCC, providing evidence for the high quality of the Swiss national emission inventory.

4.3.6. Discussion session and Wrap up (Greet Janssens-Maenhout, JRC)

Contrary to the ffCO_2 session, the CH_4/N_2O session found much more agreement between the National GHG inventory Agencies (NGHGIA) and of the climate and emission scientists/ modellers (CES/M), confirming that observations and inverse modeling could bring here a lot of improvement for the CH_4 and N_2O emission estimates. Examples of improvements in UK and Swiss NGHGI (with inverse modeling results reducing the emission uncertainties as reported in an annex to the NGHGI) were demonstrating this and it was acknowledged by all participants.

With the mentimeter survey tool, we polled the following opinions on:

1. **For which emissions sources would new atmospheric and/or flux measurements significantly help revising the emission factors most?**
   The most important sectors were judged to be crop production, then livestock, and then waste.

2. **The National GHG inventory reports and data tables of the EU Member States are a huge source of information. CH4 and N2O emission estimates have been increasingly enhanced but still face some large uncertainties. Which task would you tackle first for further improvement?**
   First the spatial distribution, then the top down evaluation with inverse modeling and then the seasonal distribution were listed as tasks in order of decreasing priority.

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3. **What are the challenges for improving CH4/N2O Inventories?**
   Measurements are considered to be most crucial for improving implied emission factors and for assessing the spatial and seasonal distribution of the emissions.

4. **Where do you see the largest assets of top down inventories using observations and inverse modeling?**
   This is most useful for reducing the uncertainties and for increasing our understanding of the emission processes into the atmosphere.

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5. Conclusions

The second network meetings brought together experts from National GHG inventory (NGHGI) Agencies and the climate and emission scientists/modelers (CES/M), creating a space for a rich discussion and exchange of information between the two communities. The meeting offered also the opportunity to inform inventory agencies about the research activities undertaken by the project, displaying and discussing about the GHG budgets provided by VERIFY to improve national inventories, in collaboration with national inventory agencies.

Based on the presentations and discussion during this meeting, we can summarise the main differences between both "worlds" (emission inventorying and modelling/measurements) as follows:

	NGHGI	***CES/M***
Temporal scale	Low resolution: Yearly, until t-2 (t-1)	High resolution: Monthly, hourly
Spatial scale	Low resolution: Territorial, country specific (per Member State)	High resolution of spatially disaggregated data, applicable for - regional/global coverage without political border - local scale for verification of e.g. large point sources
Activity link	Fine granularity: Disaggregated by source, subsector, human activity specific	Course granularity: Larger groups of activities for which spatial and temporal data are available, of interest for near real time emission assessment
Challenges	Direct/indirect emissions, uncertainties, increased complexity	Modeling of processes, biofuel/biomass, Carbon Capture and Storage.

Inventory experts operate in the context of- and within the boundaries of the UNFCCC reporting guidelines and IPCC emission inventory guidelines. Reporting at a higher spatial/temporal resolution would be beneficial for independent verification, but is as yet outside the scope of formal/legal requirements. However, this meeting shows there is scope for better collaboration between emission inventory experts and modelling & measurement experts; for instance in creating science based emission datasets at higher spatial- and temporal resolution.

As shown in several synthesis studies in the context of VERIFY, comparisons between datasets may be hampered by differences caused by the application of different tiers and methods used in calculating emissions, and allocation of emissions to different sectors.

Scientists have made progress over the past few years in developing methodologies that may help in both comparison of- and verifying the inventories. Tools are made available through the LSCE VERIFY website **https://verify.lsce.ipsl.fr/**. There is a huge potential e.g. in developing and applying Earth Observation tools; but also inverse modelling. An extension of the measurement network over Europe might be beneficial in this context. The main objective (illustrated in the figure below) will guide the remaining work of VERIFY and the progresses will be discussed again in a final Networking Meeting to be organized late 2021.

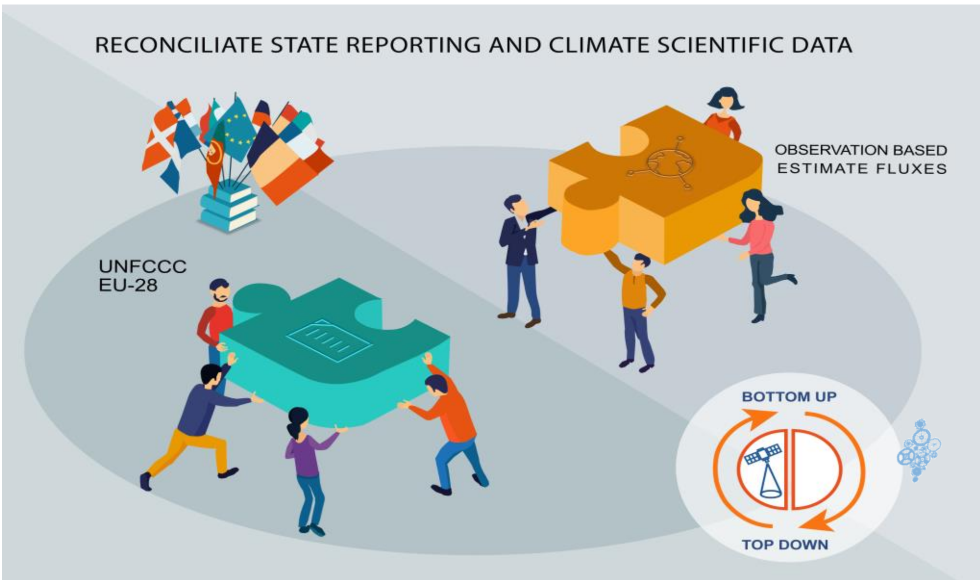

Figure 2: Illustration of the main objective of VERIFY: reconciliation between state reporting and climate scientific data.

6. Annex : List of participants

Each of the meetings on 10, 12 and 13 November were attended by some 60-70 experts each; in total 105 experts registered for the meetings. This includes (inventory) experts from Austria, Belgium, Croatia, France, Finland, Germany, Greece, Hungary, Iceland, Italy, Latvia, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Turkey and United Kingdom. Furthermore representatives from the European Commission, JRC, EEA and WMO.
Also experts from a number of non Annex I and non European countries had been invited, but did not participate.

The list of participants is not included in the report because of the GDPR.