Third EYE-CLIMA outlook summary

DELIVERABLE 5.6

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1.0	25-02-2026	Final draft with improvements	Reidun Marie Romundstad (CICERO), Glen Peters (CICERO), Robbie Andrew (CICERO), Wilfried Winiwarter (IIASA), Rona Thompson (NILU)
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Summary

An "EYE-CLIMA Outlook" summarises the key findings and project outcomes from the preceding project year, which are most relevant for users. There will be four summaries published during EYE-CLIMA (January 2024, January 2025, February 2026, December 2026). This deliverable is the third EYE-CLIMA Outlook Summary (February 2026).

This Outlook gives a summary of the main deliverables from 2025, where input datasets, both observation-based and modelled, were updated and finalized, and major progress was made on the atmospheric inverse-modelling work.

The formal deliverable has a slightly different format to other deliverables (no introduction, methods, results, etc), and its content consists of the final outlook (in "fact sheet" format). The EYE-CLIMA Outlook Summary is the body of the deliverable (pages 4-9). A separate version of the outlook (only pages 4-9) will be used for standalone distribution.

There are no deviations from the description of work.

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EYE-CLIMA Outlook no. 3

February, 2026

EYE-CLIMA aims to improve estimates of emissions and removals of the most important greenhouse gases: CO_2, CH_4, N_2O and six F-gases (i.e., synthetic gases containing fluorine), as well as aerosols containing black carbon to support European and international policies to reduce their emissions.

EYE-CLIMA Outlooks summarise the key findings and project outcomes from the preceding project year that are most relevant for users. This Outlook covers the third year of the project (2025), where input datasets, both observation-based and modelled, were updated and finalized, and major progress was made on the atmospheric inverse-modelling work. These efforts have laid a solid foundation for the final project year, when the focus will shift to verifying national greenhouse gas inventories.

All project information and deliverables are accessible at https://eyeclima.eu/

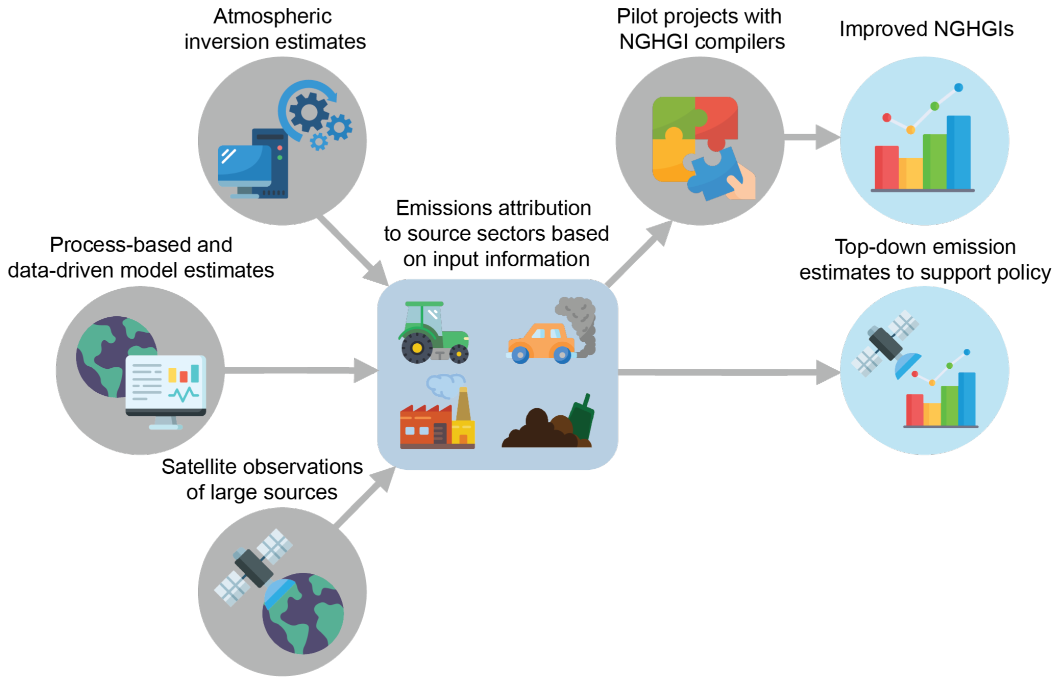
Informing emission inventories using observations

Methods for reporting national GHG emissions to the UNFCCC are based on emission factors and activity data. However, these methods have uncertainties especially for non-CO_2 GHGs, and for CO_2 emissions and removals from LULUCF. Thus, independent verification of the emissions needs to be provided.

EYE-CLIMA rigorously examines how atmospheric-inversion based flux estimates can be used to support national emission inventories. Although atmospheric inversions provide a mass balance constraint on the fluxes, they generally cannot provide a strong constraint on the source type, which is needed to provide useful information on emission inventories.

Therefore, EYE-CLIMA focuses on the attribution of the fluxes from inversions to source types by analysing the spatiotemporal patterns of the fluxes and through using auxiliary information from e.g. process-based modelling. For CH_4, some constraint by source type is possible by including its stable isotopes (e.g. $\delta^{13}C$) in atmospheric inversions.

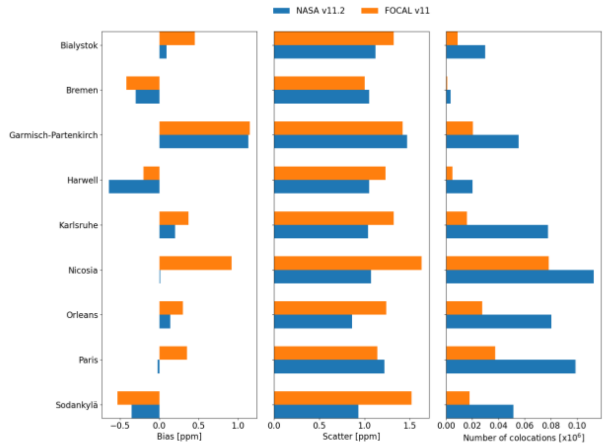
EYE-CLIMA works together in pilot projects with three agencies who compile national emission inventories to develop a prototype methodology to compare atmospheric inversion fluxes with inventories. This will form the basis of a guideline on how to attribute atmospheric inversion fluxes to sectors and how these can be used to support and verify inventories.



Deliverable 1.3: Assessment of CO_2 column data from OCO-2

Two carbon dioxide (CO_2) data products from the OCO-2 satellite (the official NASA product and the IUP FOCAL product) were compared against each other and assessed against ground-based data from the Total Carbon Column Observation Network (TCCON). Both datasets show high accuracy when compared to ground-based TCCON measurements, with strong correlations and low biases (mostly below 0.5 ppm). The NASA product generally offers better coverage, especially over European land areas, and slightly lower biases and scatter than FOCAL. While both datasets agree well globally and over time, small systematic differences remain, such as land-sea contrasts and seasonal amplitude. Overall, both products provide reliable, high-quality CO_2 measurements.

For more information see the deliverable D1.3 available here: https://eyeclima.eu/products/public-reports/

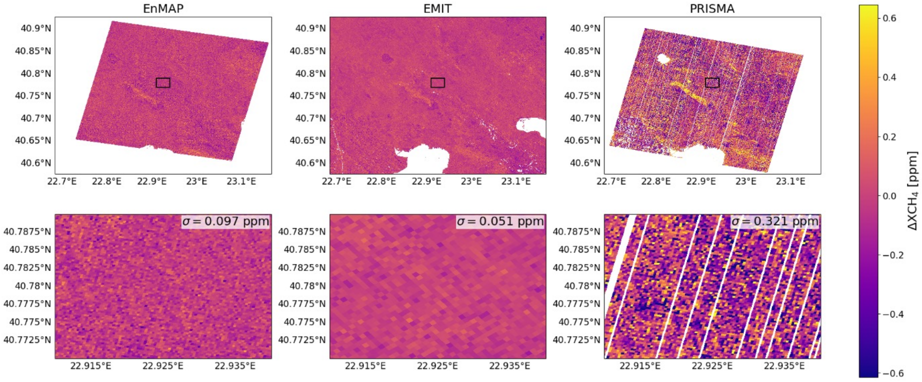


Comparison of OCO-2 XCO_2 data products with TCCON.

Deliverable 1.4: Inventory of point source emissions of CH_4 estimated from high resolution satellite data

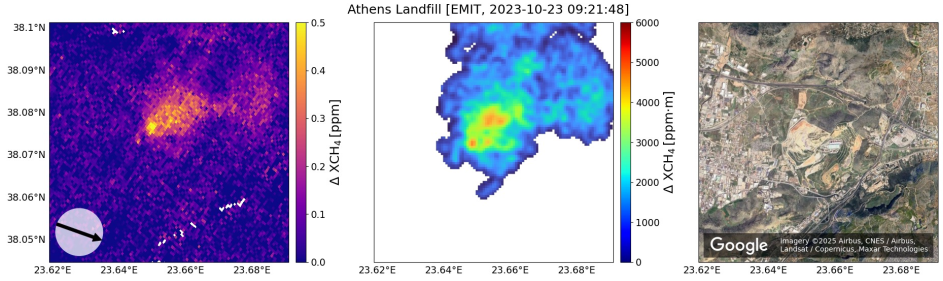
Methods for detecting methane emissions using high-resolution satellite instruments are reviewed, and applied to hyperspectral satellite data from PRISMA, EnMAP, and EMIT to evaluate methane emissions from point sources in Europe. Fourteen potential emission sites were analyzed, including landfills, coal mine ventilation shafts, and unknown sources.

For sites where methane plumes were detected, emissions were estimated, ranging from 0.35 to 6.82 tons per hour. PRISMA proved unsuitable for European sources, while EMIT and EnMAP detected plumes but provided only single observations for most sites because of limited satellite overpasses in cloud-free conditions. Comparisons with official inventories and data from Carbon Mapper and GHGSat show general agreement within uncertainty ranges. Future work will expand datasets and include case studies beyond Europe.



Comparison of XCH_4 enhancements with the different three satellites EnMAP, EMIT and PRISMA for a scene near Thessaloniki. The top row shows the retrieved XCH_4 for a large area. The black rectangle indicates the position of the analysed area shown enlarged in the bottom row.

Comparisons of CH_4 retrievals from EMIT for a landfill near Athens. Left: HiFi result; Centre: Carbon-Mapper; Right: satellite image.



Deliverable 1.8: Updated review of existing biomass and biomass change datasets

Existing above ground biomass and biomass change datasets have been reviewed for their suitability in greenhouse gas inventories and as benchmarks for national UNFCCC reporting. A first review was made earlier in the project (deliverable D1.7, as described in the first EYE-CLIMA outlook). Three datasets emerge as most relevant:

1) ESA CCI Biomass provides detailed, multi-sensor biomass and change maps with uncertainty estimates and strong ground-based calibration, though inconsistencies across reference years can affect change estimates.

2) LVOD-based datasets offer a long, sensor-consistent time series but face calibration challenges that limit the robustness of biomass change assessments.

3) The European biomass map for 2020[1] aligns closely with national statistics, making it a strong reference dataset.

Additional value comes from the European Forest Disturbance Atlas, which clarifies drivers of change. Visual assessments indicate that ESA CCI Biomass products may overestimate change extent, though major trends in biomass loss and gain are captured correctly.

[1] Avitabile et al. (2023). Forest Biomass dataset for Europe. figshare. Collection. https://doi.org/10.6084/m9.figshare.c.6465640

Deliverable 2.4: Updated high-resolution fluxes and uncertainties of CO_2, CH_4 and N_2O for Europe

Estimates of major greenhouse gas fluxes (CO_2, N_2O, and CH_4) across Europe are provided from high resolution (~10 km) process-based models. A first version of the input dataset was provided earlier in the project (deliverable 2.3, as described in the first EYE-CLIMA outlook). This is an update of the collected data that defines the final version of the input dataset.

These bottom-up estimates support atmospheric inversions, national and sub-national annual GHG budgets, and analyses of key drivers such as land management, climate, atmospheric CO_2 and nutrient inputs.

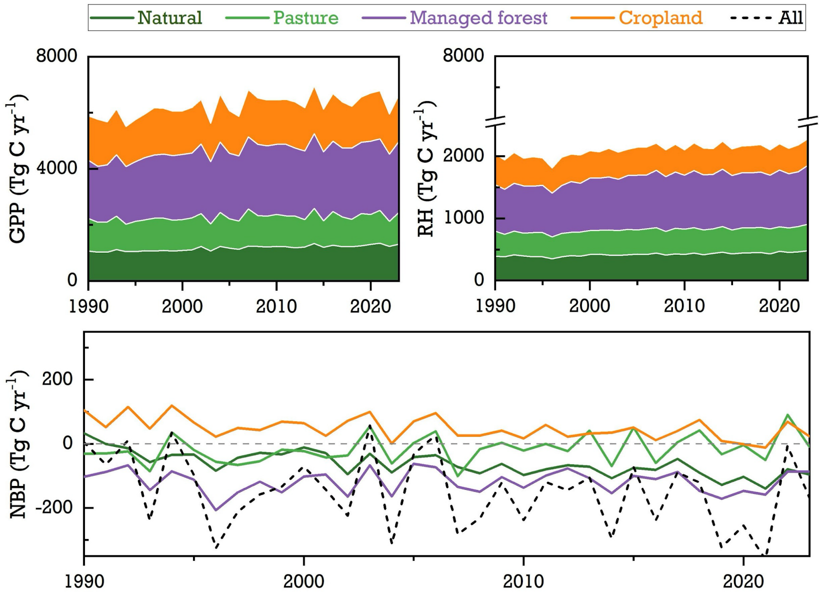
Three ecosystem modelling frameworks are used:

1) LPJ-GUESS for net ecosystem exchange of CO_2, and soil N_2O from natural, pasture, and crop ecosystems.

2) ORCHIDEE, which provides integrated estimates of all three gases from European ecosystems.

3) JSBACH-HIMMELI for CH_4 emissions from wetlands, mineral soils, and inundated land.

For more information see the deliverable D2.4 available here: https://eyeclima.eu/products/public-reports/



Simulated total annual CO_2 fluxes (Tg C yr^{-1}) in natural vegetation, pasture, managed forest, and cropland by LPJ-GUESS over EU27+3 countries between 1990-2023. Gross primary production (GPP), heterotrophic respiration (RH) and net biome production (NBP). Negative values of NBP indicate carbon uptake.

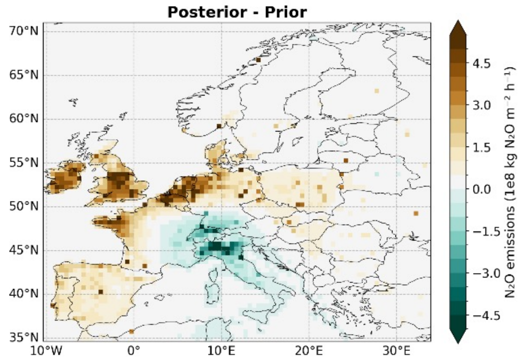
Deliverable 3.2: Final fluxes of CO_2, CH_4 and N_2O at 0.5° from 2005

Atmospheric inversions of CO_2, CH_4, and N_2O fluxes were performed for Europe using ground-based and, for CO_2 and CH_4, satellite observations.

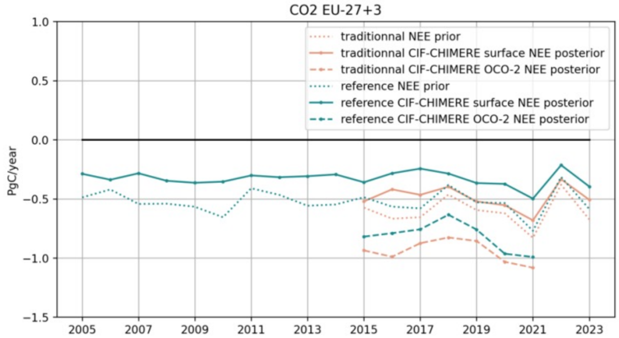
For CO_2 surface-based inversions have been performed for the period 2005-2023 and satellite-based inversions have been performed for the period 2015-2021.

For N_2O and CH_4, the inversions cover the period 2005-2023, respectively. For CH_4, the posterior total European emission was very close to the prior estimate, but with major regional changes: agricultural emissions increased in Germany, France, and Benelux, while they decreased in the UK and Poland, compared to the prior. N_2O emissions increased from 1.0 to 1.5 Tg(N_2O)/year, with peaks in early summer and hotspots in western Europe. CO_2 inversions confirmed Europe as a carbon sink, averaging –0.34 PgC/year from surface data and –0.84 PgC/year from satellite data.

For more information see the deliverable D3.2 available here: https://eyeclima.eu/products/public-reports/



Mean N_2O posterior-prior flux difference from the CIF-FLEXPART inversion at the resolution of 0.5°×0.5° from 2005 to 2023.



Times series of annual estimates of CO_2 NEE + F_{LUC} from surface-based and satellite-based inversions, from 2005 to 2023 for EU27+3 countries (units PgC/year).

Deliverable 3.4: Final fluxes of CO_2, CH_4 and N_2O at 0.2° from 2018

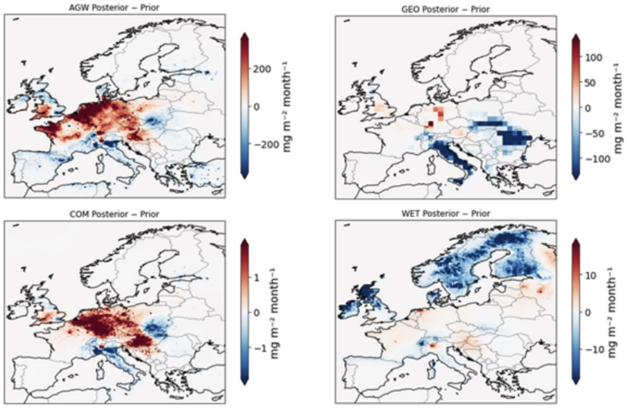
Final high-resolution regional inversions of CO_2, CH_4 and N_2O fluxes for Europe are presented.

For CH_4 (2018-2023), the results indicate that prior inventories were lower than the inversions for agricultural and combustion emissions in northwestern and central Europe, while higher in Italy, Romania and the UK. Geological and wetland emissions were adjusted downward relative to the prior, although seasonal patterns remained realistic.

For N_2O (2018-2023), posterior emissions were about 35% higher, with the largest upward corrections in northwestern Europe and reductions in northern Italy and parts of central–eastern Europe.

High-resolution CO_2 inversions (2019-2022) improved agreement with observations and indicate that European ecosystems act as a substantial carbon sink, with a posterior estimate of -0.78 PgC/yr. The CO_2 inversions will be extended to cover 2018-2023.

For more information see the deliverable D3.4 available here: https://eyeclima.eu/products/public-reports/

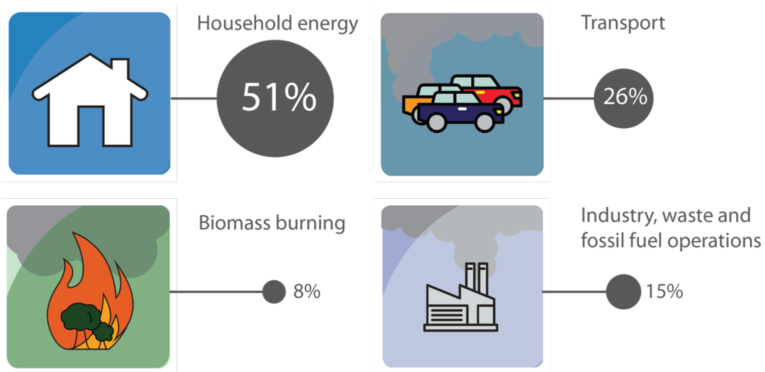


Mean spatial distribution of CH_4 estimates from CIF-FLEXPART inversions (2018-2023) at the resolution of 0.2°×0.2°. Posterior minus prior flux difference. Upper left: Agricultural emissions; Lower left: Combustion emissions; Upper right: Geological emissions; Lower right: Wetlands emissions. The blue areas indicate a downward adjustment of prior estimates, and the red areas indicate an increase.

Emissions of black carbon

Black carbon (BC) has a positive radiative forcing and thus contributes to global warming. However, it is also short-lived making it an interesting target for mitigating warming on short timescales, which would have benefits for air quality as well. The main sources of BC include road transport, household cooking and heating, and biomass burning.

The climate impact of BC is highly uncertain – spanning an order of magnitude and is likely to be as important as that of N_2O.



Contribution from different sources to global emissions of BC.

Global models run with BC emission inventories systematically underestimate radiation absorption by BC relative to observations, which is often attributed to an underestimation in BC emissions.

EYE-CLIMA estimates BC emissions from atmospheric observations using inverse modelling. One of the challenges of this is that BC measurements differ between methods and instruments. For this reason, EYE-CLIMA uses new harmonized observational data.

A further challenge is the large uncertainty in the modelled atmospheric ageing, which effects the particle's hygroscopicity and atmospheric lifetime. EYE-CLIMA uses a state-of-the-art atmospheric chemistry transport which includes representation of particle ageing and scavenging.

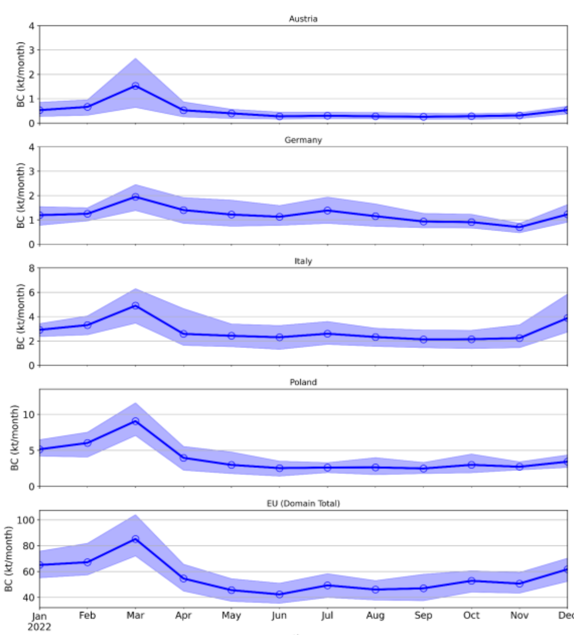
EYE-CLIMA also uses the differences in absorption properties for BC from different sources to attribute BC to two main source categories, i.e., traffic and non-traffic, which will help support the implementation of policies related to BC emissions.

Deliverable 3.8: Preliminary emissions of BC for Europe

This study used the FLEXPART-FLEXINVERT inverse modelling framework to estimate monthly black carbon (BC) emissions across Europe in 2022, based on harmonised atmospheric observations from European monitoring networks. A new log normal error approach was successfully implemented in the model.

The results show clear seasonal patterns, with higher emissions in winter, but also reveal unusually high BC emissions in north central Europe in March 2022. These differences compared with emission inventories are likely linked to spring wildfires, increased coal use, and energy supply disruptions following the Russia–Ukraine conflict, highlighting the value of inverse modelling during exceptional events.

For more information see the deliverable D3.8 available here: https://eyeclima.eu/products/public-reports/



Monthly inverse emission time series for the countries in the east-central part of the domain (a) Austria, (b) Germany, (c) Italy, (d) Poland that showed higher emissions in March, and (e) the whole domain. Solid blue line: average a posteriori emissions across all the inversions performed. Shaded regions: uncertainty ranges, 10th and 90th percentiles.

Deliverable 3.9: Methane inventory informed by TROPOMI

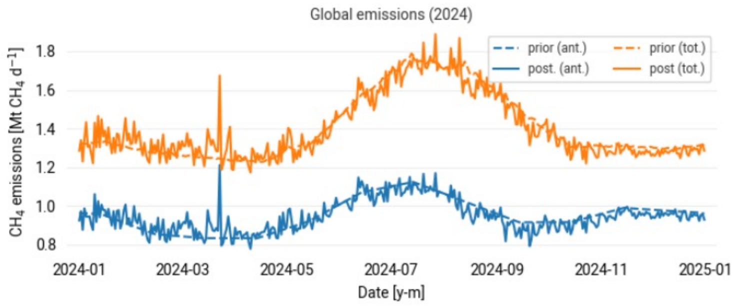
A global methane (CH_4) inversion for 2024 is presented, using ECMWF's IFS 4D-Var system which simultaneously optimizes meteorology, atmospheric CH_4 concentrations, and emissions. Satellite data from TANSO, IASI, and TROPOMI were assimilated to produce daily emission scaling factors.

Extending the assimilation window from 12 to 24 hours and including TROPOMI data improves detection of strong local emission events, though transient plumes remain difficult to capture.

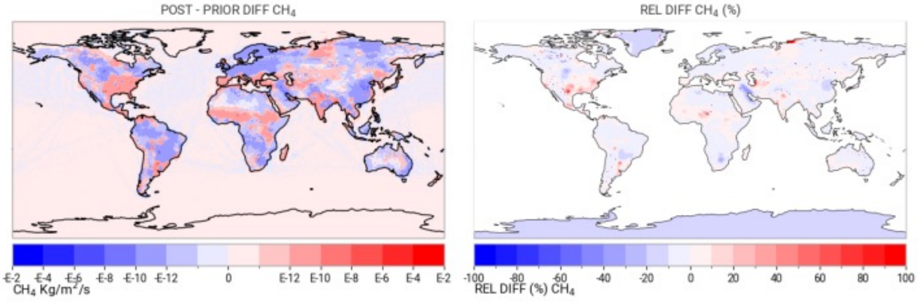
An upgrade of the IFS cycle (CY48R1 to CY49R1) showed minor global changes (<5%) but better agreement with observations.

Overall, global methane emissions were estimated at 550 Mt/year , only slightly lower than prior estimates, but with regional differences up to 40% in oil and gas producing areas.

For more information see the deliverable D3.9 available here: https://eyeclima.eu/products/public-reports/



Temporal variability in the global sum of prior (dashed lines) and posterior (solid) emissions for anthropogenic (blue) and total (orange) CH_4 fluxes. Ocean grid cells have been excluded from these time series.



Annual average CH_4 total emissions from IFS inversion at 0.25°×0.25° for 2024. Posterior minus prior flux difference (left), and relative difference as 100 × (post - prior)/prior (right).

Deliverable 4.2: Compilation of uncertainty estimates reported in national greenhouse gas inventories

A compilation of reported greenhouse gas (GHG) inventory uncertainties is presented, for 30 European countries (EU27, UK, Norway, and Switzerland) based on the 2025 submissions to the UNFCCC.

The combined uncertainty for EU27+3 in 2023 is estimated at ±5% of total GHG emissions (CO_2 equivalent), with variation across sectors. Land Use, Land-Use Change and Forestry (LULUCF) contribute the most (40%), followed by Agriculture (26%), Fuel combustion (23%), Waste (7%), Fugitive emissions from fuels (2%) and Industrial processes and product use (2%).

Between 1990 and 2023, the reported level of uncertainty has decreased both in relative values and in absolute values. The LULUCF sector is the main contributor to this uncertainty reduction, going from ±136% in 1990 to ±46% in 2023.

Sector	GHG	CO_2	CH_4	N_2O
1A. Fuel combustion	±3%	±1%	±26%	±16%
1B. Fugitive emissions from fuels	±37%	±44%	±48%	±57%
2. IPPU	±8%	±3%	±24%	±15%
3. Agriculture	±19%	±14%	±9%	±52%
4. LULUCF	±46%	±38%	±40%	±43%
5. Waste	±31%	±21%	±32%	±115%
Total - CRT 1 to 5	**±5%**	**±4%**	**±11%**	**±38%**

Summary of level uncertainties by sectors, in percentages, at EU27+3 level for year 2023.

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