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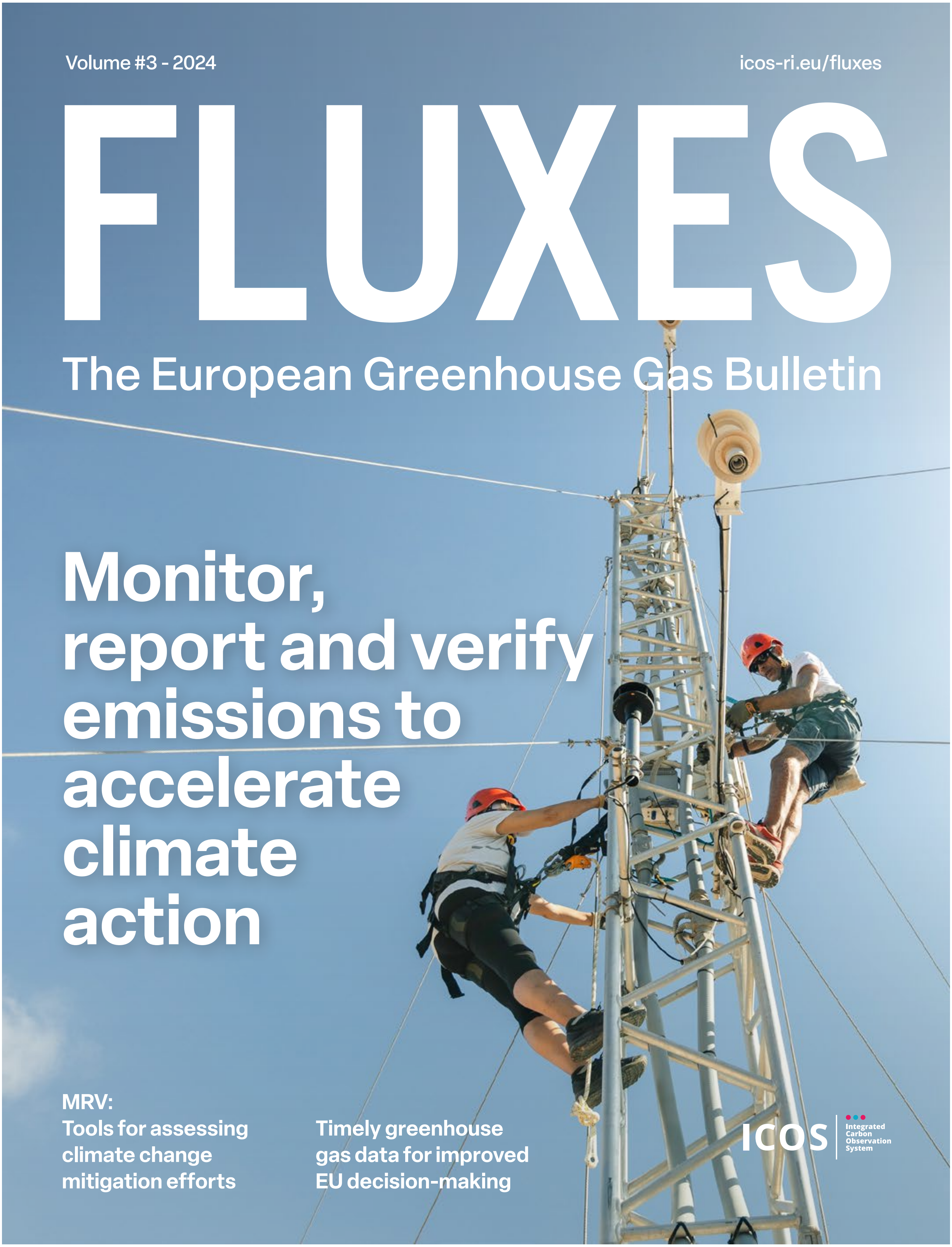
# FLUXES

## The European Greenhouse Gas Bulletin



# Monitor, report and verify emissions to accelerate climate action

**MRV:**
**Tools for assessing climate change mitigation efforts**

**Timely greenhouse gas data for improved EU decision-making**

ICOS Integrated Carbon Observation System

# FLUXES by ICOS

FLUXES is a yearly publication by ICOS, the Integrated Carbon Observation System. The aim is to highlight climate issues to policy advisers and climate journalists. The first volume was published in 2022.

ICOS is a Europe-wide greenhouse gas research infrastructure. It produces standardised data on greenhouse gas concentrations in the atmosphere as well as on carbon fluxes between the atmosphere, ecosystems and oceans. This knowledge supports policymaking and decision-making to combat climate change and its impacts.

The high-quality ICOS data is based on measurements from 179 observation stations – run by top universities and research institutions across 16 European countries and is produced by nearly 800 scientists.

The ICOS Carbon Portal offers unlimited access to thousands of datasets and other advanced digital products as well as services. ICOS has European Research Infrastructure Consortium (ERIC) status with a legal capacity recognised in all countries within the European Union.

icos-ri.eu

Cover photo: Pekka Pelkonen, ICOS RI

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In this edition



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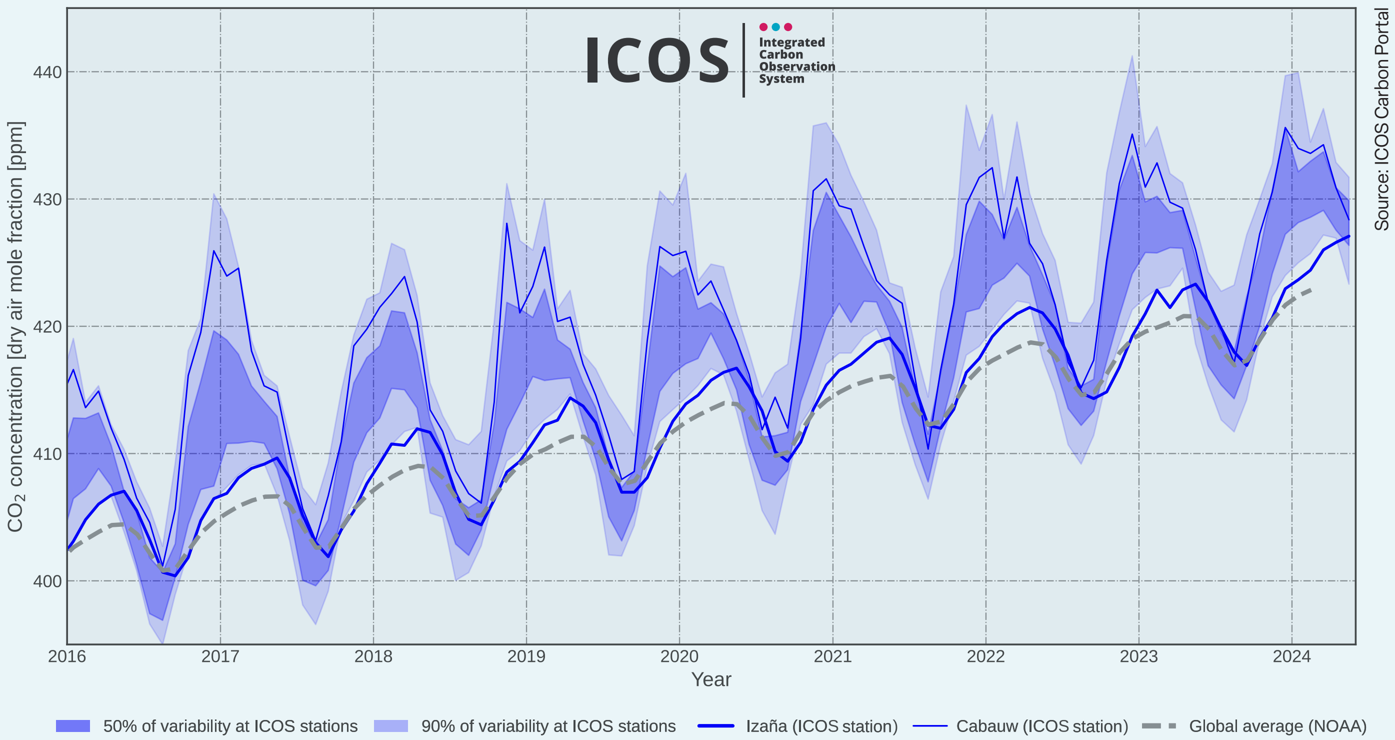
**$CO_2$ observations at 39 ICOS stations and global average**




## Atmospheric $CO_2$ concentrations are inexorably increasing

Latest ICOS data displays an annual growth rate of 2.7 ppm $CO_2$ in the atmosphere during the year 2023. Most of this increase is due to fossil fuel emissions which were still not reduced.

The ICOS network of systematic observations and near-real-time monitoring of greenhouse gases gives information on fossil fuel emissions. It also reveals how the natural carbon cycle responds to extremes and explains the slight increase in 2023 compared to previous years. The climate phenomenon El Niño influenced the natural carbon fluxes. Consequently, more of the $CO_2$ from fossil fuel emissions remained in the atmosphere and the atmospheric growth rate increased.

> “Latest ICOS data displays an annual growth rate of 2.7 ppm $CO_2$ last year, showing that fossil fuel emissions were still not reduced during 2023.

The graph shows the compiled results from 39 stations in the ICOS Atmosphere measurement network. All the stations show the global trend of a 2-2.5 ppm increase in $CO_2$ per year, in addition to the seasonal changes. This increase results from continued fossil fuel emissions.

The dark purple area in the graph shows typical $CO_2$ concentrations for Europe from about half of the ICOS stations each month.

The lighter purple areas include the remaining stations, of which 25% are above the dark purple range, and 25% are below.

Two of the measurement stations, Izaña and Cabauw, are located in environments representing two extremes and, therefore, showing bigger variations in emission patterns. The mountain station Izaña in Tenerife, Canary Islands, is representative of so-called background conditions, far from human-induced emissions. In contrast, the Cabauw station is located in between the triangle of the major cities of Rotterdam, Utrecht and Amsterdam in the Netherlands.

**DR WERNER L. KUTSCH**

Director General of the Integrated Carbon Observation System (ICOS)

Almost weekly, we hear about floods, droughts, heat waves and the related loss and damage including public health emergencies. Climate change is progressing and the time to act is now. The truth is not in glossy speeches made at international conferences, like COP28, the truth is in the atmosphere. Global warming is caused by excessive concentrations of greenhouse gases and the inconvenient truth is that these continue to rise unabated (see the figure on the left).

Almost a decade after the Paris Agreement, we still see increasing fossil fuel emissions every year. While the window for action is closing, the world is still waiting for a real turnaround in fossil fuel emissions and the decarbonisation of economies.

Over the last few decades, the scientific knowledge about greenhouse gases and our capacity to observe concentrations and fluxes has grown significantly. Scientists now have a large toolbox to support societies in their efforts to curb fossil fuel emissions. In addition, researchers can help identify the best ways to remove greenhouse gases from the atmosphere.

In this edition of FLUXES, we want to open this toolbox and explore how science-based Monitoring, Reporting and Verification (MRV) systems are part of the solution. This is not trivial – there are many different perspectives on what MRV systems are:

> “Science supports societies in being efficient in their climate actions.

**Monitoring** (or measurement) refers to data and information regarding emissions. Depending on the MRV system in question, this could be measurements of greenhouse gases or emission estimates. The UNFCCC system uses emission inventories based on statistical data on activities and related emission factors, while scientific approaches use observations of greenhouse gas concentrations in the atmosphere, for example.

**Reporting** is the act of compiling this information into inventories and disseminating them (e.g. to the UNFCCC). This ensures that the monitored information can be accessed by a variety of users. Scientific reporting may happen via the IPCC or independently by NGOs, such as the Global Carbon Project.

**Verification** is, within the UNFCCC process, the act of another party independently verifying the reported information to ensure accuracy. Scientifically, the term also includes the reconciliation of reported inventories and greenhouse gas observations, meaning that an independent parameter (e.g. greenhouse gas concentration in the atmosphere) ‘verifies’ the reported inventory of a country or region which helps improve its accuracy.

All of this means that MRV is a critical tool for tracking climate action and empowering countries to improve their progress in reducing greenhouse gas emissions. In this volume of FLUXES, we are exploring how research, systematic observations and ICOS scientific community can be of support in employing MRV systems. ■

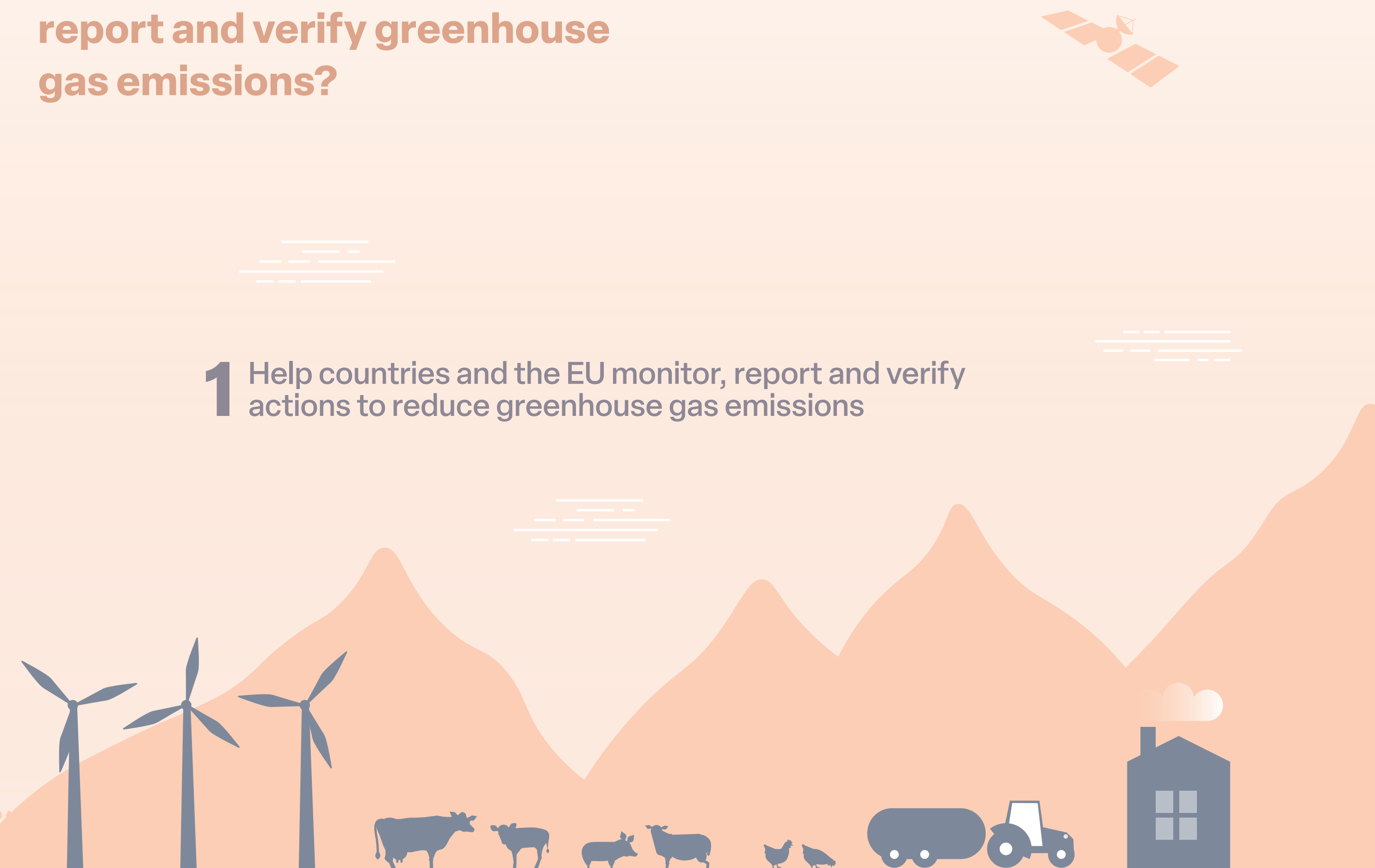
Monitoring, Reporting and Verification (MRV) systems

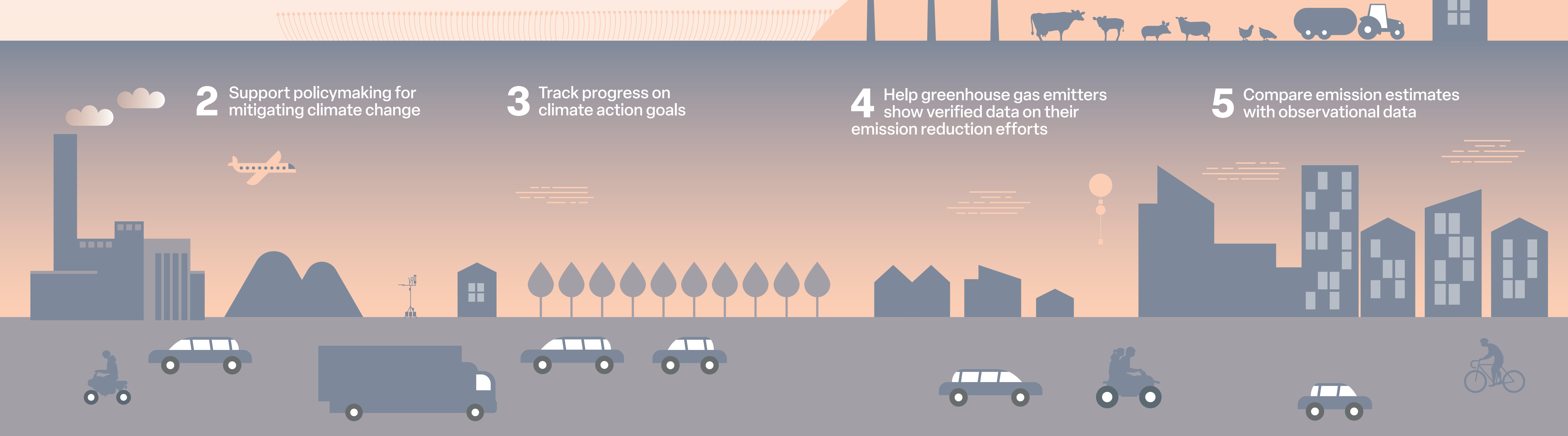
# A critical tool for tracking climate action progress

The world needs to drastically reduce its greenhouse gas emissions to avoid the worst impacts of climate change. But how can we confidently measure the effectiveness of our efforts? Monitoring, Reporting and Verification (MRV) systems could provide the answer.

By Peter Taggart

## Why is it important to monitor, report and verify greenhouse gas emissions?



## Key takeaways

- MRV systems are science- and procedure-based, and help countries, cities, organisations and companies monitor, report and verify their individual and collective actions to reduce greenhouse gas emissions.
- MRV systems are designed to complement and support existing reporting procedures, such as the UNFCCC inventories.
- Everyone benefits from MRV systems because they operate on a local, national and global scale.
- MRV systems require long-term investment – financial, technical and personnel – to function.

Countries need to monitor, report and verify what they are doing individually and collectively to reduce greenhouse gas emissions. At its core, an MRV system is designed to do just that, supporting policy and actions to mitigate climate change.

## Who benefits from monitoring, reporting and verification of carbon emissions?

Despite its origins, the term 'MRV' is not limited to the realm of national inventories. Robust, observation-based MRV systems benefit decision makers on the local to global scale:

**Local and regional level:** Cities and regions often have climate action plans in place as well as established MRV frameworks to track progress, assess their climate actions and report on their carbon reduction targets. MRV systems, particularly observation-based MRV systems located in urban areas, have the potential to support and complement other existing frameworks.
**Businesses**: Companies need to show their stakeholders verified data on their efforts to reduce emissions or their measures to remove carbon dioxide from the atmosphere. They also use data to participate in emission trading systems or carbon markets.
**National governments**: Observation-based MRV systems can help countries track their progress on a variety of climate mitigation plans and policies, such as carbon farming systems.
**The European Union**: The EU has ambitious emissions reductions targets – a recent, non-binding proposal by the European Commission could see the region aim to cut net emissions by 90% by 2040 compared to 1990 levels. These sorts of targets cannot be achieved without effective 'follow-up' systems. MRV systems make it easier to track progress.
**Globally**: The Global Stocktake, a United Nations-led process in which countries and stakeholders assess collective progress towards meeting the Paris Agreement goals, requires methods beyond the national inventories.

## How can observational data play a part in MRV?

Observations are direct measurements of the concentration of greenhouse gases in the atmosphere at a certain moment, most commonly carbon dioxide and methane.

Using observational data in MRV systems is beneficial because the combination of information from ground-based networks and satellites provides a pattern of greenhouse gas concentrations over space and time. That data contains valuable information about gas exchanges (fluxes) between land, oceans and the atmosphere.

Analysing these patterns provides important knowledge on fossil fuel emissions and more.

"For me, MRV is a capacity to make use of atmospheric observations - this would be the monitoring part," explains Dr **Marko Scholze,** Senior Lecturer at the Department of Physical Geography and Ecosystem Science at Lund University.

"In a nutshell, MRV allows you to see if you can reconcile whatever you estimate from models using atmospheric records (data) with reported emissions (inventories)."

Observation-based MRV systems are not designed with the intent of replacing inventories. Instead, they have the potential to improve inventories. One example of observations-based MRV enhancing national reporting comes from the United Kingdom.

Photo Met Office

Observation-based MRV systems have the potential to improve inventories, says Professor Alistair Manning.

"For the last two decades, the Met Office has been developing the Inversion Technique for Emission Modelling," says Professor **Alistair Manning** at the University of Bristol and the UK Met Office.

"Our measurements showed that hydrofluorocarbons – powerful greenhouse gases found in refrigerators and air conditioners that replaced ozone-depleting gases like chlorofluorocarbons (CFCs) - declined much more sharply than the UK's inventory reported for the same period. This finding prompted questions about the UK's inventories' counting methodologies," says Manning and continues:

"Are we counting something incorrectly? Do we need to invest in a better understanding of the hydroflurocarbons emissions from a certain sector?"

In other words, this observation data prompted the UK government to reassess elements of their inventory methodologies, thereby strengthening their annual reporting to the UNFCCC.

"MRVs are simply another tool to improve a country's inventories – not to replace them!" adds Manning.

> "MRVs are simply another tool to improve a country's inventories – not to replace them.
>
> Professor Alistair Manning

## Challenges of establishing MRV systems

MRV systems are not simple to set up and maintain, particularly from a global perspective. There are challenges which need to be addressed, such as establishing models, resolving regional gaps in data provision and ensuring MRV systems are supported by proper infrastructure and funding.

Understanding the function and longevity of an MRV system is one hurdle. "An MRV system requires research to function, but it should not be run as a research project. An MRV can't be run on, say, a five-year research grant and then be over. It requires operational staff to support and maintain it long-term," explains Scholze.

There are also methodological questions to solve when setting up MRV systems.

"When we measure atmospheric concentrations, either by using ground-based or satellite observations,

## What is MRV?

**Monitoring** (or measurement) refers to data and information regarding emissions. Depending on the MRV system in question, this could be measurements of greenhouse gases or emission estimates.
**Reporting** is the act of compiling this information into inventories. This ensures that the information being monitored can be accessed by a variety of users.
**Verification** is the act of a third-party independently verifying the reported information to ensure accuracy.

we need a model that links these concentration measurements to emissions and natural fluxes at the surface. Then we need additional models for the ocean and terrestrial carbon cycle, and for various kinds of human-induced emissions on land, such as those caused by land use or by burning fossil fuels, for example," says Scholze.

Alongside this, directly measuring all types of emissions is a hard task to accomplish, says Dr **Richard Engelen**, Deputy Director of the Copernicus Atmosphere Monitoring Service (CAMS) at the European Centre for Medium-Range Weather Forecasts (ECMWF).

"While we might be able to make direct observations from point sources, such as factories or heating facilities, this becomes much more difficult when trying to measure emissions from cars, for instance," he explains.

Running long-term MRV systems that incorporate observations requires high technological knowledge of the personnel. MRV systems also require financial support. In Europe, the EU funds several MRV projects which are moving towards becoming operational systems. Financial support is essential to purchase the supercomputers required for computation, data handling and storing many terabytes of data.

When incorporating observations into a global MRV system, these challenges take on a new dimension. Some parts of the world, such as Europe and North America, have well-developed ground-based observation networks and the people to operate them but even these have gaps in their coverage.

Meanwhile, some regions would need to find ways to develop networks. This is not just in terms of physical installations but also concerns the development of data pipelines and modelling systems with well-trained personnel.

In spite of these challenges, the number of independent observation-based MRV projects has grown in recent years. Initiatives like the Global Greenhouse Gas Watch (see page 48) benefit from the significant strides that have been taken already towards establishing observation-based MRV systems. ■

Photo: Pekka Pelkonen, ICOS RI

Kyriaki Papoutsidaki is checking samples from the ICOS Finokalia station in the university laboratory in Crete, Greece. Running MRV systems based on observations requires high technological knowledge of the personnel.



## Setting up MRV systems

**NOT A RESEARCH PROJECT**
MRV systems are not temporary research projects – they should be operated long term

**FUNDING**
Funds are required to employ staff, purchase supercomputers and set up the data centres

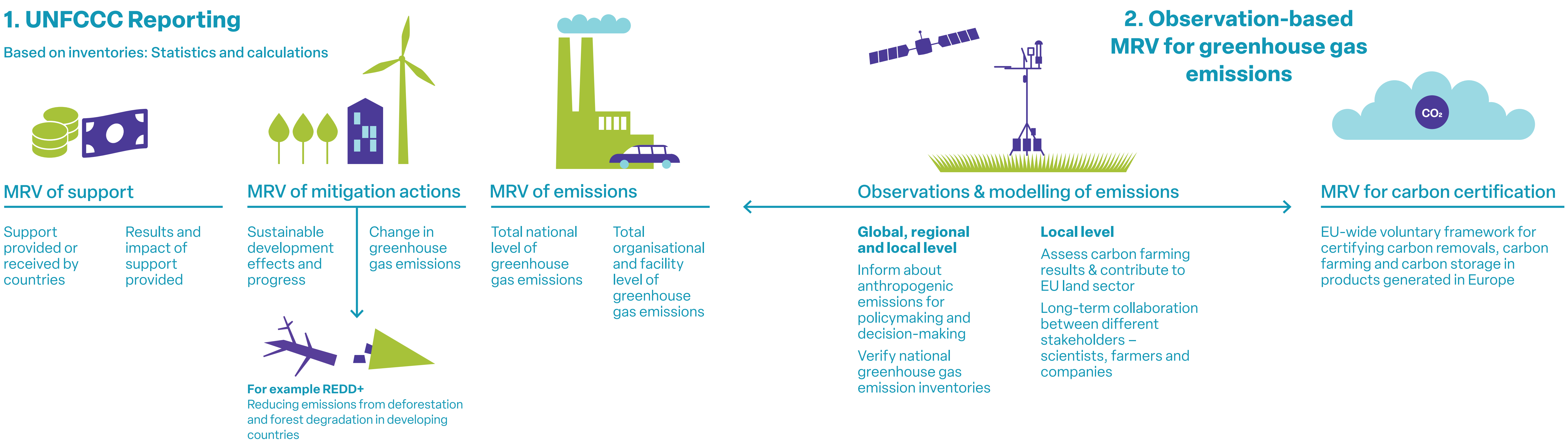
**NON-STATIC POINTS**
Typically, ground-based sensors are at fixed locations, and so it is hard for them to measure emissions from sources that move, like ships or aeroplanes

**DATA STORAGE CAPACITY**
Models require high-performance computing capacity to carry out complex calculations, and many terabytes of storage capacity is needed to store the data

**TRAINING AND EXPERTISE**
Not just anyone can run an MRV system – the staff needs specific expertise and knowledge to run the system on a regular basis

**GEOGRAPHICAL & GLOBAL DISPARITY**
Some parts of the world have a well-developed network of ground-based measurement stations and the trained staff to run them, while others lack this.

## Monitoring, Reporting and Verification (MRV) types




# The rise of greenhouse gas inventories and observations

In 1992, governments around the world agreed to act together to stabilise the amount of greenhouse gases in the atmosphere. This created a need to measure emissions.

Such a complex task required new systems and tools, as well as guidance. Governments requested guidelines from the Intergovernmental Panel on Climate Change (IPCC) on how they could calculate their emissions over a period based on national data on activities, processes and using appropriate emission factors.

These are best known as National (Greenhouse Gas) Inventory Reports which are provided to the United Nations Framework Convention on Climate Change (UNFCCC). Countries produce these reports using statistical data, broken down into emissions from six sectors: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land Use, Land-Use Change and Forestry (LULUCF), and Waste. Verifying these reports is a complex process linked to legislative and accounting practices.

In short, this was the starting point of MRV. Since then, MRV systems have developed into three main categories:

- **MRV of greenhouse gas emissions** (e.g. the emission inventory): The countries report these to the UNFCCC.
- **MRV of mitigation actions** (e.g. policies and projects): Inventories are used to define Nationally Determined Contributions (NDCs) and national climate action plans.
- **MRV of support** (e.g. climate finance and capacity building): Countries monitor the financial support provided towards mitigation efforts and building capacity.

**Independent, observation-based MRV**

A number of independent approaches to MRV have developed outside the UNFCCC. For instance, there are databases on emissions such as the European Commission's Emissions Database for Global Atmospheric Research (EDGAR). Other systems use atmospheric concentration data and inverse modelling to reconcile inventories and data from the atmosphere, such as the Monitoring and Verification Support system developed by Copernicus (the Earth Observation component of the European Union's space programme).

Alongside these, ICOS provides observational data that can support these MRV systems. For the inventories, ICOS data is used to improve emission factors. The Copernicus system also uses ICOS atmospheric data to verify its inverse modelling. Meanwhile, ICOS ecosystem and ocean data are used to calculate natural greenhouse gas exchanges between the air and the ocean or ecosystems. This gives valuable input to the inverse modelling as it integrates all emissions from an atmospheric perspective.

Read the story: Greenhouse gas inventories
Page 16

## Disparity between different domains

**Observation-based MRV systems have not developed equally in all fields. While there are developments and projects based on atmospheric observations, ecosystem and ocean observation MRV systems are not as advanced for a number of reasons.**

"One of the underlying reasons behind this disparity comes down to countries' reporting requirements," suggests Professor Alistair Manning from the UK Met Office. "Let's look at oceans. Countries have to report their own emissions, so why would they report emissions from, say, the mid-Atlantic, if they don't have to? They are not required to go beyond their borders."

"More generally, most human-related emissions take place over land and are required to be reported. Processes like ocean fluxes have no formal reporting requirements and so they are given far less attention," he adds.

For the land ecosystem, the story is different. "LULUCF is an important sector in official reporting, and so ecosystem modelling is extensively investigated," says Manning.

"But ecosystem modelling is really tricky because there are many significant uncertainties - the respiration of trees at night, the activity of bugs in soils, the list goes on. Things change by the hour. Therefore, it is really hard to upscale information from small field trials to the national level."


Photo: Pekka Pelkonen, ICOS RI

Giorgio Alcide di Sarra and Damiano Sferlazzo installing the new flask sampler at the Italian Lampedusa atmosphere monitoring station in the ICOS network. The flask sampler is used to collect air samples and calibrate equipment at certain ICOS stations, while also detecting fossil fuels in the $CO_2$ measured. This way, scientists can distinguish the origin of the $CO_2$.

# The Greenhouse Gas Inventories - calculating country-level emissions

**In the labyrinth of climate data, where every number tells a story, the national greenhouse gas inventories serve as an important information source for the Global Stocktake. The inventories typically rely on estimations, but ground-based measurements can contribute to the verification of these.**

By Charlotta Henry

Estimates, data and reports form the scientific core of the Global Stocktake (see page 42). At the centre of this operation are the national greenhouse gas inventories. **Dirk Günther**, the Head of the Emission Situation Section at the German Environment Agency, explains how the inventories are produced:

"We calculate emissions based on national official statistical data. The calculation is pretty simple. We take the activity data, for example the amount of produced steel, animals in the agricultural sector and the amount of coal burned in power plants and multiply this with a specific emission factor of a gas or pollutant."

The greenhouse gas inventories are the monitoring and reporting building blocks of the UNFCCC MRV system. The verification consists of an international technical review of the inventories by a team of international experts that produces a report for each country with recommendations or encouragements.

"The inventory needs to be transparent, and the calculation has to be plausible. One also needs to be able to follow how the calculation has been made. The calculation needs to be accurate and comparable," Günther explains.

## Statistics versus measurements

The greenhouse gas inventories not only show what the countries are releasing into the atmosphere in terms of emissions but also calculate carbon sinks and carbon removal from land use change and forestry. In Germany, this is done every decade. In between, a forest carbon stocktake is also done every five years and carbon removals are calculated on an annual basis using official forest and timber statistics.

"Every 10 years, we do an inventory of our forests with actual measurements, where people go to the woods, measuring the trees on certain reference points. Then, there is a model for calculating the increase or decrease of the forest sinks based on the statistics, the harvesting and weather extremes," says Günther.

Actual measurements and observational ground-based data can also add to the estimations and calculations of the greenhouse gas inventories. However, for most emission categories, the calculation is more accurate than the observation:

"Ground-based observations cannot distinguish whether the methane emission source is the cattle farm or the waste disposal site. In the iron and steel industry, we have to distinguish between five different sources from steel plants. An observation could never distinguish these five sources because it is just one attribute."

If the inventory reports higher emissions of methane for example, the observational data cannot show why there is an increase. This requires other statistical data and/or models. Combining both observational data, estimates and calculations is the best method, according to Günther.

"Measurement data is already really good for the verification of the inventories. If you're talking about the verification of national totals, then you can compare," says Günther.

"We observed this amount of methane and the calculation from the inventories gives another number, then you can try to explore. What is the reason for the differing numbers?" ■

Photo: German Environment Agency

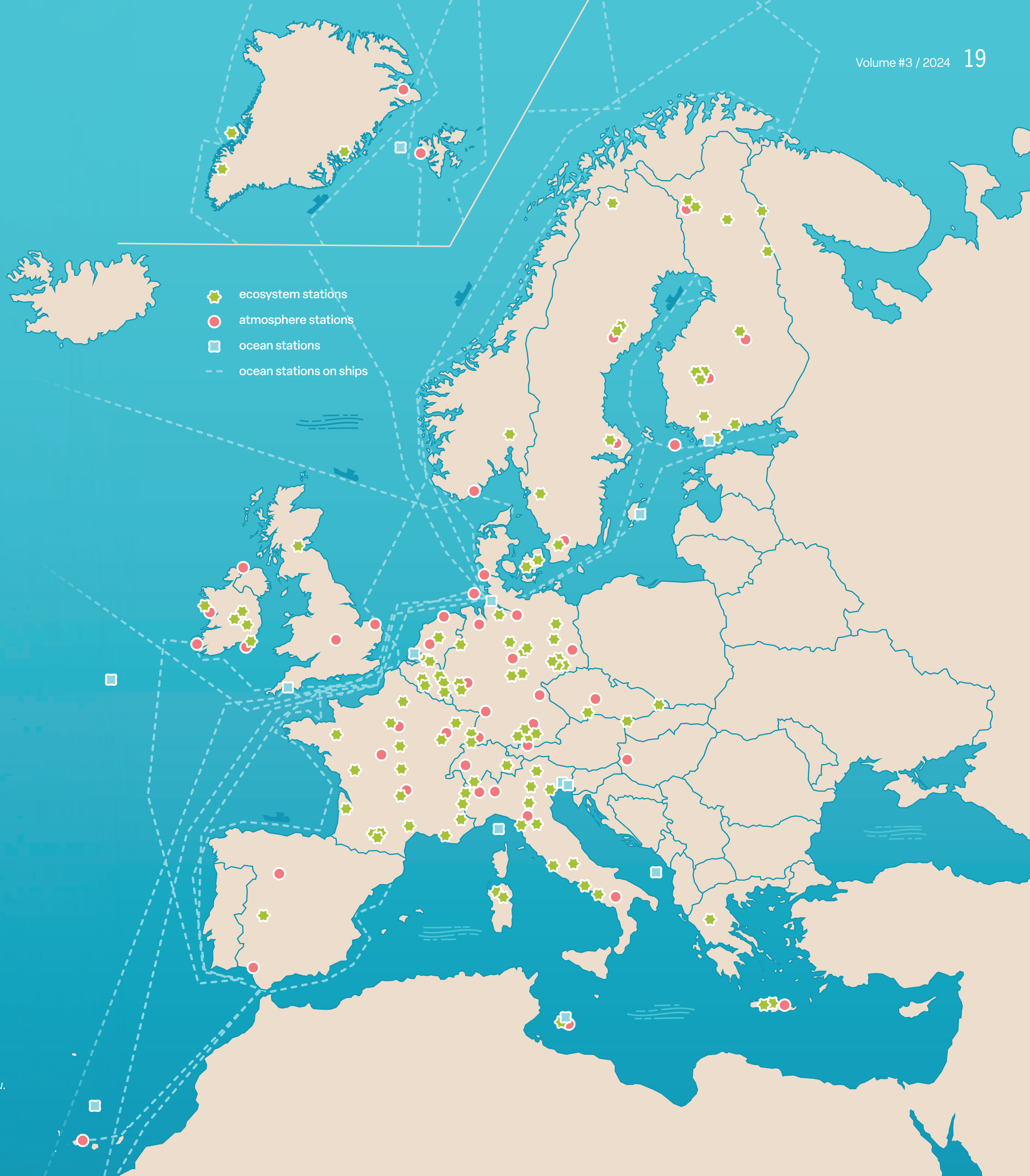
Frederik Pischke and Dirk Günther at the German Environmental Agency are both involved in the Global Stocktake process. According to Günther, combining observational data, estimates and calculations gives the most reliable results.

# The truth is in the atmosphere

The fight against climate change calls for accurate data on greenhouse gas emissions. The ICOS network of observation stations, spread across diverse environments in Europe, addresses the challenge by providing near-real-time greenhouse gas data for research and climate models. This helps shed light on how human actions drive climate change.

By Maria Luhtaniemi

ICOS (Integrated Carbon Observation System) is a European research infrastructure with a network of nearly 180 stations in 16 countries, measuring greenhouse gas concentrations with the aim of improving the accuracy of climate models.




*An illustration of the ICOS station network in Europe (not to scale). The full map is available on icos-ri.eu.*

## Key takeaways

- ICOS produces high-quality greenhouse gas data from the atmosphere, ecosystems and oceans from close to 180 measurement stations across Europe.
- High-quality observational data can reduce uncertainties in greenhouse gas inventories and increase understanding of natural fluxes.
- ICOS' data and expertise are also used to understand the impacts of carbon farming. This information is key in incentivising landowners to engage in more sustainable practices.

National greenhouse gas inventories are the main way for countries to estimate their emissions. The inventories, compiled using guidelines from the Intergovernmental Panel on Climate Change (IPCC), are an annual calculation of the greenhouse gas emissions and removals, generated in certain sectors in a country's territory.

However, such inventories typically include uncertainties due to the complexities of estimating and quantifying emissions from multiple sources across different sectors. They also focus more on human impact and less on natural fluxes, such as gas exchanges between ecosystems and the atmosphere.

This is where the Integrated Carbon Observation System (ICOS) comes in, providing independent data from atmospheric observations to support the inventories.

"Natural fluxes are a complex beast. If we want to understand what is going on in the atmosphere, we need information on human emissions and on natural fluxes," says Dr **Werner Kutsch**, Director General of ICOS.

"Even though there is some uncertainty in the fossil fuel emission inventories, the bigger uncertainty is in the natural fluxes. The uncertainties can be addressed through modelling using ICOS ecosystem flux data," he adds.

## High-quality observational data can reduce uncertainties in inventories

ICOS provides near-real time greenhouse gas data from the atmosphere, ecosystems and oceans from nearly 180 measurement stations in 16 countries in Europe and beyond.

The idea is to create more accessible data by following what is known as the FAIR principle – that data should be Findable, Accessible, Interoperable and Reusable for machines and people.

"ICOS observational data finds its way into the inventories and MRV systems in many ways, through science, emission factors, inverse modelling and through projects developing concrete services," explains Kutsch.

The ICOS ecosystem stations are located in a wide range of environments, from forests to wetlands, and crop sites to grasslands. These contribute to various MRV systems with reliable and standardised greenhouse gas data.

Alongside this, the research infrastructure also measures emissions in urban areas through its EU-funded ICOS Cities project. Cities are hotspots for emissions, making it crucial to measure them.

"ICOS offers high-quality, standardised and open greenhouse gas measurements from different regions in Europe. In the MRV4SOC project (see page 28), we are able to use ICOS data to increase the accuracy of our estimations and provide more reliable results," says Dr **Marta Gómez-Giménez**, a Remote Sensing Specialist and Coordinator of the MRV4SOC project, which monitors carbon farming in 14 demo sites across Europe.

"With standardised data and approaches, we will be able to build a robust MRV system for the EU land

> Natural fluxes are a complex beast. We need information on human emissions and natural fluxes.
>
> Dr Werner Kutsch

Photo: Nele Van Schoor

Tim De Meulder (left), Principal Investigator of the ICOS Westmalle station and Dr Marilyn Roland, Station Manager of several ICOS Belgium stations, are measuring the impacts of carbon farming.

sector. Moreover, with open data, we will reduce the implementation cost. All in all, the ICOS network has great potential to complement other key data sources to monitor, report and verify carbon removals," Gómez-Giménez continues.

The demo sites include five ICOS stations: Hurdal in Norway, and Brasschaat, Dorinne, Lonzée and Westmalle in Belgium.

"The contribution of the ICOS scientists from the demo sites has been very useful. They will help the MRV4SOC-project make the most of the available datasets," she adds.

### Increasing understanding of carbon farming

On top of supporting greenhouse gas emission inventories and contributing to MRV systems, ICOS data can also be used to understand the effectiveness of carbon farming. This approach, where land use practices aimed at increasing carbon stored in vegetation and soil are rewarded, is seen as a crucial way for the agricultural sector to contribute to climate change mitigation.

However, it is also important to keep track of its successes. For example, the ICOS Westmalle station in Belgium is running a long-term experiment to measure the impacts of carbon farming. The field is split into two areas: one with carbon farming practices and the other managed in a business-as-usual manner. The difference is then measured by comparing the parallel eddy covariance setups of each field.

"On the business-as-usual side, there is a rotation of maize, followed by a winter crop. But on the experimental side, we try to improve the crop rotations by including more permanent crops that can grow all year round, or by growing crops with deeper roots, so carbon can be stored deeper in the soil," explains **Tim De Meulder**, Principal Investigator at the Westmalle station.

"Then, there are crops such as clover, beans and peas which can be ploughed under the soil when the main crop is harvested to increase the amount of carbon in the soil," he continues.

Dr **Marilyn Roland**, who manages several ICOS stations, including Westmalle, believes the station's research has the potential to inform carbon farming practices in Belgium and beyond.

> "Research can help create more knowledge so that people can adapt carbon farming practices to their context, whether it is the size of the farm, the climate or other conditions in their country.
>
> Dr Marilyn Roland

Measurements made using the eddy covariance method are particularly interesting for developing an MRV for carbon farming.

The technique, central to all ICOS ecosystem stations, measures the exchange of $CO_2$ between terrestrial ecosystems and the atmosphere. This is key to get a high level of accuracy.

"Eddy covariance measurements can play a big role in MRV because they are such a good way to accurately measure carbon sequestration. This is something that is really in demand in Europe right now," Roland says.

Measuring the success of carbon farming is key as landowners are increasingly interested in it.

"The landowners are quite eager to collaborate with us and become more sustainable because agriculture has gotten such a bad name in terms of its climate impacts in the recent years. There is a big movement among the farmers that is striving to change that," she explains.

"Research can help create more knowledge so that people can adapt carbon farming practices to their context, whether it is the size of the farm, the climate or other conditions in their country," she adds. ■

# ICOS can contribute to a science-based monitoring system

Carbon removals refers to the process of removing carbon dioxide from the atmosphere and storing it for a long period in technical reservoirs or naturally in biomass or soil organic matter. The European Union is currently developing a carbon removal certification system to verify these.

Under the EU Carbon Removal Certification Framework, carbon removals would need to be correctly quantified, ensure long-term storage, prevent leaks and contribute to sustainability. Assessing all these aspects requires a robust methodology, which in turn, could become the basis for a related monitoring, reporting and verification (MRV) system. The question is how to create this.

"A successful MRV system is a dilemma. It needs monitoring tools that are simple and inexpensive when it comes to concrete measures, yet it needs to be comprehensive, accurate and transparent," says **Werner Kutsch**, Director General of ICOS.

"All aspects are, however, hard to achieve: A too-simple system might be cheap but also prone to fraud or large uncertainties. On the other hand, highly sophisticated monitoring would be too expensive and consume all the money that could be gained by a certificate."

In Kutsch's opinion, an independent MRV system for carbon removals would combine the monitoring of a concrete measure (e.g. at a farm) with broad scientific knowledge and a sophisticated monitoring system that quantifies the carbon removal of this measure.

ICOS could help design such a system. It is already carrying out high-quality monitoring of the necessary parameters and has the competence for analysis and guidance. ICOS could provide a scientific reference service but would not carry out the actual verification cases.

Assessing carbon removals from carbon farming is an example of where ICOS could be useful.

"As there will be no one-size-fits-all-solution, we should perhaps consider connecting the level of uncertainty to the amount of monetary compensation," says Kutsch and continues:

"Ideally, there would be a combined solution where accurate but expensive monitoring programmes, similar to those at existing ICOS ecosystem sites, are applied to a few removal effort sites that are willing to host such programmes. These would then serve as a testbed to quantify the average result and the uncertainty of measures."

This quantification process could be combined with models and a hierarchy of cheaper and simpler monitoring programmes, such as repeated soil stocktakes.

"The advantage of such a system is the financial decoupling of the MRV costs from a single, concrete certificate and yet keeping highest scientific standards," says Kutsch. "Even the risks of droughts, etc. could be incorporated."

The required resources for an MRV system should be collected in a fund, Kutsch concludes:

"Given the volume of the market, a 1 % fee on each certificate paid to this fund may be sufficient to support a comprehensive scientific MRV system."

This initial idea, the levels of sophistication and methods for assessing the uncertainty as well as possible funding will be developed in the upcoming years in a Horizon Europe project called IRISCC.

Photo: Pekka Pelkonen, ICOS RI

Case studies:

# Successes and challenges when using MRV

Scientists across Europe are developing effective Monitoring, Reporting and Verification (MRV) systems, relying on high-quality data. New projects showcase tools to monitor emissions from human activities, and develop methods to monitor soil organic carbon under different local climate conditions and climate change scenarios.

By Maria Luhtaniemi

## Key takeaways

- Two EU-funded projects, MRV4SOC and CoCO2, aim to create a solid scientific base for MRV.
- MRV4SOC focuses on creating a monitoring system for soil organic carbon. The results will help establish an MRV system for the EU's land use sector.
- The CO2MVS, created within the CoCO2 project, monitors human-induced greenhouse gas emissions through ground-based and satellite measurements and computer modelling.

MRV systems are developed for a wide range of uses: to help countries verify their national greenhouse gas inventories, to report the results of a certain climate mitigation action or to monitor the impacts of carbon farming. Some processes are more community-driven and local, while others aim to provide a bigger picture and serve entire regions and countries. Some focus on verifying activities for the carbon credit market, while others focus on fixing uncertainties in the inventories.

Significant contributions to the improvement of MRV systems have recently been made in two projects funded by the European Commission: CoCO2 and MRV4SOC. The projects aim to create a solid scientific base for MRV.

CoCO2 created the prototype for the Copernicus $CO_2$ Monitoring and Verification Support system, CO2MVS for short. This new European service will monitor human-induced greenhouse gas emissions. The other project, MRV4SOC, focuses on creating a monitoring system for soil organic carbon.

FLUXES spoke to the project coordinators to find out what challenges the projects aim to solve, how they are reaching their goals and how they plan to scale up results – read the Q&As on the next spreads.

> “Our first challenge was the lack of a standardised methodological approach for measuring carbon stocks across various land use classes and management practices.
>
> Dr Marta Gómez-Gimenéz

## ICOS data complements greenhouse gas inventories

Several countries in Europe, including Switzerland and the United Kingdom, are independently complementing their greenhouse gas inventories using measurements, i.e. with a top-down method. This approach, called inverse modelling, uses precise, high-frequency atmospheric measurements of greenhouse gas concentrations, along with a computer model, to show how the gas moves from its source to where it is measured.

In 2003, the United Kingdom became the first country to independently compare its inventories with direct measurements. It uses observations from various sites, including two ICOS Atmosphere stations: Ridge Hill and Weybourne. Data from the ICOS Atmosphere station in Mace Head, Ireland, is also used.

Photo: Pekka Pelkonen, ICOS RI

Some MRV systems focus on verifying activities for the carbon credit market, while others focus on fixing uncertainties in the inventories. The ICOS Lison station in northern Italy is located in a vineyard, where the team continuously measures the carbon budget. Here, Monica Canton is measuring the chlorophyll content in the plant.

# 5 questions to the scientists

## Q&A Monitoring soil organic carbon to support carbon farming

The MRV4SOC project aims to monitor the changes in organic carbon in soil, caused by climate change and land management practices. The goal is to standardise MRV systems in the EU's land sector and, ultimately, establish a methodological MRV framework to increase trust in voluntary carbon markets.

The project uses data from 14 demo sites across Europe, five of which are greenhouse gas measurement stations in the ICOS network. These are the forest station Hurdal in Norway and four sites in Belgium: a forest station in Brasschaat, a grassland station in Dorinne, and two cropland sites, one in Lonzée and the other in Westmalle. The ICOS stations, in particular, contribute significantly to increasing the understanding of carbon farming practices.

FLUXES spoke to Dr **Marta Gómez-Giménez**, Coordinator of the MRV4SOC project and Project Manager & Remote Sensing Specialist at GMV, a private capital technology business group.

**1. What challenge is MRV4SOC set to solve?**
The main objective of the project is to monitor the changes in long-term soil organic carbon (SOC) accumulation in nine ecosystem types, each representing a distinct land use type within the EU. We are particularly interested in changes in soil organic carbon caused by carbon farming practices under different local climate conditions and climate change scenarios.

**2. What is MRV4SOC doing to solve this?**
The project aims to develop a robust, standardised, transparent and cost-effective MRV system to be implemented on different scales through ground-based and satellite data and process-based models. This MRV system is focused on monitoring changes in soil organic carbon in different ecosystems, such as peatlands and wetlands, forests, croplands and grasslands, just to name a few. The goal is also to increase trust in the voluntary carbon markets.

**3. When do you expect results?**
The final results will be released in 2026. Intermediate outcomes will be published in scientific journals and open repositories over the following years.

**4. How can the results be used on the national, regional and local scales?**
Our local and landscape approach is being developed within the framework of national greenhouse gas inventories. The results will help us define guidelines and recommendations to establish an MRV system for the EU land use sector.

**5. What have been the project's most significant challenges and successes thus far?**
Our first challenge was the lack of a standardised, robust, and transparent Tier 3 (see glossary page 57) methodological approach for measuring carbon stocks across various land use classes and management practices. The second challenge was the absence of a standardised MRV framework for the EU land sector. In addition, the lack of suitable long-term data sources (e.g. soil properties, vegetation, management practices) has slowed down the development of such a highly complex methodological approach. Tier 3 methods, especially to be used within voluntary rewarding mechanisms, require that this data should be available not only on national level or province level but disaggregated for smaller areas, such as farm holdings. This degree of detail is not publicly available or not even collected in many countries in the world.

On the other hand, the collaborative efforts of the European Research Executive Agency, the Directorate-General for Climate Action, and the Joint Research Centre have successfully brought together the private and public sectors, providing momentum for the project to develop robust, standardised, cost-effective and transparent Tier 3 MRV systems. The EU's ambition to achieve climate neutrality by 2050 has motivated us to seek reliable, interoperable and cost-effective solutions within complex ecological and socioeconomic contexts. ■

The EU-funded project got its name - MRV4SOC - from monitoring, reporting and verification (MRV) and soil organic carbon (SOC).

Photo: Claudia Droscelli

"The goal is to develop a robust and cost-effective MRV system.
Dr Marta Gómez-Giménez

**Dr Marta Gómez-Giménez**

Project Manager at GMV and MRV4SOC Coordinator.

**Location:** Madrid, Spain
**Research topic:** Environmental Remote Sensing
**What do you like most about your work?** I love working with professionals from different fields of expertise to find comprehensive solutions to complex environmental problems.
**What have you learned from working in the MRV4SOC project?** There is a wide community of stakeholders interested in improving soil health and fighting against climate change. The most vulnerable communities must be appropriately rewarded so that no one is left behind.

Photo: European Centre for Medium-Range Weather Forecasts

**Dr Richard Engelen**

Deputy Director of the Copernicus Atmosphere Monitoring Service (CAMS) at ECMWF

**Location:** Bonn, Germany
**Research topic:** Atmospheric composition
**What do you like most about your work?** I manage the implementation of the new CAMS emission monitoring services, which requires both state-of-the-art science and interaction with users. Managing these two aspects is what I really enjoy doing.
**What have you learned from working in the CoCO2 project?** Improving the required science and technology is critical for the success of the new emission monitoring services, but the endeavour will fail without continuous interaction with the many potential user communities.

## 5 questions to the scientists

### Q&A A breakthrough service to monitor human-induced emissions

The $CO_2$ Monitoring and Verification Support capacity (CO2MVS) is a service developed by Copernicus that aims to monitor human-induced carbon dioxide and methane emissions in the atmosphere. It combines ground-based and satellite measurements with detailed computer models in a service that can be used to track emissions on the regional, national and local scales. The prototype was created as part of the EU-funded CoCO2 project (2021-2023) and the plan is to launch its operational system in 2026.

Dr **Richard Engelen**, Coordinator of the CoCO2 project and Deputy Director of the Copernicus Atmosphere Monitoring Service (CAMS) at the European Centre for Medium-Range Weather Forecasts (ECMWF), spoke to FLUXES about the project.

> "On the member state level, we aim for countries to use the data to evaluate or improve their greenhouse gas estimates.
> Dr Richard Engelen

**1. What challenge did the CoCO2 project want to solve?**
At the time of the Paris Agreement negotiations, the European Commission decided that they need more information to support climate mitigation actions. One of the ideas was to use the existing Copernicus programme to provide observation-based information for countries and the EU Commission. This idea resulted in a series of recommendations, reports and task forces, eventually leading to EU projects such as CoCO2. The CoCO2 made a prototype for a monitoring and verification service, currently called CO2MVS.

**2. How did you solve the challenge?**
The prototype system of CO2MVS allows estimates of carbon dioxide ($CO_2$) and methane ($CH_4$) emissions from human activities on the global, regional and local scales. It uses a similar level of mathematical rigour that is used in other applications, such as numerical weather prediction and air quality predictions. The service can improve the effectiveness of greenhouse gas measurements like never before.

**3. What are the results?**
The work was finished in 2023, and now the Copernicus Atmosphere Monitoring Service (CAMS) will implement these plans. The $CO_2$ Monitoring, Verification and Support system should be operational in 2026, which is aligned with the launch of a new Copernicus Sentinel satellite mission. Then, countries could already use observations from the service in the second UN Global Stocktake, when they assess their progress towards the goals of the Paris Agreement.

**4. What is the process for scaling up the results?**
The $CO_2$ Monitoring, Verification and Support system will be run by the Copernicus programme, which is funded by the European Union. On the member state level, we aim for countries to use the data to evaluate or improve their greenhouse gas estimates. On the global level, we are working closely with new initiatives, such as World Meteorological Organisation's Global Greenhouse Gas Watch (see page 48). Developing countries will have to start reporting their greenhouse gas emissions from 2024 onwards, and so if this tool can help them achieve their goals that would be a success.

**5. How can the results be used on the national, regional and local scales?**
Users have started to adopt the system: Germany has initiated the use of some of the pre-operational data in their national emissions reporting as additional information. On the EU level, we are working to provide more up-to-date information on methane through local monitoring to some of the Directorates-General (DGs) of the Commission. ■

**SIMON KAY**
Deputy Head of Unit, DG CLIMA European Commission

**JOHN VAN AARDENNE**
Head of Group, European Environment Agency

# Timely and reliable data is needed for EU climate policy to succeed

Keeping tabs on carbon removals and emissions from managed land, forests and soils is key for the European Union, not only for the reports it sends to the United Nations, but also to inform EU actions pushing forward with the Green Deal.

Climate policy is complex and evolving rapidly. The EU has new and revised laws like the Land Use, Land Use Change and Forestry Regulation (LULUCF), the Carbon Removals Certification Framework and the proposal for the Forest Monitoring Regulation. All of these laws aim to increase the efficiency of carbon removals and storage by these sectors. They need to be underpinned by monitoring, reporting and verification (MRV) systems and techniques.

MRV systems are key to understanding what is happening on the ground, providing a picture of the condition of soil and biomass across the EU. They can also help support decision making and aid the implementation of EU laws.

> "By 2040, the EU could target a 90% net emissions reduction.

EU member states and associated countries can also use the MRV of carbon fluxes to understand, firstly, the implications of policies affecting farmers and foresters when land is converted away from agricultural production. Secondly, MRV systems can give insights into what the drivers of biodiversity loss are and, thirdly, how to best use incentives to drive change.

## The EU's use of MRV set to improve

Every year, EU countries put together a greenhouse gas inventory, using national statistics, satellite imagery and ground-based measurements. The data is checked by a third party, the European Environment Agency, which helps compile the collective inventory for the EU. Then, the data is sent to the UNFCCC.

EU data on greenhouse gas emissions and carbon removals from agriculture, forests and soils is now set to improve, thanks to data from Copernicus satellite monitoring. This includes the European Environment Agency developing an EU-wide data set to compare what land is used for (forest, cropland, etc.) and make data available quicker to help member states keep track in line with annual reporting required by regulations.

This improved monitoring will allow EU countries to design, employ and adjust the implementation of EU policies in a way that helps them meet their climate targets.

Up to 2021, under the Kyoto Protocol, much of the monitoring and reporting done by EU countries was based on aggregated statistics. EU countries are now set to go further, by using digital mapping, remote sensing data and a combination of other geographically explicit datasets to create a quick and precise understanding of land management, even down to hectare scale.

For example, from 2026 onward, EU countries will enhance their basic estimates of removals by applying more detailed and locally relevant empirical data and input information – so-called 'Tier 2' (see glossary page 57) monitoring under IPCC.

Then, for future development, vulnerable types of land cover and use, high carbon stock areas (such as peatlands, or dense, old forests) or places with adaptation action plans should have estimates based on modelling methods (IPCC Tier 3) using a variety of more detailed inputs, such as ground-based measurements and remote sensing.

Such data could help EU member states overcome a major stumbling block in policy implementation: delays in getting high quality, timely data on forests and agricultural land.

## Improving implementation of mitigation actions

To ensure the availability of high-quality data across the EU, and to complement mitigation action through LULUCF policy implementation, like changing land management, the Forest Monitoring Law, tabled in November 2023, foresees a way to compile standardised Earth observation and ground-based measurements for forest land use.

Monitoring data derived from satellite imagery - combined with ground-based data to make sure it is correctly capturing the reality of how soils and managed lands are contributing to climate actions – will be crucial to ensuring that EU countries realise in time if the carbon capture potential of forests is declining. It will also help keep track of natural disturbances, the frequency of which is expected to increase as climate change worsens.

## Relevant EU legislation

**On top of improving the inventories of its member states, observation-based MRV systems have the potential to inform specific legislation in the European Union.**

**Regulation on land, land use change and forestry (LULUCF):** This legislation sets out how the land use sector contributes to the EU's climate goals. It has a separate land-based net carbon removals target of 310 million tonnes of $CO_2$ equivalent by 2030.

**Directive on Soil Monitoring and Resilience:** This proposed law aims to have all soils in healthy condition by 2050. One stated method of achieving this is a comprehensive and coherent monitoring framework. An MRV system that incorporates accurate observations would greatly help with tracking the success of the soil management rules.

**EU Carbon Removal Certification Framework:** The proposal aims to ensure high quality carbon removals in the EU and establish a governance certification system to avoid greenwashing, by correctly applying and enforcing the EU quality framework. An MRV system that incorporates observations has the potential to greatly assist the implementation of verification checks by independent certification bodies.

**Forest Monitoring Law:** Forests play a key role in responding to climate change. So, it is crucial to have precise, complete and up-to-date information on European forests. The regulation would provide open access to detailed, accurate and timely information on the status and trends of EU forests.

By May 2024, only the LULUCF regulation has been adopted and is in force, the rest are in proposal phase.

Alongside this, MRV is key to the EU's Carbon Removal Certification Framework. This legislation, which was agreed by the European Parliament and EU countries in spring 2024, aims to verify the carbon removals and emissions reductions achieved in the land use sector by individual actors.

To provide a clear incentive in an otherwise unregulated carbon market, it is crucial to know when and where the carbon removal is certified. This avoids double counting and the double claiming of benefits. Because of this, the certification process also needs to build upon a foundation of geographic information, supplemented by ground data such as from the ICOS network.

### To 2030 and beyond

With 2030 already on the horizon, it is crucial that EU countries roll out MRV enhancements within the next two to three years to properly track the implementation of policies.

In the past, similar transitions into using digital geographic data and remote sensing technology have been rolled out in a comparable time frame. For example, two decades ago, the Common Agricultural Policy went through a similar transformation in the space of a few years. The benefits of that transition in terms of the improvements in the way farmers received subsidies made it a tremendous step forward. However, achieving such a paradigm shift requires EU countries, the European Environment Agency and other organisations to work together.

In the run up to 2040 the improved data gathered will help inform new policy decisions. By 2040, the EU could target a 90% net emissions reduction, as suggested in the Commission's recent 2040 communication.

The European Commission's analysis envisions that emissions reductions and removals in land and agriculture will become more significant towards 2050 - partly because other sectors' emissions will have decreased, and the EU will need to maintain or increase removals.

Altogether, the next two decades will be significant for policy implementation across the land sector, and this will need to be monitored with improved, collaborative techniques to help tackle the climate crisis.

Photo: Salla Merikukka

## Interview

By Kira Taylor

# MRV: A building block to encourage EU carbon removals

**The European Union is looking to carbon removals to help reach its emission reduction targets. By 2030, it wants to increase removals by its land sector to 310 million tonnes and, by 2050, it will need removals to equal emissions to reach carbon neutrality.**

In an interview with FLUXES, **Ville Niinistö**, a Green member of the European Parliament, explains how several land use and carbon removal laws will bolster MRV and help incentivise carbon removals. Over the last few years, Niinistö has worked on the Land Use, Land Use Change and Forestry Regulation (LULUCF), the Carbon Removal Certification Framework (CRCF), and the forest monitoring law. These are expected to work together to improve MRV and boost carbon removals.

Under the LULUCF regulation, EU countries will need to increase their collective carbon sink - something that has been declining in recent years - to 310 million tonnes by 2030. The law also introduces quicker, more detailed MRV to ensure these removals happen. If the forest monitoring law is agreed, this will further strengthen MRV.

"We have a carbon sink policy for the EU and for the member states, for the first time in history. It's not just for accounting - MRV also has a big role in making sure that there is also a policy in place," says Niinistö, who negotiated the LULUCF law for the Greens.

This will be supported by the new EU Carbon Removal Certification Framework (CRCF), which aims to verify carbon removals and land use activities that reduce emissions and increase carbon storage. Good monitoring, reporting and verification is crucial for implementing this and ensuring that removals sold on voluntary carbon markets are credible.

Carbon removals will also be important post-2030. By 2040, the European Commission has suggested that the EU region should reduce net emissions by 90%. Niinistö's Green party wants to reach net zero emissions by that year. Whatever goal is chosen, it is clear there will need to be removals to support it.

"The higher the targets, the more obvious it is that they can only be achieved by the best possible combination of carbon sinks, technological storages and emission reductions," he explains.

This will require EU countries to overachieve their targets in land use and forestry - for instance, by using carbon farming activities verified under the Carbon Removal Certification Framework, he explains. This, in turn, requires a public financial instrument to encourage landowners to reduce emissions.

In the past, a key barrier to setting up such a financial system has been the quality and retroactive nature of the data, according to Niinistö. The new laws can help change this.

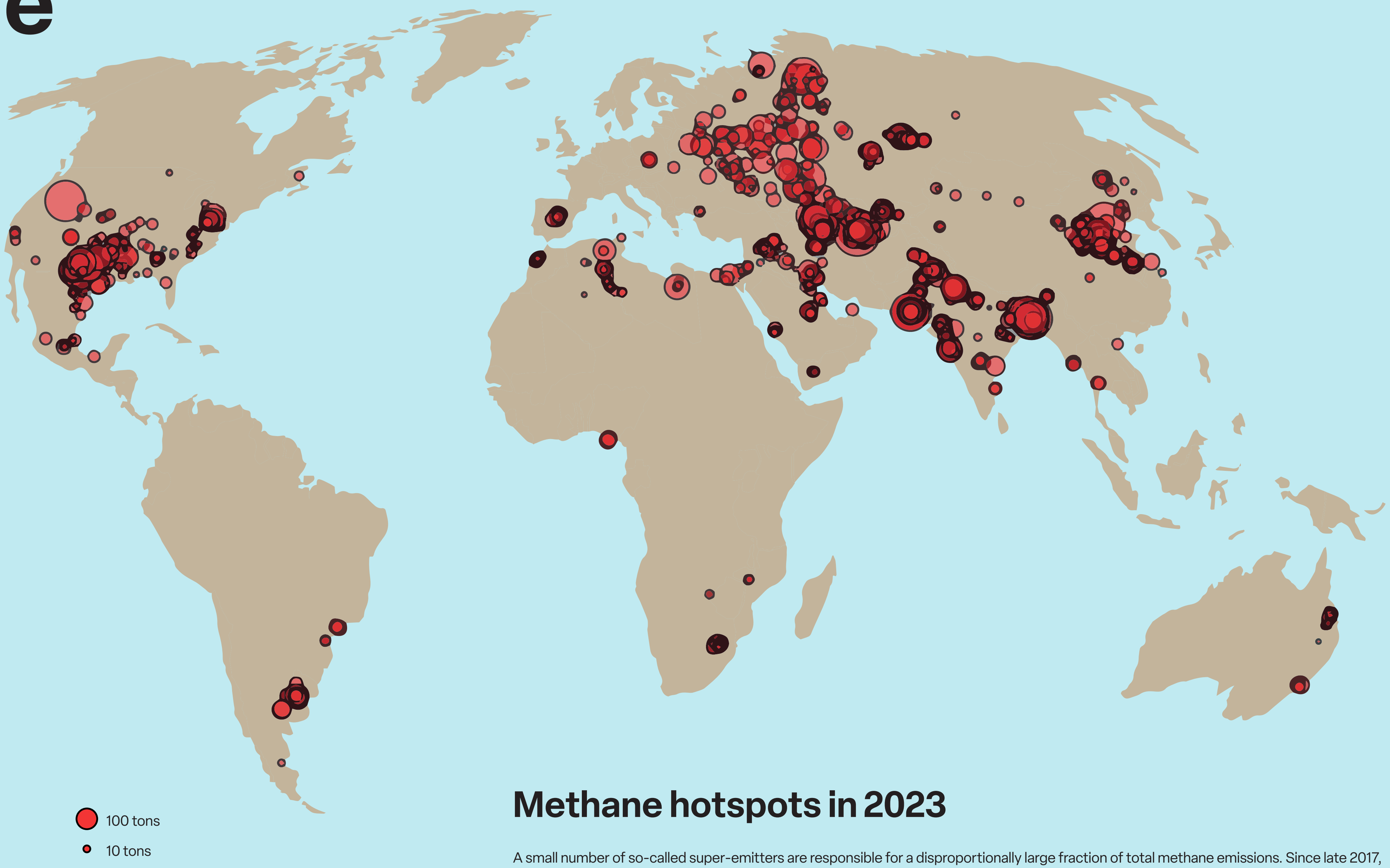
"With the right combination of the LULUCF targets, the MRV in LULUCF, the Carbon Removal Certification Framework, and the 2040 targets - in a way that maintains a clear emphasis on emissions reductions - we will have a more proactive policy in place to create financial incentives for landowners to increase sinks after 2030," he says.

Tracking methane emissions:

# Making the invisible visible

Methane emissions have a huge impact on the climate and are responsible for around 30% of the current rise in global temperatures. To address this, over 150 governments have signed the Global Methane Pledge to cut emissions of the greenhouse gas by 30% by 2030 compared to the 2020 levels. However, a successful implementation of the pledge requires proper monitoring, reporting and verification to ensure the actions taken are effective.

By Kira Taylor




## Methane hotspots in 2023

A small number of so-called super-emitters are responsible for a disproportionally large fraction of total methane emissions. Since late 2017, the TROPOspheric Monitoring Instrument (TROPOMI) has been in orbit, providing daily global coverage of methane mixing ratios. This map shows the methane super-emitter detections in 2023. The size of the circle indicates the quantity of emissions. The emissions come from the oil and gas industry, coal mining, and landfills / waste dumps. Source: Schuit et al., 2023.

## Key takeaways

- Monitoring, reporting and verification (MRV) is crucial to ensuring the success of policies aimed at reducing emissions of the potent greenhouse gas methane.
- Satellites, drones and ground-based measurement are used to detect methane emissions. Together, these help build a picture of the scale and location of emissions.
- An EU law, in the final stages of agreement, will create reliable MRV for methane emissions and help reduce these within its borders and beyond.

Countries are looking at how to make a 30% reduction of methane a reality by 2030, focusing on the oil and gas sector. For instance, in the US, the Methane Emissions Reduction Program introduces a charge on methane emitted by certain oil and gas companies. This charge will apply to facilities emitting over 25,000 metric tons of $CO_2$ equivalent every year and will start at $900 per metric ton reported in 2024.

Meanwhile, the EU will soon pass a law to create reliable MRV for methane emissions and help reduce these within its borders and beyond. Alongside obliging the fossil fuel industry to roll out MRV, it will ban routine venting and flaring of gases, and mandates oil and gas companies to carry out regular surveys to detect and repair methane leaks in the EU.

Such efforts require data to implement and ensure their effectiveness.

"If you don't know where the emissions come from, then you cannot do anything about them. Also, when we are talking about having an effect internationally, then we have to extend our monitoring, reporting and verification outside our borders and this is only possible when we have reliable, comparable data," says **Jutta Paulus**, a Green MEP from Germany, who helped negotiate the EU's methane law.

She says that measuring methane emissions has gained traction in recent years, not just in the EU but also in the US. The charge for methane emissions will also require reliable data, she explains.

That is where monitoring, reporting and verification (MRV) comes in. Systems vary from satellites that can measure large emissions, to more localised techniques, like drones and ground-based measurements. Together, these help build a picture of the scale and location of methane emissions.

"We know that the methane problem exists. We know that emissions are very, very much higher than what they are currently reported as, but we don't know how much is actually emitted," explains **Flavia Sollazzo**, Senior Director of the EU Energy Transition from the Environmental Defense Fund Europe, a US- and UK-based environmental non-profit.

### Monitoring from space gives a big picture

Methane emissions are easier for satellites to spot than carbon dioxide, due to the greenhouse gas being less present in the atmosphere. Satellites can build a picture of a wide area, find large sources, and access areas potentially inaccessible for ground-based techniques. There are several already in orbit, such as the Copernicus Sentinel-5 Precursor (S5P) mission, which monitors methane emissions in Europe and globally.

The satellite's instrument detect the unique fingerprints of gases across different parts of the electromagnetic spectrum, delivering daily high-resolution global information on emissions. It has already revealed numerous individual incidents of unintended and deliberate methane leaks around the planet.

"We have detected several super-emitters also over Europe related to urban areas, e.g. Madrid and Bucharest as well as coal mining emissions in Poland and Ukraine," says Dr **Ilse Aben**, Senior Scientist at the SRON Netherlands Institute for Space Research and Co-Principal Investigator for the S5P TROPOMI detecting system.

"On a global scale, these methane super-emitters are only the tip of the iceberg in terms of overall total anthropogenic methane emissions. But they have also proved to be important in raising awareness for methane emissions – both at the political level and at the level of the polluters and other relevant stakeholders. Making visible what is invisible really works as an eye opener for many stakeholders," she adds.

In 2026, another three satellites will be launched by the European Space Agency to help monitor carbon dioxide and methane emissions as part of the EU's Copernicus programme.

The Copernicus Anthropogenic Carbon Dioxide Monitoring (CO2M) satellites will carry a near-infrared and shortwave-infrared spectrometer to measure atmospheric carbon dioxide and methane at high spatial resolution. The observations will be combined with ground-based measurements and modelling to understand human-made emissions compared to those from natural sources.

CO2M will be operated by the European operational satellite agency for monitoring weather, climate and the environment (EUMETSAT). What makes it pivotal, is that it will provide a unique and independent information source to assess the effectiveness of climate policy measures. Nations throughout the world will be able to assess and compare how they are meeting their targets with transparent data.

"EUMETSAT will operate the CO2M satellites and receive, process and disseminate their data, which will be crucial for monitoring carbon emission reduction efforts globally, in line with the Paris Agreement," says Dr **Phil Evans**, EUMETSAT Director-General.

Meanwhile, the MethaneSAT mission, run by the Environmental Defense Fund, is already in orbit combining different types of monitoring: broad overviews and close-ups on problem areas. The satellite is revolutionary, both from a technological perspective but also because the data will show emissions over time and be freely available.

"It is the most advanced [methane-tracking satellite] now in operation because it has a 200 kilometres wide view and then it also has a high resolution to see small point sources as well," says Sollazzo.

"It bridges the gap that there is at the moment. What it also does is that it basically continuously monitors emissions from up to 80% of the global oil and gas

> If you don't know where the emissions come from, then you cannot do anything about them.
>
> Jutta Paulus, MEP, Germany

## Methane in global numbers

- The energy sector - oil, natural gas, coal and bioenergy - accounts for more than 30% of methane emissions from human activity.
- Agriculture and livestock produce roughly 32% of methane emissions.
- Solid waste produces 12% of methane emissions with food waste as the main culprit.
- Methane has a warming effect over 80 times greater than carbon dioxide over a 20-year timeframe, which means action to cut emissions now can unlock significant near-term benefits for climate action.
- Methane is responsible for around 30% of total warming since the industrial revolution and is the second largest contributor to global warming after $CO_2$.
- Cutting methane emissions from fossil fuels by 75% before 2030 is vital to limit warming to 1.5°C.
- Over 75% of methane emissions from oil and gas operations and 50% of emissions from coal today can be abated with existing technology.
- 35% of oil and gas emissions and 10% of coal mine emissions could be avoided at no cost.

Source: International Energy Agency, Global Methane Forum 2024, C40 Knowledge Hub producing regions. This allows us to see quite quickly if there are changes," she continues.

It is hoped that this type of technology will support laws like the EU's upcoming methane regulation by providing a reference point to see if the data provided is accurate.

"Having the ability to see what the emissions are will allow us to set a baseline that then can be used in the EU for its current gas purchases, but then also across the board for buyers and sellers," says Sollazzo.

## Ground-based monitoring helps pin down leaks

While the exact range at which a satellite can measure methane emissions varies, they can only detect very big emissions.

"They do not provide all of the information needed to go out and fix leaks," says **Ioannis Binietoglou** from the non-profit Clean Air Task Force. He wants to see a mix of complementary technologies, including ground-based measurements and emissions estimates, created using models or engineering calculations.

Ground-based methods include using flux chambers to capture and measure emission levels and lasers on mobile equipment, like drones and vehicles that can capture real-time data. These have to be converted to emission estimates.

"The approach of the mobile analysers is super successful," says Dr **Thomas Röckmann**, Professor at Utrecht University.

"You have some idea from the modelling on the footprint area, but then the mobile analyser can go to the footprint area and try to find out where the point of emission is. Often you know that there is a farm or there is a wastewater treatment plant and so on, but then you go to all these individual installations and find out how they emit. So with these methods atmospheric research goes to a much more granular scale," he adds.

Röckmann has used the technology to measure methane leaks in city gas networks and in previously unstudied oil and gas production areas in Romania. In both cases, the additional data helped raise awareness of the methane emissions and technology that can be used to track them.

However, there are still challenges in taking ground-based measurements, especially the accuracy of the emission estimates. This is because emission plumes move with the wind.

"If you transect the plume 10 times, you will get 10 very different results usually, and sometimes they can be an order of magnitude different, so that's really big because the plume dynamics change so quickly," explained Röckmann. While there are some ways to reduce the meteorological variability, including taking measurements from further away, it is still a problem.

The most precise approach at the moment is the tracer release approach, where researchers release a gas not present in the area and measure it together with the unknown gas. This helps boost the accuracy of emission estimates, but can only be done when the emission point has been located and does not work when there are lots of emission points, such as in landfills.

## Cooperation to use and improve MRV

While there is no global standard for MRV for methane emissions yet, the EU's methane law will help standardise some approaches.

Meanwhile, the US has a Greenhouse Gas Reporting Program that requires monitoring and reporting by regulated sources, including for methane emissions from petroleum and fossil gas facilities. This is verified through a combination of automated and manual checks that flag potential errors.

Another prominent system is run by the Oil and Gas Methane Partnership, a group of companies working with the United Nations to apply advanced monitoring and share best practices.

The group's gold standard of MRV requires direct measurements of source-level methane emissions complemented by measurements of site-level methane emissions. This standard is used in over 38% of the global oil and gas production. It also forms the basis of the EU's methane regulation.

While MEP Paulus believes the new EU law will be a big driver of methane emissions reductions around the world, more work is needed on the verification side.

"We do have a problem there because we simply don't have enough verifiers out there yet. I'm pretty confident that we still have some time [...] to bring them on board and to have sufficient people out there who can actually verify those emissions," she explains.

Methane is a complicated greenhouse gas and there are still gaps in tracking emissions. Improved observation can help bridge these gaps, increase understanding of what is happening in the atmosphere and boost global efforts to reduce its impact on the climate, but more is still needed. ■

Satellites and ground-based measurements allow us to track methane emissions more accurately, which should help curb them. Here, a modelling picture of the EU's new Sentinel-5 Precursor (S5P) satellite.

Photo: European Space Agency

"

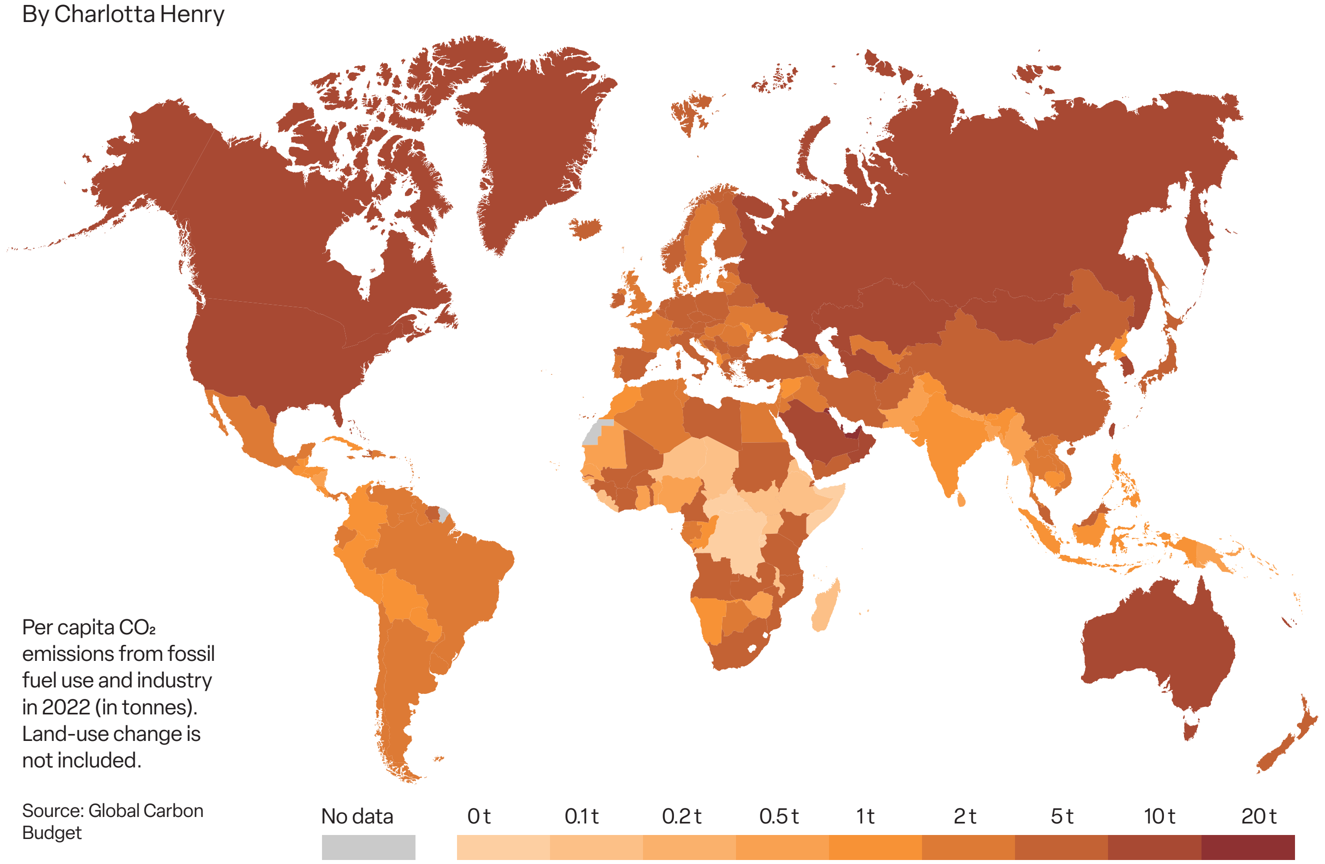
**Making visible what is invisible really works as an eye opener for many stakeholders.**

Dr Ilse Aben, Senior Scientist, Sentinel 5P satellite

# Assessing the progress, ambitions and challenges of the Global Stocktake

The world stands at a crossroads in the battle against climate change. With the impacts of climate change already being felt around the world, we asked some of the leading EU negotiators to reflect on the first Global Stocktake process.

By Charlotta Henry




Per capita $CO_2$ emissions from fossil fuel use and industry in 2022 (in tonnes). Land-use change is not included.

Source: Global Carbon Budget

**Key takeaways**

- The Global Stocktake shows whether the world is collectively making enough progress towards the goals of the Paris Agreement including the temperature goal, increasing resilience, adaptation, aligning financial flows and providing climate finance.
- The world needs to transition away from fossil fuels, triple renewable energy and double energy efficiency.
- To keep the 1.5°C temperature goal in reach, an emission reduction of 43% is needed by 2030. The world is on track for just a 2% decrease with its current climate targets.
- The upcoming COP meetings in Azerbaijan and Brazil will delve into collective, quantified goals on finance, and updating the Nationally Determined Contributions (NDCs).
- The success of the first Global Stocktake will be determined in 2025 once the updated NDCs are tabled.

The Global Stocktake, which takes place every five years, provides a snapshot of the world's advancement towards the Paris Agreement goals. In 2023, the first stocktake served as yet another wake-up call, emphasising that the world is off track to meet these goals and limit global warming.

The steps needed to get back on track are clear: The world needs to transition away from fossil fuels, triple renewable energy and double energy efficiency. EU negotiators were pushing for this at the last COP meeting in Dubai.

“I think the IPCC [Intergovernmental Panel on Climate Change] has been very clear. We have the tools, technology and knowledge needed – now we have to implement that,” says Dr **Frederik Pischke,** Scientific Adviser at the German Environment Agency, who represented the EU in the UNFCCC Global Stocktake negotiations.

> “Even if we reached the targets that countries are setting, we would only be about 2% below the 2019 emission levels in 2030.
>
> Dr Frederik Pischke

“We need to triple renewable energy, double energy efficiency by 2030 and phase out fossil fuels, while making sure that the different sectors - energy supply, transport, buildings, industry and agriculture - play their role in a decarbonised world. Now, it is about taking the hard decisions for a low-carbon, climate resilient and equitable future and making climate change a priority,” he adds.

### The immense ambition gap

Following COP28, the focus is now moving on to the submission of the updated Nationally Determined Contributions (NDCs), where countries lay out their new climate action plans. The NDCs need to be submitted nine to 12 months before COP30, which will take place in Brazil in 2025. Countries will need to fix the major ambition gap between their plans and global climate goals:

“The current NDCs fail to reach the goals of the Paris agreement: The UNEP Emissions Gap report and UNFCCC analysis show a big ambition gap on where we're supposed to be in terms of emission reduction and where the NDCs will bring us,” Pischke explains.

"Even if we reached the targets that countries are setting, we would be falling far short – we would only be about 2% below the 2019 emission levels in 2030. To keep the 1.5°C temperature goal in reach, a 43% decrease would instead be needed by 2030, according to the IPCC,” he continues.

Pischke emphasises the critical role of NDCs, outlining how they guide countries in increasing ambition and taking climate action.

> The focus is on the overall progress, without differentiating or singling out specific countries.
>
> Dr Frederik Pischke, Scientific Adviser

"In their new NDCs, the countries have to specify how they are reflecting these results of the Global Stocktake."

Dr **Kaarle Kupiainen**, Ministerial Adviser at the Ministry of Environment in Finland and leader of the EU negotiation team in the Global Stocktake stream, says that the main purpose of the Global Stocktake is to inform the parties, when they update their NDCs.

"The success of the first Global Stocktake will be determined in 2025 when we see the updated NDCs. They will collectively show whether countries have taken up the call and information from the first Global Stocktake and translated it into their ambitions to collectively achieve the goals of the Agreement."

## Solutions needed to address multiple crises

The Global Stocktake focuses uniquely on collective progress rather than individual country achievements. It also includes the engagement of cities and sub-national actors to collectively progress towards the Paris Agreement.

"The Stocktake shows whether we are advancing towards the goals of the Paris Agreement on a collective level: the temperature goal, increasing resilience, adaptation and aligning financial flows and providing climate finance. Therefore, the focus is on the overall progress, without differentiating or singling out specific countries," Pischke says.

The implementation of ambitious targets poses a considerable challenge amid competing global priorities.

"We have been a bit worried about the implementation of the decisions made in the Global Stocktake because it is not very concrete on how we are going to follow up on the important targets. What we are currently working hard to achieve is to get these issues reflected in the future decisions and in the process itself," says Kupiainen.

Pischke underscores the need for smart solutions that address multiple crises simultaneously:

"The implementation part is a huge challenge. We are confronted with several obstacles, there are a number of wars and we have just come out of a pandemic. There are multiple priorities that governments have to address. We need solutions that are part of the circular economy approaches, strengthen sustainable lifestyles and which have the potential to address multiple crises while taking societies forward."

## Climate finance can become a hurdle

While acknowledging diverse perspectives on climate action, Pischke sees the Global Stocktake as a unifying force. It provides a common understanding and a roadmap for achieving the Paris Agreement goals. The upcoming COP meetings in Azerbaijan and Brazil will delve into collective, quantified goals on finance, and NDCs.

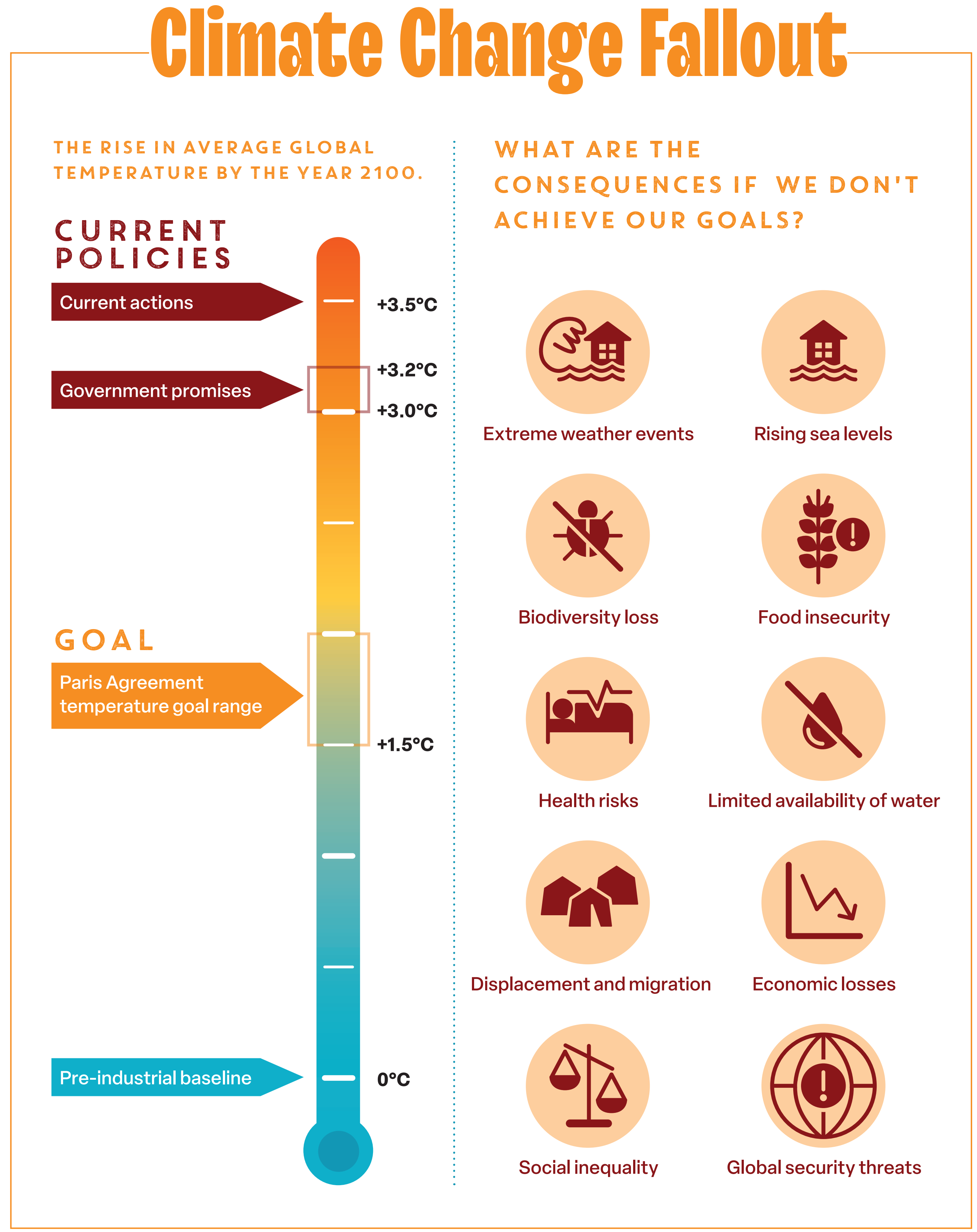
"Some argue that, if we fail to reach a consensus and an ambitious common goal on climate finance, it can actually harm the update of the NDCs in 2025 and risk the implementation," Kupiainen says and continues:

"Financing is an important enabling component of global action: the implementation of domestic climate actions reflected in the NDCs requires both support and financing for the developing states, particularly for the least developed. However, it remains to be seen and of course, the UNFCCC is working hard to get a good outcome from the next COP."

Climate change threatens a number of human rights, including the right to life, water and sanitation, food, health, housing, self-determination, culture and development. The most vulnerable people in the world are the most affected.

Pischke emphasises the need for a wider perspective on climate impacts in the Stocktake:

"I think it is very important to include civil society and the diversity of actors. What also could be stronger, in my view, is how to consider human rights in the context of climate change and climate action as well as gender consideration. We are still lacking a lot of gender related data. That should also be improved." ■

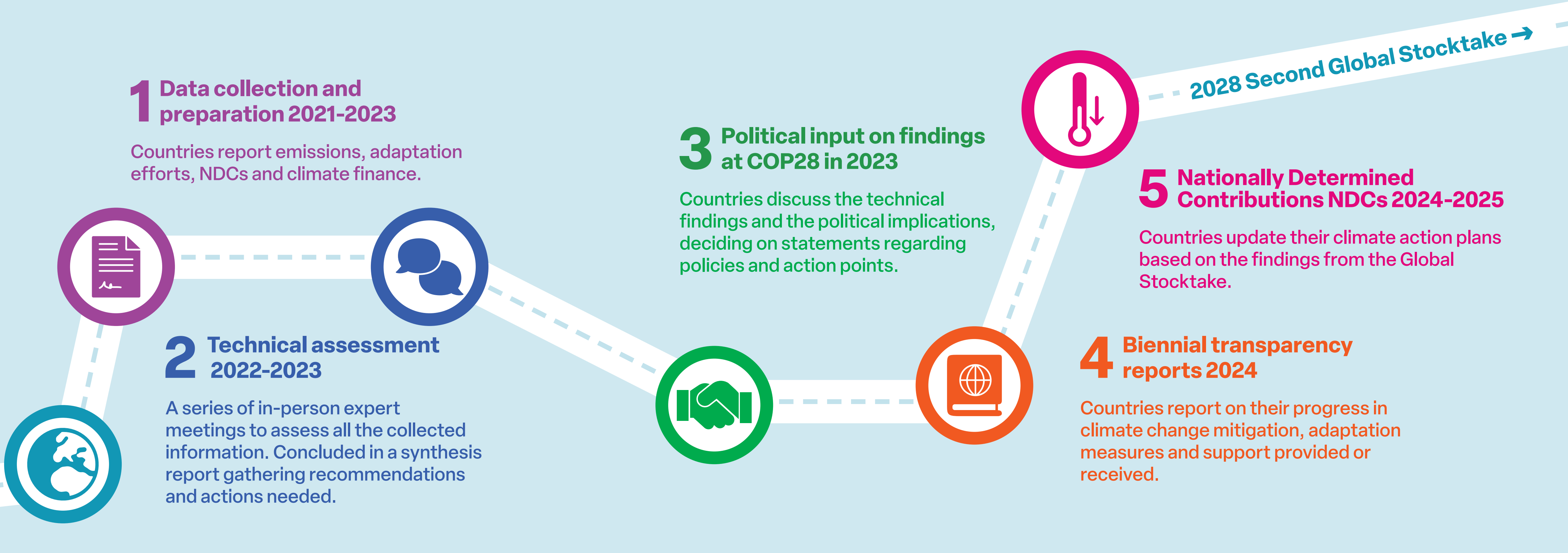


Source: IPCC

# The path through the first Global Stocktake

The Global Stocktake is a multi-stage assessment process established in the Paris Agreement. In the first stocktake, countries across the globe gathered data on emissions and adaptation efforts for a technical analysis, culminating in high-level discussions at COP28 in Dubai 2023.

By Charlotta Henry




The first data collection and preparation phase of the Global Stocktake resulted in over 1,800 documents submitted, totalling more than 200,000 pages.

"There was a wealth of information. I think it was quite overwhelming to analyse and take all that in. We need to reflect on how to streamline it. What has been very helpful is the analysis by international organisations, in particular, the IPCC and also agencies for renewable energy, that showed us pathways on how the world could decarbonise," says **Frederik Pischke**, Scientific Adviser at the German Environment Agency, representing the EU in the UNFCCC Global Stocktake negotiations.

The Enhanced Transparency Framework with its biennial transparency reports will make it easier to assess the documents collected for the second Global Stocktake in 2028. In the transparency reports due at the end of 2024, countries will report on their progress in climate change mitigation, adaptation measures and support provided or received. The countries also need to highlight the selected indicators for tracking the progress of their Nationally Determined Contributions (NDCs) - their climate action plans.

## Urgent need for system-wide transformations

Transitioning to phase 2, the technical assessment, Pischke highlights the collaborative effort involving member states, sub-national governments, civil society organisations, and intergovernmental bodies such as the IPCC. This phase is centred around two key questions: Where are we and what are the opportunities for more ambitious climate action? The technical phase concluded in an overarching Synthesis Report, mainly basing on the IPCC assessment reports.

"There was a strong interaction with the IPCC and that's really important since the Global Stocktake is supposed to be based on the best available science."

The Synthesis Report underscores the fact that there is a rapidly narrowing window to raise ambition in order to limit warming to 1.5°C above pre-industrial levels: Much stronger action is needed before the second Global Stocktake in 2028.

The report also emphasises the urgent need for system-wide transformations that can cut greenhouse gas emissions and ensure a climate-resilient future.

In addition to phasing out fossil fuels and scaling renewable energy, while significantly decarbonising transport, industry and building sectors, mitigation actions should consist of preserving nature, ending deforestation and embracing sustainable agriculture.

The report stresses the urgency of increasing adaptation support and addressing loss and damage, particularly for vulnerable communities. To address these issues, it underscores the need to reorient trillions of dollars in global finance to meet investment needs and mobilise significant resources in support of a zero-carbon, climate-resilient and equitable future.

## Stronger political view needed

The political phase concluded in Dubai 2023 at COP28.

"This is where we lost a few points that came out strongly during the technical assessment. We would have needed a stronger view on the findings from the technical assessment from a political perspective. Nonetheless, a number of very important points came out strongly, and the final decision has taken up the most significant signals. Now, the tricky part is left. It's easy to set ambitious targets, but hard to follow up on them, and to follow through."

Now, all levels of governments, including cities and regions, civil society and intergovernmental organisations are reflecting on the outcomes of the first Global Stocktake and areas for improvement. Feedback submissions were due in March 2024, setting the stage for a comprehensive review. ■

### The Global Stocktake Explorer

Dive into the wealth of information in the documents submitted for the first Global Stocktake in 2023, using the Global Stocktake Explorer. Here you can access all submissions to the Global Stocktake, including the Nationally Determined Contributions, IPCC reports and more.

The Global Greenhouse Gas Watch:

# Transforming climate change mitigation accountability

A global effort is under way to provide near real-time data on greenhouse gas concentrations covering all continents. Launching in 2028, the Global Greenhouse Gas Watch (G3W) initiative brings together a global network of satellite operators, surface-based observation systems and modelling expertise to gather the best existing knowledge and technology. In Europe, Copernicus and ICOS are providing the blueprints for the monitoring system.

By Charlotta Henry

## The components of the Global Greenhouse Gas Watch

The components of the monitoring system consist of a network of satellites and surface-based observation systems all across the globe. In addition, strategic partnerships will be set up with shipping companies, airlines and cell tower operators to enhance observational capabilities, particularly in remote areas.


Dr Gianpaolo Balsamo is leading the Global Greenhouse Gas initiative: "G3W gives us a tool to inform and guide climate action."

Photo: Jaroslav Monchak

## Key takeaways

- The Global Greenhouse Gas Watch is a complex observational network covering almost all Earth domains: land, ocean and atmosphere.
- The aim is to provide surface-based and space-based observations on greenhouse gases across the globe.
- The system will compile monthly data on greenhouse gas emissions at a 100 km x 100 km grid on a global scale.
- It requires a large-scale collaboration between international organisations, government agencies, research institutions, private sector and a variety of initiatives.
- A first mock-up of the system will be ready in 2027 and the G3W will be up and running in 2028.

Despite claims of emission reduction efforts, global greenhouse gas emissions continue to rise, with 40 billion tons of $CO_2$ still emitted every year. While the world's land surface absorbs roughly 10 billion tons and the ocean another 10 billion tons, half of the global emissions are left in the atmosphere each year.

"Atmospheric concentrations of the main greenhouse gases, such as carbon dioxide, methane and nitrous oxide are all increasing, which is connected to a carbon economy and the dominant use of fossil fuels," says Dr **Gianpaolo Balsamo**, Director at the World Meteorological Organization (WMO), leading the Global Greenhouse Gas initiative (G3W).

The G3W is a complex observational network covering almost all domains: land, ocean, atmosphere and cryosphere (ice caps, glaciers and areas of snow and permafrost). It consists of surface-based and space-based observations and requires a large-scale collaboration between international organisations, government agencies, research institutions, the private sector, and a variety of initiatives.

In Europe, the G3W will mostly build on the existing technology and knowledge from Copernicus and the Integrated Carbon Observation System (ICOS). On a global scale, the G3W will integrate systems from all the continents under one global umbrella.

"It is a very collective work. We need to make the different communities come together - the modelling, observations, ocean, terrestrial and air quality sectors, but also geographically - the North Americans, Europeans, the Chinese, Japanese, etc. We need to work together to develop a common plan," says Dr **Vincent-Henri Peuch**, Director for Engagement with the EU and Head of the European Centre for Medium-Range Weather Forecast (ECMWF). He has been leading the group developing the G3W implementation plan.

## Real-time data for informed decisions

The G3W system, due to be partly up and running in 2027, is designed to track greenhouse gases across the globe, particularly $CO_2$. The aim is to compile monthly data on greenhouse gas observations at a 100 km x 100 km grid on a global scale. The ultimate goal is to reach a 1 km x 1 km grid within the next decade. The G3W data will support the greenhouse gas inventories with dynamic, timely and geographically detailed data, using observations, data management and modelling.

Unlike inventories, which are produced annually and focus on national or sub-national totals, the G3W network will provide a more dynamic, faster response with monthly results. This offers valuable insights into the Earth system's responses to occurring changes.

"This way, we get a tool to inform and guide climate action as well as evaluate the efficacy of the Nationally Determined Contributions (NDCs)," says Balsamo.

The World Meteorological Organisation is relying on a range of collaborations with existing observational networks to set up the G3W system and the 193 WMO member countries need to stand behind it. The system comes with a hefty price tag: The total global cost estimate for the project is $1 billion. The aim is to save costs using already existing infrastructures and capabilities in the member countries to avoid duplication and enable a rapid path from research to operation.

"To be clear, the G3W is not just one system – we are talking about three, four, five systems spread across the world. The figures coming from Europe, China, USA or Japan will be reasonably compatible. If all the systems are converging, i.e. saying that emissions are higher or lower than what is estimated, it will be a very good incentive to look into detail," says Peuch.

> "We need to invest substantially to permit every country to engage in surface-based observations, quality control and assessment, verification and reporting.
>
> Dr Gianpaolo Balsamo

Photo: Jaroslav Monchak

"Unlike research projects dependent on fixed-term funding, we need to aim for a routine, sustained data production, ensuring continuous output independent of fluctuating research funds", says Dr Oksana Tarasova, Senior Scientific Officer at the WMO.

The implementation plan will be presented to WMO member countries in June 2024 and then the concrete work can start. According to Peuch, one of the biggest obstacles is presenting the products for what they are.

"It would be a big danger to appear as the greenhouse gas police and basically present figures that would make the UNFCCC parties very uncomfortable," says Peuch.

"The UNFCCC parties mostly use inventories for statistics right now – the G3W products will be as good or as bad as forecasts – they are a piece of information and evidence that we can bring to the country as additional information. It is not a 'big brother watching you' type of approach, instead it is supporting the countries to see whether the measures that are taken are effective," he adds.

The G3W system will help improve the quantification of both natural and human induced greenhouse gas sources and sinks.

"It will allow us to see how much greenhouse gases we emit, how much $CO_2$ enters and exits the atmosphere. This will significantly improve the accounting on who is doing what. We basically need to solidify the scientific basis for decision making. Otherwise, the necessary decisions will not be made," says Dr **Lars Peter Riishojgaard**, former WMO Director and one of the G3W lead architects.

### Overcoming challenges monitoring remote areas

The preparations for setting up the G3W network are already progressing at full speed, according to Senior Scientific Officer Dr **Oksana Tarasova** at WMO, one of the initiators of the project.

"We should have pre-operational data and a first mock-up of the system in 2027. The second Global Stocktake will wrap up in 2028 and the G3W will feed into that," she says.

"Then, the initial operational phase starts, where we identify and mobilise resources to build the most critical elements to move to full implementation. By 2032, the enhanced operational phase of the G3W will support the Paris Agreement implementation by assessing the impact of policymaking," she explains.

However, implementing a global initiative of this scale poses several challenges. The plan is to start with a comprehensive assessment of available observations to make use of the already existing infrastructure in the different countries. Satellite, sensor technology and observational coverage are already at advanced stages in the United States and in Europe, and emerging in China and Japan. However, there are areas of the globe that need to be covered where the technology is still not in place and surface-level observation is required.

"We do not have enough surface-based observations. The tropics are incredibly important because most of the terrestrial carbon is stored there, and so we need to monitor them much better than we are doing today," says Riishojgaard.

In addition to the tropics, there is a lack of comprehensive surface-based observations, particularly in the boreal forests, permafrost areas, and the global ocean areas.

"75% of the planet is ocean. We do have satellites that are global in nature, but the satellite observations are not sensitive enough to measure the differences in atmospheric concentrations over the ocean. Therefore, we have a strong need to observe the ocean concentrations also from surface-based platforms, for example from ships. So we need to be pretty creative," says Tarasova.

To help tackle this, the G3W network is aiming to set up strategic partnerships with shipping companies, airlines, and cell tower operators to enhance observational capabilities, particularly in remote areas. Moreover, it is important to transition from research-based observations to an operational system with 24/7 capabilities, says Tarasova.

"On a global scale, there is a lack of investment in atmospheric observations and modelling. Unlike research projects dependent on fixed-term funding, we need to aim for a routine, sustained data production, ensuring continuous output independent of fluctuating research funds," she explains.

"At a political level, there should be a push for additional use of direct atmospheric data in support of climate policy, which is not the case. In the political processes we need to get much better representation of what happens in the real world – and the answer is not in the carbon credits," she adds.

"It is not a 'big brother watching you' type of approach, instead it is supporting the countries to see whether the measures that are taken are effective.

Dr Vincent-Henri Peuch

### Empowering nations to boost observation

G3W aims to give a comprehensive picture of the state of the atmosphere, land, and oceans – but that requires all nations to have the capacity to contribute to real-time measurements and data collection. In Europe, there is already good observational coverage.

"ICOS is the key player for surface-based observations in Europe. It has provided the leadership

## NDCs and MRVs

Nationally Determined Contributions (NDCs) are the core planning policy document to track the progress of climate action on a national and global level. In the context of NDCs, Monitoring, Reporting and Verification (MRV) refers to the process by which countries track and report on the implementation and impacts of mitigation and adaptation actions, and the finance used to support these actions. These three core elements – mitigation, adaptation and finance – can be part of one integrated, national MRV system or separate MRV systems.

coordination on many aspects and is a major asset. The other important player in Europe is Copernicus. Together, we are bringing together a big number of very important academic institutions," says Peuch.

However, a 2023 survey of the 193 WMO member countries, showed that up to 63% do not have a greenhouse gas monitoring plan in place.

"That is a majority of countries, which means that the G3W products would really be needed. The G3W will allow all the countries of the world to have the figures and to use them to make plans, update them and report their emissions using tools that are at the same level as the most advanced countries in the world," says Peuch.

The climate crisis and the lack of equal possibilities to contribute need to be tackled at the same time, according to Balsamo.

"In practical terms, we have to bring all countries to a sufficient level of greenhouse gas monitoring through a capacity building effort. We need to invest substantially to permit every country to engage in surface-based observations, quality control and assessment, verification, and reporting. Empowering the nations on the monitoring is a key aspect. But we must be mindful of being inclusive. That's the number one priority," he says.

On the other hand, political or economic tensions can have a big influence on observational networks. In 2021, the Russian government stopped its greenhouse gas measurement programme. The country has the most extensive area of boreal forests in the world, an immense carbon reservoir.

"They also have the largest area of permafrost, which is sort of a ticking time bomb because it's slowly melting, and it will outgas a lot of methane. We don't know exactly how quickly or how much," says Riishojgaard.

## Diversity of economic and political interests

Another significant hurdle in the implementation of G3W is the diversity of economic and political interests, especially in countries heavily reliant on fossil fuels.

"As a minister once said in one of our meetings - the problem is that we don't know how to do what we need to do and get re-elected," Riishojgaard says.

According to Tarasova, there could be a way to bring monetary resources to countries that may not be able to fund observational networks themselves.

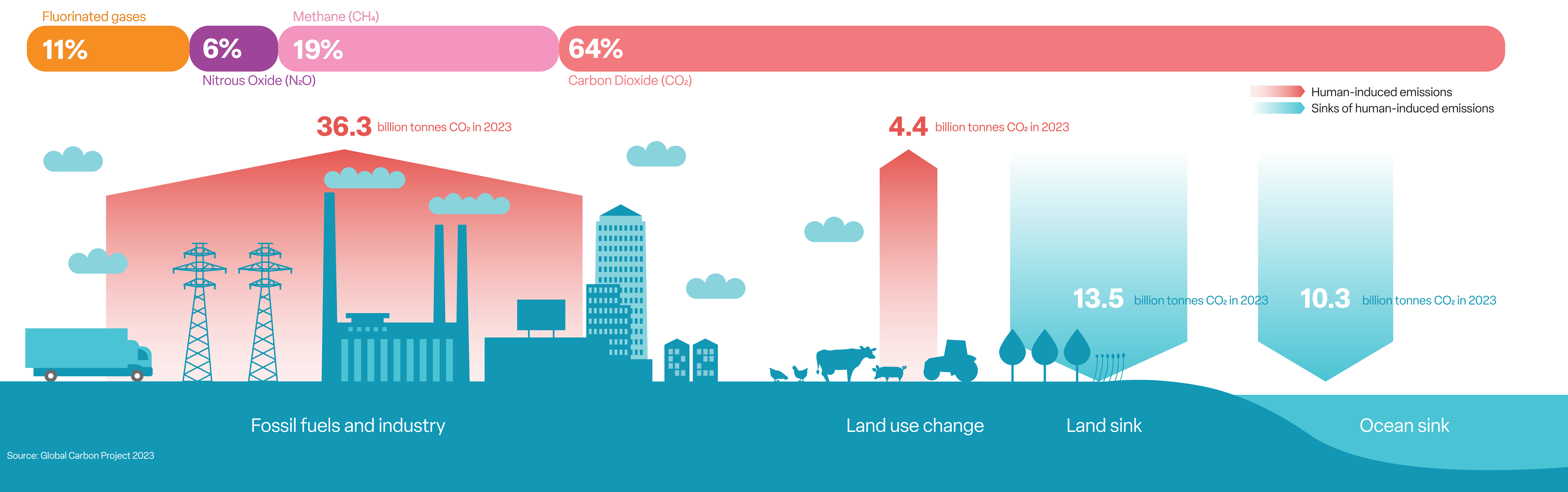
"There could be a mechanism that allows those countries that cannot meet the minimum technical or financial requirements for measurements to get funds from the G3W system. The money could come from development funds and be results-based – as long as you deliver data, you get the funding," Tarasova says.

Managing the reduction of greenhouse gases according to the Paris Agreement is a binding pact, but the world still needs concrete means to follow up on its actions.

"The nations need a reliable greenhouse gas monitoring system that is based on science and observational evidence, and that can serve the 198 UNFCCC parties, keeping the goals of the Paris Agreement within reach. The solution is the Global Greenhouse Gas Watch, which is solid, valuable and necessary to mitigate the risks that climate change poses to society," Balsamo concludes.

## Global greenhouse gas emissions & sinks

The percentages of greenhouse gas emissions show the global accumulation in the atmosphere until 2022. If current emission levels persist, the world could exceed 1.5°C of warming in seven years, according to the Global Carbon Budget.




Source: Global Carbon Project 2023

# Glossary

**carbon farming** Agricultural methods to optimize carbon sequestration in soils and terrestrial biomass by implementing practices that are known to improve the rate at which $CO_2$ is removed from the atmosphere.

**carbon sequestration** The process of removing carbon from the atmosphere and storing it in reservoirs for long periods.

**climate resilient** Able to prepare for, recover from, and adapt to impacts of climate change

**CO2MVS** $CO_2$ Monitoring and Verification Service - a global system to monitor human-induced $CO_2$ emissions, based on observations of $CO_2$ in the atmosphere, with an emphasis on new satellite missions

**COP** Conference of the Parties. Main decision-making body of the UNFCCC. Often refers to UNFCCC international meeting focusing on climate.

**Copernicus** Earth observation component of the EU Space programme, combining satellite Earth Observation and in situ data.

**data pipeline** Process of transferring data from different sources to a data repository like Carbon Portal. The process is automated, efficient and may involve quality control of the data.

**eddy covariance** A method to directly measure the exchanges of gas, energy, and momentum between ecosystems and the atmosphere

**Environment Defence Fund** A global nonprofit organisation

**Enhanced Transparency Framework** The framework guides countries on reporting their greenhouse gas emissions, progress toward their NDCs, climate change impacts and adaptation, support provided and mobilized, and support needed and received

**equitable** Dealing fairly and equally with everyone involved

**EUMETSAT** European organisation for the exploitation of Meteorological Satellites

**FAIR** Findable-Accessible-Interoperable-Reusable

**flux chamber** A box isolating area of interest from external air movement. Air flows across the isolated surface and the exiting air is collected for chemical analysis.

**GGGW, G3W** Global Greenhouse Gas Watch, WMO initiative

**greenhouse gas removals** Removal of greenhouse gases like carbon dioxide, methane and nitrous oxide from the atmosphere by natural or man-made processes

**global stocktake** Process for taking stock of the implementation of Paris Agreement goals

**greenwashing** Conveying a false impression of reducing one's emissions

**hydrofluoro-carbons** Powerful greenhouse gases found in refrigerators and air conditioners destroying the ozone layer

**inverse modelling** Using observations of greenhouse gases and flow in the atmosphere to calculate fluxes and emissions

**IPCC** Intergovernmental Panel on Climate Change

**ITMS** Project for an integrated greenhouse gas monitoring system for Germany

**leaching** In agriculture, it is the loss of nutrients in the soil due to excess run-off, rains etc

**LULUCF** Land Use, Land-Use Change and Forestry

**MEP** Member of European Parliament

**MRV** Monitoring, Reporting and Verification

**MRV4SOC** Project for Monitoring, Reporting and Verification of Soil Organic Carbon and Greenhouse Gas Balance

**NDC** Nationally determined contributions. The heart of the Paris Agreement. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change.

**permafrost** A thick subsurface layer of soil that remains below freezing point throughout the year

**plumes** Long cloud of gases (or particulate matter) released into the atmosphere from sources like volcanoes or chimneys.

**ppm** Part per million. A standard measure of the concentration of a gas in the atmosphere.

**Soil Organic Carbon, SOC** Soil Organic Carbon. It is the carbon component of organic compounds in the soil.

**surface-based observation systems** All measurements that are done at the location whether on land or water, rather than at a distance (like satellites)

**terrestrial carbon** Carbon in soils and terrestrial biomass

**The Sentinel-5 Precursor (S5P)** The first of the atmospheric composition Sentinels satellites, launched in 2017

**tier** Tier refers to the extent of various methods that are used to measure emissions. Level of precision: Tier 1 estimation, Tier 2 activity-based MRV estimates, Tier 3 verification of results.

**TROPOMI** TROPOspheric Monitoring Instrument - a satellite instrument onboard the Sentinel-5 Precursor satellite measuring trace gases like nitrous oxide, methane and ozone, as well as aerosols.

**UNEP** UN Environment Programme

**UNFCCC** The United Nations Framework Convention on Climate Change, an international climate treaty since 1992.

**venting and flaring of gases** The release and burning of gases (carbon dioxide and methane), produced as by-products of petroleum production, to the atmosphere. These releases may be necessary for safe operations.

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