European Environment Agency

Handbook on the updated LULUCF Regulation EU 2018/841

Guidance and orientation for the implementation of the updated Regulation

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List of abbreviations

Abbreviation	Name
CAP	Common Agricultural Policy
CCS	Carbon Capture and Storage
CLC	Corine Land Cover
CLMS	Copernicus Land Monitoring Service
CRCF	Carbon Removal Certification Framework
CRF	Common Reporting Format
CRT	Common Reporting Tables
EC	European Commission
EEA	European Environment Agency
EO	Earth Observation
ESR	Effort Sharing Regulation
ETS	EU Emissions Trading Systems
EU	European Union
FMCP	Facilitative, multilateral consideration of progress
FRL	Forest Reference Level
GAEC	Good agricultural and environmental conditions
GHG	Greenhouse gas
GIS	Geographical Information System
GSA(A)	Geo-Spatial Application
HRL	High-Resolution Layer (Copernicus)
IACS	Integrated Administration and Control System
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
LPIS	Land parcel information system
LUCAS	Land Use and Coverage Area frame Survey
LULUCF	Land Use, Land Use Change and Forestry
NDC	Nationally determined contributions
NECP	National Energy and Climate Plan

NECPR	National Energy and Climate Progress Report
NFI	National Forest Inventory
RED	Renewable Energy Directive
SIOSE	Sistema de Información de Ocupación del Suelo de España
TACCCP	Transparency, completeness, consistency, comparability, accuracy, publicly available
TER	Technical expert review
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Term	Meaning	Source
Accounting	The use of standardised rules for taking into account emission and removal estimates in the context of target compliance. In the context of the LULUCF Regulation, in the period 2021 to 2025, three types of accounting are differentiated: • Gross-net accounting: reported net removals or emissions are fully accounted for (applied for afforestation and deforestation); • Net-net accounting: reported net emissions or removals are compared to average emissions and removals in a base period (applied for managed cropland, grassland, and wetlands); • Accounting against a reference level: reported net emissions or removals are compared to a projected reference (applied for managed forests using the Forest Reference Level (FRL)). After 2025 all land use categories are accounted as reported (gross-net).	LULUCF Regulation
Activity	A practice that takes place on an area of land over a specific period.	
Activity data	Describes the amount of an activity that causes emissions or removals and takes place over a given period. Knowledge about activity data is necessary to calculate greenhouse gas emissions and removals.	
Afforestation	Establishing forest on lands which, historically, have not contained forests.	
Agroforestry	Collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components.	IPCC 2022, Special report on Climate Change and Land, Annex I
Anthropogenic greenhouse gas emissions and removals	Greenhouse gas emissions and removals directly or indirectly caused by human activities	
Approach (for land representation)	The complexity of methodologies for the representation of land areas is tailored to differences in data availability and capacities of countries. The IPCC defines three methodological levels for the representation of land areas:	IPCC 2006

	Approach 1 is the least complex, and Approach 3, geographically-explicit land monitoring is the most complex.	
Biomass	Organic material, in this case produced by plants. It encompasses biomass above ground and below ground, and both living and dead, e.g. trees, crops, grasses, tree litter, roots etc.	
Carbon cycle	The flow of carbon across the different components of the earth system: atmosphere, lithosphere, biosphere on land and in the ocean and hydrosphere	
Carbon dioxide equivalent	A measure used to compare different greenhouse gases based on their global warming potentials (GWPs). The GWPs are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme CO_2 over a period (usually 100 years).	IPCC 2006
Carbon pool	A system within the territory of a Member State and within which carbon, any precursor to a greenhouse gas containing carbon, or any greenhouse gas containing carbon is stored. It can be the whole or part of a biogeochemical feature. Examples of carbon pools are forest above ground biomass, wood products, soils, and the atmosphere.	LULUCF Regulation
Carbon removal	The process by which carbon is removed from the atmosphere and stored in a biogenic carbon pool, thereby leading to an increase in carbon stocks.	
Carbon stock	Mass of carbon stored in a carbon pool.	LULUCF Regulation
Climate neutrality (in the EU)	Achieving net zero greenhouse gas emissions for EU Member States as a whole	EU Climate Law
Cropland	This category includes arable and tillage land, and agro-forestry systems where vegetation falls below the threshold used for the forest land category, consistent with the selection of national definitions.	IPCC 2006
Dead organic matter (DOM)	Includes dead organic carbon (litter and deadwood). For the reporting of forest land DOM is separated into litter and deadwood.	IPCC 2006
Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the ground, dead roots, and stumps.	IPCC 2006
Emission factor	A coefficient that quantifies the emissions or removals of a gas per unit of an activity. Emission factors are often based on a sample of measurement data, averaged to develop a	

	representative rate of emission for a given activity level under a given set of operating conditions.	
Emission trend	The change of greenhouse gas emissions or removals across a time series of reported greenhouse gas emission or removal levels.	
Flux	Rate of flow of a greenhouse gas in a given time and area.	
Forest land	Land covered by trees with a minimum area of 0.05 – 1.0 hectares with tree crown cover of more than 10 – 30 per cent with trees with the potential to reach a minimum height of 2 – 5 metres at maturity. National definitions are applied within these thresholds. Forest land can be managed or unmanaged (cf. Managed forest land).	IPCC 2006
Forest management	A system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest.	IPCC 2006
Forest reference level	An estimate, expressed in tons of CO_2 equivalent per year, of the average annual net emissions or removals resulting from managed forest land within the territory of a Member State, used for accounting under the LULUCF Regulation in the period 2021-2025.	LULUCF Regulation
Grassland	This category includes rangelands and pastureland that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and is not expected to exceed, without human intervention, the thresholds used in the forest land category. This category also includes all grassland from wild lands to recreational areas as well as agricultural and silvo-pastural systems, subdivided into managed and unmanaged, consistent with national definitions.	IPCC 2006
Harvested wood product	Any product of wood harvesting that has left a site where wood is harvested.	LULUCF Regulation
Indirect Land Use Change	Land use change that results from an activity that does not directly occur on the land under observation.	
Land use	The type of activity being carried out on a unit of land.	
Land use category	As defined by the IPCC, the six reporting categories for greenhouse gas emissions and removals from the land sector.	IPCC 2006
Land Use, Land Use Change and Forestry (LULUCF)	The category of the greenhouse gas inventories where emissions and removals occurring on land, and not included in any other sector, are captured.	IPCC 2006
Litter	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10	IPCC 2006

	cm), lying dead, in various states of decomposition above the mineral or organic soil in forests.	
Living biomass	A carbon pool consisting of all living biomass above and below ground including stem, stump, branches, roots, bark, seeds, and foliage.	IPCC 2006
Managed (forest) land	Land (i.e. forest land, cropland, grassland or wetlands) that is managed, i.e. human interventions and practices have been applied to perform production, ecological or social functions. Under the LULUCF Regulation this term is used in the period 2021 to 2025 where specific accounting rules apply.	LULUCF Regulation, IPCC 2006
Methodological adjustments	Adjustments to the greenhouse gas emission inventory data submitted by a Member State by the Commission in case of changes of the methodology used by Member States to estimate inventory data. These are needed for ensuring consistency of inventory data used for assessing compliance, national targets and budgets and the Union's target. To be differentiated from technical correction.	Governance Regulation
Mineral soils	Mineral soil means soil that is mainly made up of minerals (sand, silt, clay) in varying amounts and is low in organic material.	IPCC 2006
Natural disturbances	Any events or circumstances that cause significant emissions in forests and the occurrence of which is beyond the control of the relevant Member State, and the effects of which the Member State is objectively unable to significantly limit, even after their occurrence, on emissions. For example, fires or storms.	LULUCF Regulation
No-debit rule	Ensures that emissions from in the LULUCF sector are balanced by equivalent removals of CO_2 from the atmosphere. The LULUCF Regulation applies this rule as a commitment for EU Member States to comply with in the period 2021 to 2025. Over this period accounted emissions (debits) must not exceed accounted removals (credits).	LULUCF Regulation
Organic soils	An organic soil is a soil with a high concentration of organic matter. High concentration means that it contains a thick layer of organic material and in total more than 20% or 30% or organic carbon weight depending on water saturation conditions. Every soil that is not an organic soil is classified as a mineral soil, following the 2006 IPCC Guidelines.	IPCC 2006
Reforestation	Re-establishing forest by planting and/or deliberate seeding on land previously not classified as forest.	
Reporting	Refers to the process of systematically collecting, documenting, and communicating information related to GHG emissions and removals in the LULUCF sector. This	

	reporting is essential for monitoring and assessing the impact of land use practices on climate change.	
Reporting category	Division in which emissions and removals under the LULUCF regulation must be reported.	LULUCF Regulation
Settlements	This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions.	IPCC 2006
Sink	Any process, activity or mechanism that removes a greenhouse gas, an aerosol, or a precursor to a greenhouse gas from the atmosphere.	LULUCF Regulation
Soil organic carbon (SOC)	The carbon pool that includes all organic material in soil, excluding coarse roots of the belowground biomass pool.	IPCC 2006
Source (emission source)	Any process, activity or mechanism that releases a greenhouse gas, an aerosol or a precursor to a greenhouse gas into the atmosphere.	LULUCF Regulation
Substitution effect	Refers to changes in GHG emissions in sectors outside LULUCF caused by replacing products based on fossil fuels with bio-based products.	
Technical correction	There are two types of technical corrections referred to in EU legislation: 1) In the LULUCF Regulation technical corrections are referred to in Art. 8(11) and constitute an adjustment to the forest reference level (FRL) to ensure methodological consistency between the FRL and the estimates of actual GHG emissions and removals. 2) Under the Governance regulation Art. 38, technical corrections mean adjustments to the national GHG inventory estimates made in the context of the review if it found that submitted inventory data are incomplete or are prepared in a way that is not consistent with relevant international or Union rules or guidelines and that are intended to replace originally submitted estimates. To be differentiated from methodological adjustments.	Governance Regulation, LULUCF Regulation
Tier (1 to 3)	The complexity of methodologies for estimating GHG emissions and removals is tailored to differences in data availability and capacities of countries. The IPCC defines three methodological levels, Tier 1 is the least complex, and Tier 3 is the most complex.	IPCC 2006
Wetlands	This category includes land that is covered or saturated by water for all or part of the year (e.g., peatland) and that does not fall into the forest land, cropland, grassland or settlements categories. This category can be subdivided into	IPCC 2006

	managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.	

Executive summary

Why this Handbook?

The **European Climate Law** sets the overall goal for Europe's economy and society to become climate-neutral by 2050. To achieve that goal, the European Union (EU) has agreed to reduce net greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels. Four key legal instruments will enable the 2030 emission reduction target to be met:

1) the **Governance Regulation**, which sets out rules for planning, reporting and monitoring,
2) the **EU Emissions Trading System** (ETS) and
3) the **Effort Sharing Regulation** (ESR). All three are designed to reduce GHG emissions from energy, industrial processes, agriculture, and waste.
4) the **Land Use, Land-Use Change and Forestry (LULUCF) Regulation**, focuses on emissions and removals from land use.

As the LULUCF sector is the only sector that removes carbon on large scale, it has become a key component of EU and Member State policy making in the transition to a climate neutral economy by 2050.

The objective of this LULUCF Handbook is to enable an **increase in the quality of GHG emissions and removals** in the LULUCF sector emission inventory data making use of latest methodologies and monitoring data. This will not only benefit the verification of progress towards targets but a more granular (detailed) insight in the size and changes in the carbon pools of the LULUCF sector will **enable more effective policy making** to achieve the 2030 LULUCF target and beyond. Investing in high quality data today will influence the success of land use policies in the future.

Therefore, this **Handbook is addressed not only to emission inventory experts but also those involved in land use policy making**, policy implementation and monitoring and reporting, including forestry and agricultural policy experts.

The European Commission (EC) and the European Environment Agency (EEA) are committed to updating this Handbook in the coming years, taking stock of the experience gained from the use of this Handbook by emission inventory experts and incorporating new findings on methodological developments and monitoring techniques.

Targets and budgets for the LULUCF sector

The LULUCF Regulation defines the contribution of the land sector to achieving the EU's climate targets. It sets a **Union-wide target for the LULUCF sector** to achieve net GHG removals of -310 Mt CO_2eq in 2030.

Member States' commitments are implemented in two distinct periods:

- In the **period from 2021 to 2025**, each Member State must comply with the 'no-debit' rule. This means that they must ensure that within their LULUCF sector, accounted emissions do not exceed accounted removals. Annexes 1 and 2 of this Handbook provide details of **specific accounting categories, accounting rules,** and underlying approaches.
- For the **period 2026 - 2030**, compliance with the targets is simplified:
  - The Regulation sets out **binding national targets for 2030 for each Member State**, covering all emissions and removals in the LULUCF sector **reported** in GHG inventories (Art. 4.3). Individual targets are derived from Member States'

  average historic net removals for the years 2016, 2017 and 2018 and the countries' **share of the total EU managed land area** used to allocate the EU target to Member States.
  - From 2026 to 2029, Member States must respect a LULUCF '**budget**' defined as the sum of all net removals that are required (Art. 4.4).

Improving monitoring and reporting for effective policies in the land sector

Improved monitoring, reporting and verification are at the heart of how the LULUCF Regulation will support Member States in adopting effective policies and measures in the land sector. Member States' GHG inventories will be the main **tool for tracking progress** towards targets, so methodological improvements and geographically-explicit results are needed.

GHG emissions and removals from the land sector must be reported in a **transparent, accurate, complete, consistent, comparable, and publicly available manner**. Using the best available methodologies, national GHG inventories will enable Member States to have a good understanding of developments in the land sector and to apply measures and policies in a timely and effective manner.

Higher Tiers increase the quality of calculations and avoid the use of default assumptions for some sectors or sub-sectors. **Geographically-explicit monitoring** of land use change allows Member States to track precisely what is happening on the field. Combining high quality data sets in a geographically-explicit framework helps policy makers to have a comprehensive and detailed view of the evolution of carbon fluxes and to assess the impact of their policies in a timely manner.

Guidance on how to improve monitoring and reporting for effective policies

The Handbook provides an explanation of all elements of the LULUCF Regulation, including reporting requirements and reporting principles. It then provides **practical tips and examples** on how to meet the requirements of the LULUCF Regulation regarding Tier levels, geographically-explicit information or 'Approach 3', interoperability of inventory data, and natural disturbances. Rather than going into technical detail, the Handbook emphasizes the synergies between these monitoring improvements and other policies or uses.

The practical guidance is illustrated by **nine case studies** that provide concrete examples of countries or projects that have implemented improved monitoring and reporting methodologies.

Opportunities for overcoming institutional and financial barriers to improved monitoring

The Handbook also presents **frequent institutional and financial barriers** and examples of opportunities to overcome them. A common challenge is the large number of stakeholders, including departments, agencies, and ministries in the public administration at the national level that are typically involved in data collection, processing, reporting, and verification of the LULUCF inventory. To **overcome institutional barriers** within and between Member States, the Handbook identifies strategies such as clarification of roles and responsibilities, dispute resolution mechanisms, and different forms of cooperation as well as re-use of data and information. To **overcome financial barriers**, the Handbook provides an overview of potential sources of funding from different EU programmes.

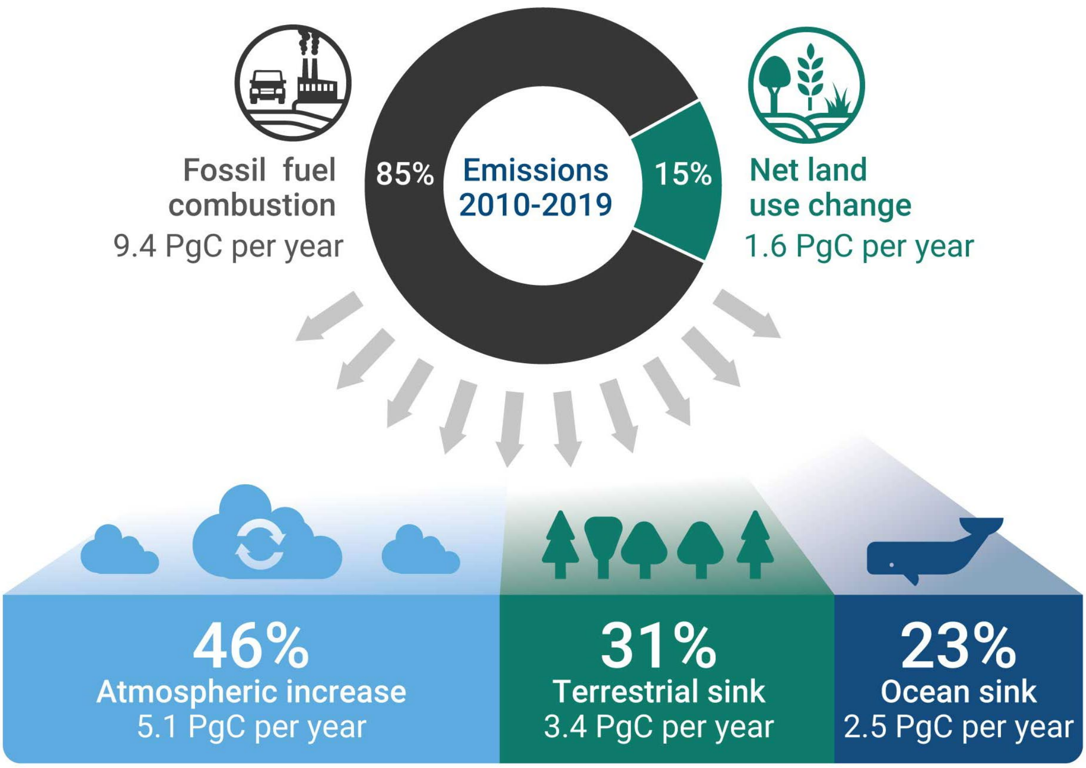
1 Introduction

1.1 Why was this Handbook created?

1.1.1 The land sector is crucial for addressing the climate crisis

Land and how we manage it is crucial for addressing the global challenge of climate change, both because it functions as a carbon sink that we need to strengthen and as a source of emissions that must be reduced. Currently, the land sector captures around 31% of annual global anthropogenic greenhouse gas (GHG) emissions (see Figure 1). It is responsible for 15% of the total anthropogenic emissions, primarily due to deforestation and peatland drainage. Policy action is necessary to protect and enhance the carbon storage capacity of terrestrial ecosystems to ensure the future storage capacity of land systems.

Figure 1: Global carbon budget 2010-2019



Source: Own compilation based on IPCC 2021, Table 5.1.

The EU 27's net terrestrial sink declined by 33% between 2010 and 2022, from -351 Mt CO_2eq to -236 Mt CO_2eq, as reported under the sector Land Use, Land-Use Change and Forestry (LULUCF) in the EU's 2021 national GHG inventory submission to the United Nations Framework Convention on Climate Change (UNFCCC). The decline in carbon removals is driven by a combination of factors. These include a rising demand for wood, more forests reaching the state of maturity in terms of biomass production, climate change impacts on forest growth, and a rise in natural disturbances such as storms, droughts, forest fires and pest infestations. The recent decrease contrasts with the increase in removals observed during the 20 years before 2010: between 1990, the starting year of GHG inventories, and 2010, removals grew by 69% from -209 Mt CO_2eq to -353 Mt CO_2eq. One reason for increased removals was a relatively low harvest intensity and a high rate of afforestation in the 1990's.

It is likely that the impact of climate change and the loss of biodiversity will lead to more frequent and intense natural disturbances. Given the important role of the land sector in storing carbon, a strategic approach to an optimised land management is required. Member States must identify and implement policies and measure that reverse the recent EU emissions trends and make use of unexploited sequestration opportunities. Moreover, policy makers by designing the right mix of policies and incentives need to ensure that the land sector becomes more resilient against climate change impacts to maintain its role as carbon sink in the future.

1.1.2 A good understanding of the land sector and its mitigation potential is required by a wider set of policy makers

The LULUCF [1] Regulation (EU 2018/841), introduced in 2018 and revised in 2023, is the primary regulation for utilising the land sector's potential for mitigating climate change of. In brief, the Regulation sets net carbon removal targets for the EU and each Member State and mandates high monitoring standards for all land-based emissions and removals across the EU (see Section 3.3 for details).

The LULUCF Regulation covers all land uses in a country and reflects the impacts of policies from a various sectors and activities that affect natural sinks: agricultural management practices, forestry, nature and biodiversity conservation, spatial planning, urban greening, transport infrastructure, soil and wetland management, peat exploitation, the use of wood products and paper, biomass energy use or food consumption trends. To optimize the land sector's contribution to climate neutrality, it is essential for a wide range of stakeholders to coordinate their actions.

Properly accounting for land emissions and removals can help Member States achieve win-win solutions or rationally manage trade-offs with adaptation, biodiversity, or the bioeconomy. The LULUCF Regulation aims to reflect enhanced removals or reduced emissions in GHG inventories promptly. This will enable Member States to implement innovative policies and profit from associated climate benefits. Therefore, all policymakers and stakeholders of the land sector, from authorities responsible for Common Agricultural Policy funding to forest managers (see Section 1.2), should become familiar with the LULUCF Regulation.

The purpose of this Handbook is to help all actors to familiarise with the LULUCF Regulation. It presents opportunities and implications for their work. The Handbook also aims to disseminate knowledge and experience on how GHG monitoring in the land sector can be improved to reflect the effects of policies and measures. This will help guide effective implementation. The Handbook highlights the advantages of improved monitoring for other policy fields.

The purpose of this Handbook is to support Member States in implementing and monitoring of land sector policies to achieve the targets under the LULUCF Regulation.

1.2 Who is the Handbook for?

The Handbook addresses experts with various backgrounds who are involved in policy making, policy implementation and monitoring and reporting.

[1] Land use, land-use change and forestry.

For those who want to have a better understanding of the land sector, its accounting rules and its integration in the overall EU climate policy framework.

You would like to get a better understanding of the LULUCF Regulation, but find the large number of technical terms confusing and challenging? Hence, you are looking for a document that is easier to read and comprehend.

- The **Glossary** provides explanations of the technical terms.
- **Section 2** explains the key concepts and approaches used in the LULUCF Regulation.

You are generally dealing with climate policies, and you want to understand how the LULUCF Regulation is integrated into the overall EU climate policy framework until 2030?

- **Section 2.1** provides information on how the LULUCF Regulation is linked to other regulations in the overall EU climate policy framework.
- **Section 3.3** focuses on understanding Member States' obligations arising from the Regulation.

For those who want to understand how forest policies or agriculture policies under the CAP contribute to the achievement of targets under the LULUCF Regulation.

Land not only stores carbon but also provides important products and services such as food, feed, wood, fibres, or other resources. Decisions on land management are hence often guided by decisions to optimise their production. If you are involved in policy making or policy implementation in agriculture or forestry and if you want to understand how your work contributes to and is relevant under the LULUCF Regulation, e.g. how eco-schemes or rural development measures under the Common Agriculture Policy (CAP) enhance removals under the LULUCF Regulation and how your policies are reflected under the regulation?

- **Section 2** offers the basics for understanding the Regulation.
- **Section 2.1** explains the relationship between the LULUCF Regulation and other policies in agriculture or forestry.
- **Section 5** provides practical guidance on how to improve monitoring and reporting to effectively capture all impacts of agriculture, carbon farming practices or forest policies that contribute to reduce GHG emissions and enhancing CO_2 removals.

For those who want to check what they need to implement

You are dealing with the implementation of the LULUCF Regulation in your country and want to understand your obligations? You also want to gain an overview of key timelines for the implementation steps up to 2030 and an understanding of the flexibilities for compliance with the targets.

- **Section 3.3** explains the requirements and obligations of Member States under the LULUCF regulation.
- **Section 5** provides practical guidance for the implementation.

For those who want to collect ideas how European data sources, research activities or examples from other EU Member States can improve their own implementation of the LULUCF Regulation

Your responsibility is to monitor and report GHG emissions and removals in areas covered by the LULUCF Regulation? And you are still facing several challenges related to data and the complete reporting of all management impacts on land areas.

- **Section 5** provides practical guidance through case studies on improving the implementation of the LULUCF Regulation.
- **Section 6** provides examples of how to address challenges related to the monitoring and reporting of emissions and removals under the LULUCF Regulation, improve data, and enhance reporting.

2 Understanding LULUCF

2.1 What is 'land use' and why is it important?

Land use activities such as cultivating crops on arable land, grazing animals on grassland, or growing trees in forests, provide the basis for human livelihoods and well-being. They supply food, multiple resources, freshwater and contribute to a wide range of other ecosystem services, as well as to biodiversity. These land use activities cause **emissions** of greenhouse gases (GHG) but also lead to CO_2 **removals** from the atmosphere through plant growth and carbon storage in biomass, soils, and wood products. To protect stored carbon or enhance carbon sequestration capacity of the land various management options are available. Such management options include planting trees, restoring natural forests, practicing agroforestry, adopting agricultural and forestry practices that protect and enhance soil carbon, protecting wetlands, restoring and rewetting peatlands, and promoting long-lasting wood products. These options can help to mitigate the effects of climate change. The LULUCF Regulation integrates the GHG emissions and carbon removals from land use and land use change into the EU climate framework to achieve **climate neutrality**. It sets targets and specific rules for reporting and accounting emissions and removals from the land sector.

The LULUCF Regulation:

- covers **three greenhouse gases:** carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O),
- defines **seven carbon pools** that should be considered: living biomass, dead organic matter (DOM) [2] (including litter and dead wood), mineral soils, organic soils, and harvested wood products (HWP),
- defines **ten land reporting categories** that correspond to
  - **six land use classes**: forest land, cropland, grassland, wetlands, settlements, and other land.
  - **four land use independent reporting categories**: harvested wood products, atmospheric deposition, nitrogen leaching and run-off, and other emissions.

The main **land reporting categories** for land use can include quite different types of ecosystems. The coverage of these categories also depends on national definitions [3]. Generally, they cover the following:

- **forest land**: land areas covered by forests and woody vegetation as defined by the national forest definition. Forest land areas may be temporarily without trees after harvest or storms and if trees will re-grow on this land area.
- **cropland:** land with annual crops or perennial crops including orchards, vineyards, or agro-forestry systems where the woody vegetation falls below the thresholds of the national forest definition.
- **grassland:** rangelands, pastures, or grassland, an any woody vegetation on grassland is included if it falls below the thresholds of the national forest definition.
- **wetlands:** areas covered or saturated by water for all or part of the year such as peatlands or water reservoirs.

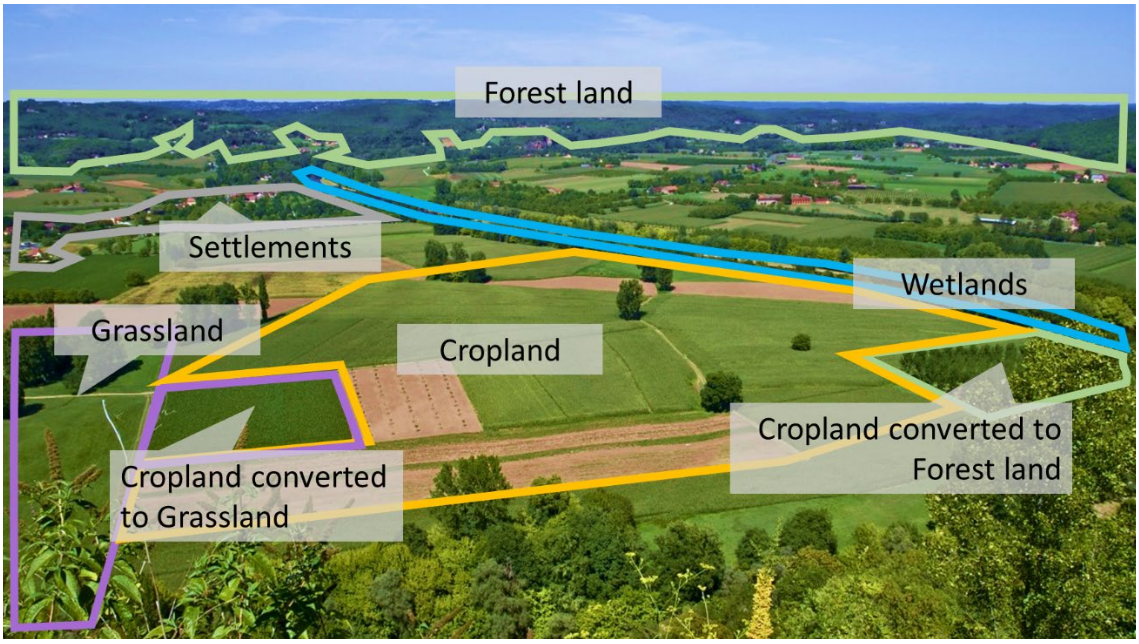
[2] Dead organic matter (DOM) includes litter and deadwood. This summary pool is used for reporting of cropland, grassland and wetland reporting categories. For forest land litter and deadwood pools are to be reported separately.

[3] The LULUCF Regulation uses the same six land-use categories defined by the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines for National GHG Inventories (2006 IPCC Guidelines).

- **settlements:** areas with human settlements, roads, or other infrastructure.
- **other land:** bare soil, rock, ice, and land that does not fall into the other categories

Each reported unit of land is assigned a land reporting category and remains in that category until a change in land use is identified. Units of land that change use are assigned to specific **transition sub-categories** that reflect the undergone land-use change (LUC). For example, when a forest area is cleared to make room for cropland, this land will be classified as 'forest land converted to cropland'. The sub-category is then reported under cropland, not forest land. The land area remains in this 'converted to' sub-category for a default of 20 years, before it moves to a 'cropland remaining cropland' sub-category.

Figure 2: Land-use categories present in a European landscape



Source: Own compilation based on https://forest.jrc.ec.europa.eu/en/activities/lulucf/.

Reporting of GHG emissions and removals under the LULUCF Regulation addresses specific **greenhouse gases:** carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases differ in their global warming potential [4] and their processes and land-use activities from which they are emitted or absorbed. Methane and nitrous oxide, also referred to as non-CO_2 GHG, make up a small proportion of total GHG emissions. Both gases are associated with biomass burning, e.g., from forest fires. N_2O and CH_4 emissions also result from peat land drainage. Direct N_2O emissions occur due to nitrogen mineralization or immobilization associated with the loss or gain of soil organic matter resulting from soil management. CH_4 emissions arise from flooded land (see also Figure 3 below). For reporting, emissions of non-CO_2 gases normally are estimated based on **emission factors** per unit of land derived from measurements and scientific literature.

Biomass growth and decomposition cause CO_2 removals and emissions, respectively. While there are emissions of CO_2 and non-CO_2 gases, removals only occur for CO_2 [5]. Unlike non-CO_2 gases, they are estimated by identifying different **carbon pools**. Carbon pools are reservoirs of

[4] Global warming potential (GWP) is a measure of how much thermal radiation a GHG added to the atmosphere absorbs over 100 years compared to CO_2. The IPCC Fifth Assessment Report assigned methane a GWP of 28, nitrous oxide a GWP of 265. This GWP is used for reporting.

[5] CO_2 removals occur through photosynthesis and the growth of biomass. There not such processes that would lead to removals of non-CO_2 GHGs.

carbon that hold a **carbon stock** (i.e. a certain amount of carbon). To estimate CO_2 emissions and removals for each pool in each land-use category, the **changes in carbon stocks** are assessed at two points in time, or the **flows of carbon into and out** of the pools are assessed over a certain period. For reporting, these estimates are calculated as annual numbers. **Carbon sinks** refer to pools that remove more carbon than they emit over one year, increase their carbon stocks over time. Pools that annually emit more carbon than they remove are referred to as **carbon sources**. When total carbon stocks across all carbon pools increase, **net removals** of carbon from the atmosphere occur. **Net emissions** occur when total carbon stocks decrease.

Changes in carbon stocks are estimated for the following carbon pools:

- **Living biomass:** differentiated into above-ground (i.e. stem, branches, and leaves) and below-ground biomass (i.e. roots);
- **Litter:** a specific pool of dead organic matter in forests;
- **Dead wood:** includes lying and standing dead trees in forests;
- **Dead organic matter** (DOM): consists of dead plant material transferred to the pools dead wood and litter; the pool is reported if dead wood and litter cannot be separated, e.g. for cropland, grassland, and wetlands;
- **Soil organic carbon** (SOC) in mineral and organic soils; and
- **Harvested wood products:** paper, wood used for construction or furniture and others.

In summary, the LULUCF Regulation provides basic rules for reporting results of rather complex processes associated with land use activities. This involves differentiating GHGs, classifying the land into reporting categories, and documenting the impact of land management on emission factors or carbon pools. In general, this concept enables Member States to report GHG emissions and removals from the LULUCF sector in a transparent, accurate, complete, consistent, and comparable way.

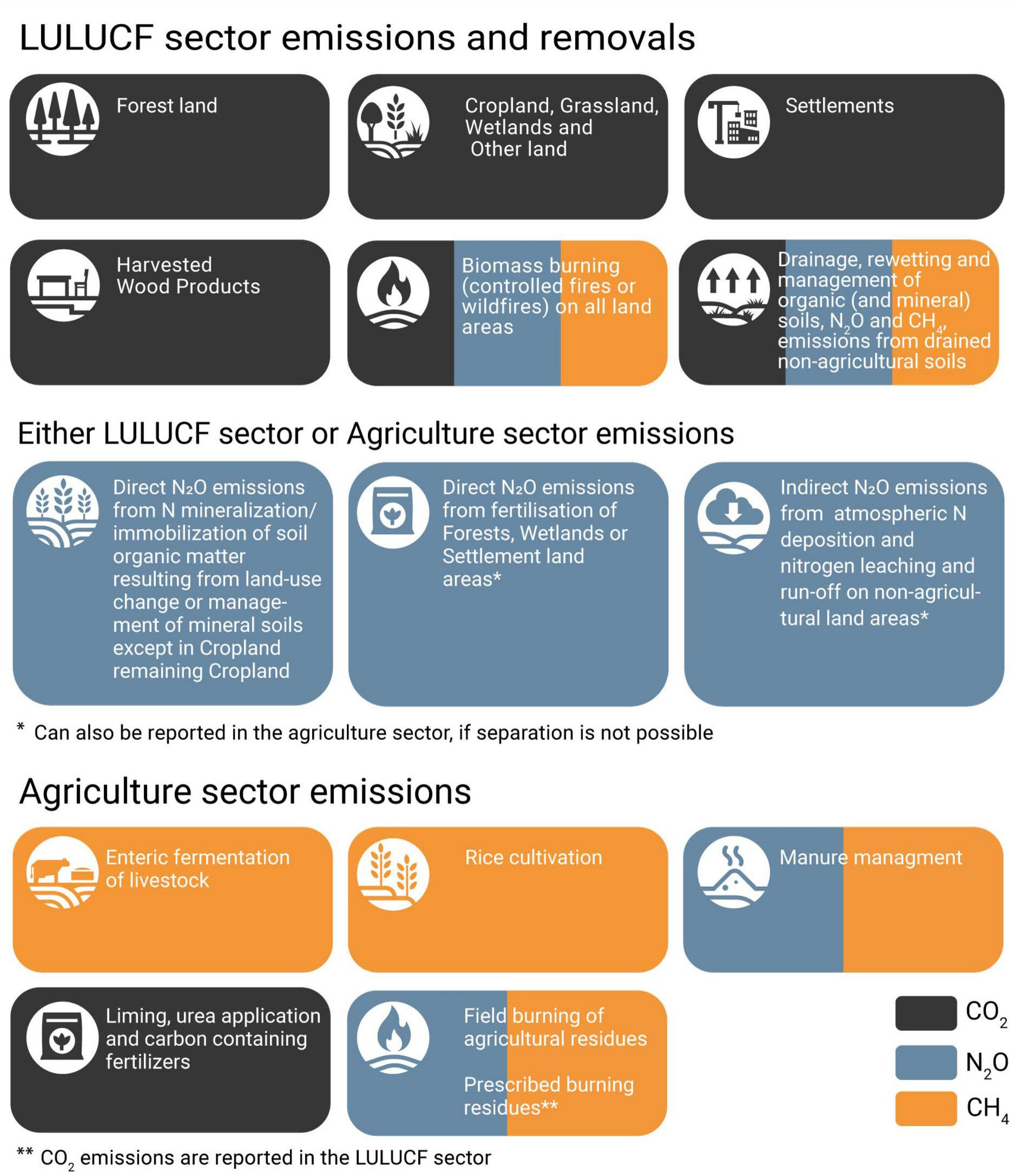
The reporting system documents land-use changes and the associated GHG emissions and removals when fully implemented. It also reflects changes in management practices within a land reporting category that occur on these areas.

2.2 What is the difference between land use, LULUCF and agriculture?

Land use refers to all activities that humans carry out on land. The EU climate policy framework maintains a regulatory separation between the agriculture and the LULUCF sector. Although agricultural and carbon sequestration activities may occur on the same land area, the resulting emissions and removals are recorded in two different sectors in the GHG inventory, although avoiding double-counting. These sectors fall under different pieces of EU legislation.

As described above, the **LULUCF sector** mainly includes CO_2 emissions and removals from biomass, soils or harvested wood products in the land reporting categories and a few land-use related sources of CH_4 and N_2O emissions. These emissions and removals are regulated through the LULUCF Regulation.

Figure 3: Overview of emission and removals sources and sinks in the LULUCF and the agriculture sector in national GHG inventories



Source: Own compilation.

The **agriculture sector** includes non-CO_2 emissions from fertiliser application, cultivation of histosols, livestock farming, including enteric fermentation in ruminant animals or manure management. The sector primarily reports on methane (CH_4) and nitrous oxide (N_2O) emissions. These emissions are regulated through the **Effort Sharing Regulation** (ESR) that sets individual targets for countries for the sum of sectors covered by the regulation [6] but not for specific sectors.

Figure 3 provides a detailed overview of how CO_2 emissions and removals, and N_2O and CH_4 emissions from agriculture and LULUCF are grouped into two different sectors within national

[6] Besides agriculture these are domestic transport (excluding aviation), buildings, small industry and waste.

GHG inventories. Emissions from fuel combustion from agriculture machinery or transport in forestry or on farms are included in the **energy** sector. These emissions are regulated through the ESR and the EU **Emissions Trading System** to be implemented in 2027 for buildings and road transport (ETS 2).

2.3 What are important features of the land sector, and how are they addressed?

There are a range of features of the land sector which the LULUCF Regulation addresses:

The land sector can lead to both emissions and removals of CO_2: Living biomass removes CO_2 from the atmosphere as it grows, while it releases GHG to the atmosphere as it decays or is combusted. To reflect this flow in the GHG inventories, the LULUCF Regulation requires reporting GHG emissions with a positive sign and CO_2 removals with a negative sign.

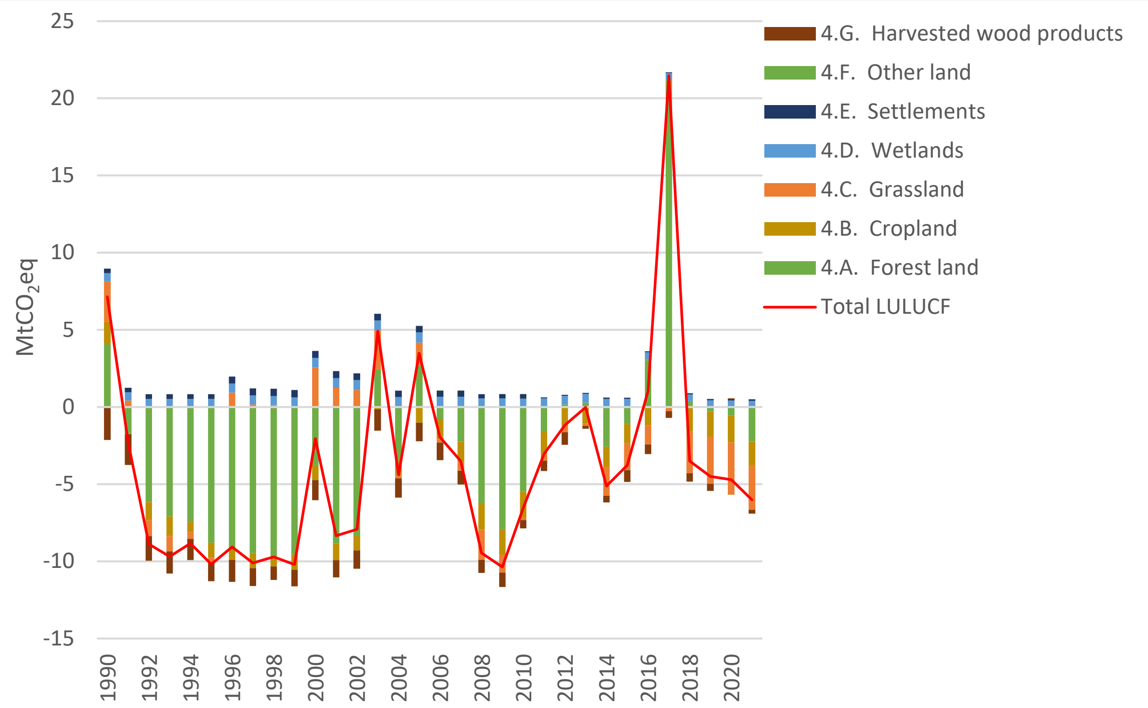
The land sector consists of distributed sources and sinks: The management of land areas leads to emissions of CO_2 and non-CO_2 gases or removals of CO_2. These emissions and removals depend on various factors, including not only the human impact, but also many site-specific parameters, for example climate conditions, soil types, tree, or plant species composition. To account for these factors, the LULUCF Regulation requires estimation methods that consider national circumstances and use geographically-explicit information.

The land sector is subject to natural and anthropogenic effects: The GHG inventories in principle cover only human-caused emissions and removals. In the land sector, natural and human processes interact, e.g., forests may recover naturally, but forest management regulates tree species composition. It is challenging to distinguish between natural and human-induced causes of emissions and removals on land. Therefore, **reporting** must include all lands and all emissions and removals. Whereas for **accounting** of GHG emissions and removals the LULUCF Regulation considers only managed land [7]. However, managed land covers 97% of the EU land area.

In the land sector, sudden and large emissions can occur due to natural impacts: Natural disturbances such as droughts, floods, windstorms, or wildfires can significantly impact emissions and removals from land use. In some years, these impacts may exceed the impacts of management practices on the same ecosystems. These events can lead to large peaks of emissions from land. Portugal experienced a high peak of emissions from forest land in 2017 due to the burning of 558 kha (6% of the country's land area) caused by forest fires, as shown in Figure 4. These emission peaks must be included in annual reporting under the LULUCF Regulation, even though they may not be entirely under human control. However, there are mechanisms for dealing with the fact that they might not be fully under the control of humans.

[7] This is according to the IPCC Guidelines which suggest that only emissions and removals should be estimated that occur on managed land, which is also known as the 'managed land proxy.'

Figure 4: Trend in emissions and removals in the LULUCF sector in Portugal



Source: National Inventory Report 2023 of Portugal, submitted under the UNFCCC.

The land sector incorporates cyclic trends and legacy effects: Emission and removals from some land use categories like forests can show regular cyclic trends, e.g. due to timber harvesting and management decisions. These management decisions, some of which were made in the distant past, can have persistent effects on emissions and removals for decades. For instance, the choice on which type of tree species are used for forest regeneration has long-term legacy effects as growth rates, the response to natural disturbances and the potential wood products are species specific. The LULUCF Regulation has specific rules for accounting emissions and removals from forests during the period 2021 to 2025.

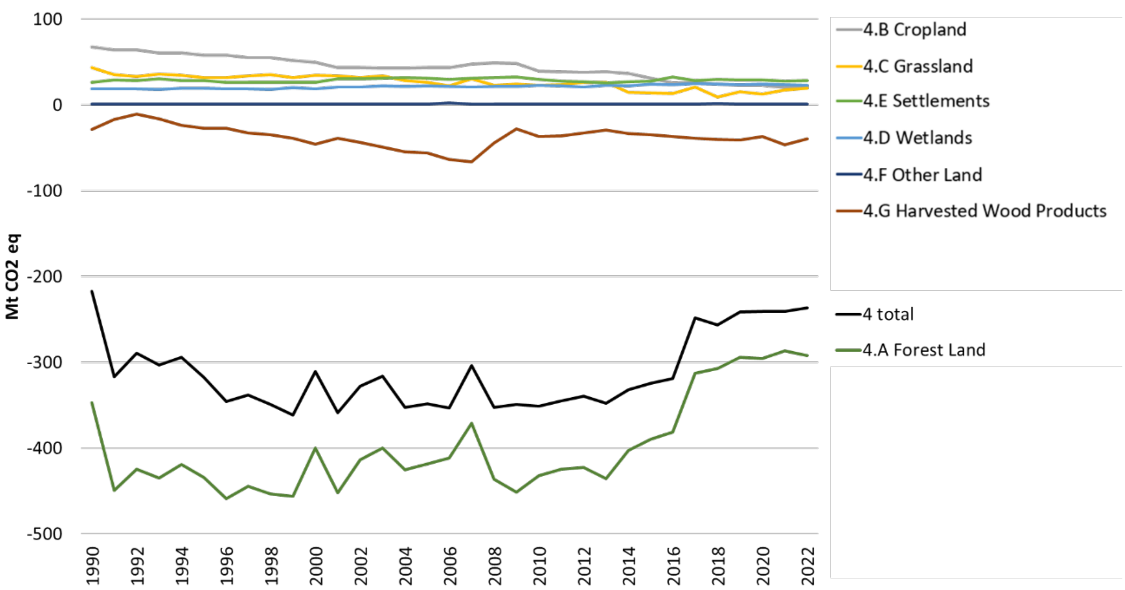
Land sector pools ultimately face saturation: At some point in time, carbon stocks in a pool, such as forest biomass or soil, reach equilibrium when gains from plant growth are balanced by losses from dying trees and biogenic carbon decay. The LULUCF Regulation mandates reporting on factors that influence this development, such as effects of forest age structure and the long-term resilience and adaptive capacity of forests.

Land sector emissions and removals have high natural and statistical uncertainties: Emissions and removals from land use are associated with higher uncertainties compared to the industry or energy sector due to the influence of many natural parameters on these processes. Additionally, there is statistical uncertainty associated with measurements and other estimation methods. The LULUCF Regulation aims to reduce uncertainty by requiring the use of advanced methodologies. By using these methodologies and better-quality data estimates can be made with greater accuracy, consistency, and detail, allowing for more effective planning of land-use sector mitigation measures.

2.4 What are the key components of GHG emissions and removals from the land sector in the EU?

On average, the net removals occurring in the LULUCF sector in the EU compensate for 7% of the total EU emissions by resulting in overall net removals from the atmosphere. In 2022, the LULUCF sector in the EU, covered land use activities on 424 Mha and was a net sink of -236 Mt CO_2eq (Figure 5). The emission trend is largely driven by forest land. Inter-annual variations in emission are primarily caused by natural disturbance events, such as windstorms in central Europe and wildfires in Mediterranean countries. The market demand for timber is another factor as well affecting net emissions.

Figure 5: EU GHG emissions (+)/ removals (-) from LULUCF sector in the period 1990-2022

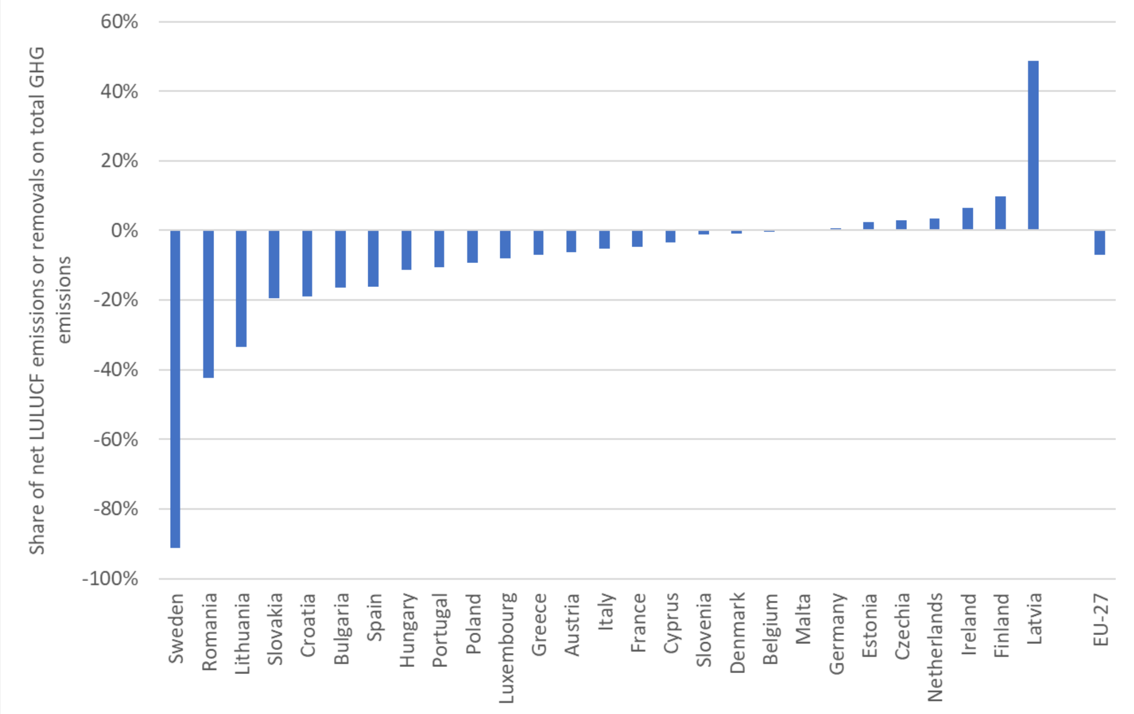


Source: EU 2024.

Forests in the EU absorb carbon, making them a significant net sink for CO_2. However, the rate of carbon stock increase has been declining since around 2013 due increased harvest rates and the impact of climate change and natural disturbances on EU forests. In contrast, croplands, grasslands, wetlands, and settlements are net sources of GHG.

The LULUCF sector's relative contribution to total emissions differs strongly among geographical regions and countries (Figure 6). Some EU Member States offset more than 20% of their emissions from other sectors through net CO_2 removals from land use, such as Lithuania, Romania, and Sweden. For other Member States, the LULUCF sector is a considerable net source of emissions (e.g. Latvia, Finland, Ireland). This indicates that the land sector differs widely among the Member States. The LULUCF Regulation incorporates national targets that consider recent data reported by countries, reflecting their national circumstances.

Figure 6: Relevance of the LULUCF sector as net sink or net source contribution to total GHG emissions in EU Member States and total EU in 2022



Source: EU 2024.

2.5 Where is biomass and its use accounted for under LULUCF?

2.5.1 Biomass used for energy

Biomass extraction from land is reported as an emission under the LULUCF Regulation in the biomass pool of the respective land use category. Biomass from annual crops is not reported because the grown biomass is harvested within one year. Therefore, emissions from bioenergy combustion, be it from annual crops or tree biomass, are not accounted for in the energy sector, to avoid double counting. The EU Emissions Trading System and the Effort Sharing Regulation assume zero emissions at the power plant or household where biomass is burnt. This makes good accounting sense and ensures that bioenergy is not 'carbon neutral' across the framework, but correctly accounted. Historically, the policy signals promoting biomass combustion have been stronger than those from the LULUCF sector, tipping the scales in favour of bioenergy despite evidence that it is detrimental to climate if the resource basis is not residues but direct harvest. Biomass use for energy as well for products can reduce fossil fuel emissions through substitution effects. These effects are reported in the respective sectors, e.g. energy and thus not visible in LULUCF reporting. The national targets set in the LULUCF Regulation are now comparable to those set in the other sectors. This should help Member States to manage the climate trade-offs involved in their forest biomass harvest and use policies, including interactions between natural disturbance risks, harvested wood products, bioenergy, and substitution effects, more explicitly (Fehrenbach et al. 2022).

2.5.2 Harvested wood products

Carbon stocks in forests and harvested wood products (HWP) are closely related and interdependent in the context of GHG reporting. Trees harvested for wood products, have their stored carbon removed from the forest ecosystem and thus reported as an emission in the forest land category.

Transferring harvested carbon into HWP, such as wood beams, paper, or furniture, delays associated CO_2 emissions until the end of the product's life. This process is reported as an inflow to the HWP pool, while the decay of existing HWP products at the end of their lifetime is reported as an outflow. The sum is reported either as a removal if the inflow is larger than the outflow or as an emission if the outflow is larger than the inflow. The carbon stored in HWP is much less than carbon in the forest biomass that is affected by timber harvest. This is because up to 30%-50% of the biomass is left to decay in the forest (including branches, roots and stumps), and some wood is lost along the processing chain. Timber is also exported and processed outside the country of origin which means it is not reported as a harvested wood product when the reporting is done following the production approach, which is the approach used by the EU for the Paris Agreement. Moreover, the largest share of harvested wood in the EU is used for bioenergy or short-lived products like paper and paperboard. Ultimately, only 10-20% of forest biomass ends up in long-lived HWP (Valade et al. 2017).

At the end of their lifecycle, HWP can undergo various fates. If left to decompose naturally, the carbon in HWP will gradually be released back into the atmosphere as CO_2 and counted as emissions from the HWP pools. If HWP are burned for energy, the carbon is directly released into the atmosphere as CO_2. When HWP are being recycled and used to make new products, the stored carbon is redirected to and stored in the new products until the end of their lifetime.

In GHG inventories, an increase in harvest reduces carbon stored in the forest pool, while it increases carbon stored in the HWP pools. Allocating more wood to long-lasting products (e.g. particleboards, insulating materials) instead of short-lived ones (e.g. paper, energy) can have higher beneficial effects on net removals compared to changes in forest management changes (Le Pierres et al. 2022; Smyth et al. 2014).

3 The wider policy context

3.1 How the LULUCF Regulation fits in the EU climate policy framework

The **European Climate Law** (Regulation (EU) 2021/1119) lays down the overall objective for Europe's economy and society to become climate-neutral by 2050. By that time, EU-wide GHG emissions and removals regulated by EU law need to be balanced. Afterwards, the EU shall aim to achieve negative emissions.

The law also sets the intermediate target of reducing net GHG emissions by at least 55% by 2030 compared to 1990 levels. **Four key legal instruments** enable the achievement of this target:

- **The Governance Regulation** [8] sets common rules for planning, reporting, and monitoring on all subjects relevant to achieving the Union's climate and energy targets.
- The **EU Emissions Trading System** (ETS) [9] and
- the **Effort Sharing Regulation** [10] (ESR) are in place to reduce GHG emissions from Energy and Industrial Processes (ETS), as well as Transport, Buildings, Agriculture, and Waste (ESR) and provide sector-specific monitoring rules.
- The **LULUCF Regulation** [11] focuses on emissions and removals occurring on agricultural land, in forests and through other land uses and land use changes (see Chapter 4 for a detailed description of requirements).

The instruments were amended in 2023 as part of the Fit for 55 package to implement the more ambitious 2030 target set under the EU Climate Law [12].

3.2 How the LULUCF Regulation works together with other EU policies

The LULUCF sector relates to various ecosystems and economic activities that depend on land and its associated services. Consequently, the LULUCF Regulation has connections and synergies with many other EU policy involve land use (Figure 7).

[8] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action (*OJ L 328, 21.12.2018, p. 1–77*)

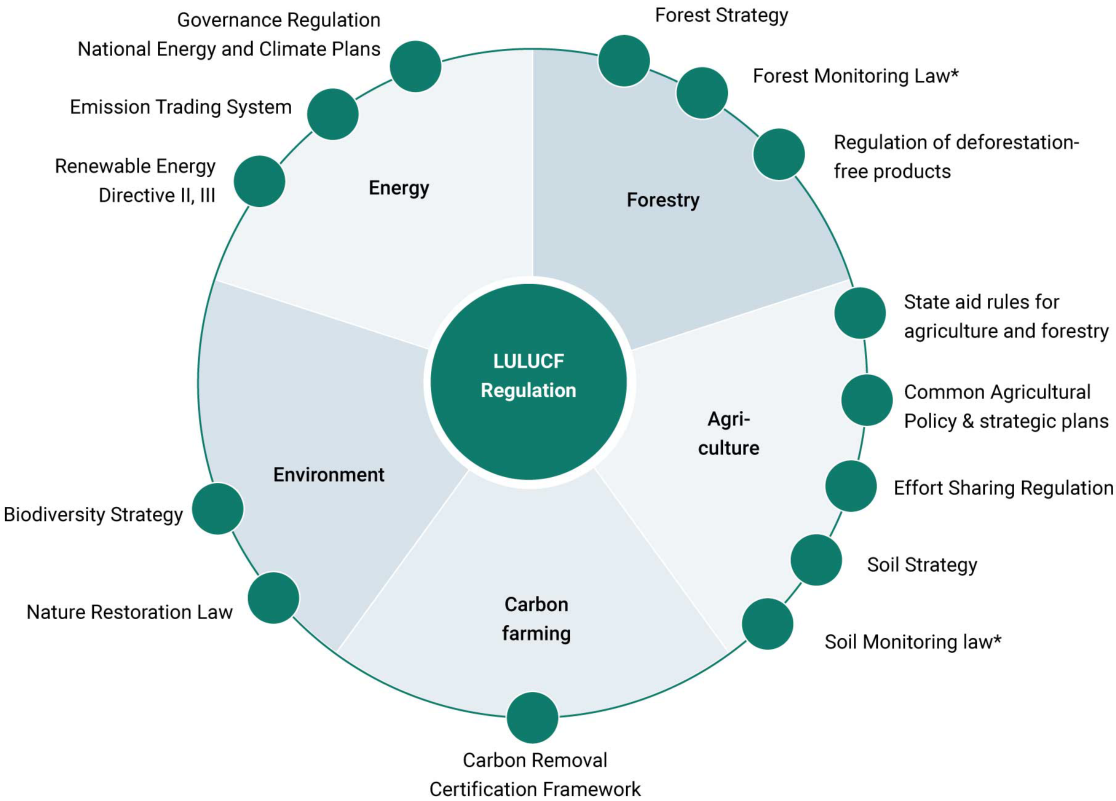
[9] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community (*OJ L 275, 25.10.2003, p. 32–46*)

[10] Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement (*OJ L 156, 19.6.2018, p. 26–42*)

[11] Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework (*OJ L 156, 19.6.2018, p. 1–25*)

[12] See (EU) 2023/959, (EU) 2023/857 and (EU) 2023/839

Figure 7: Relationship between the LULUCF Regulation and other EU policy initiatives.



Source: own compilation. * Policy proposals.

3.2.1 Common Agricultural Policy

Brief description

The **Common Agricultural Policy (CAP)** sets specific objectives for land management practices and provides funding for actions with positive effects on carbon sinks. The CAP is divided into two pillars:

- direct support consisting of in payments granted directly to farmers and
- rural development measures co-financed by Member States.

The CAP aims to contribute to climate change mitigation and adaptation, which is closely linked to the LULUCF regulation. The specific objectives to foster development and efficient management of natural resources and halting and reversing biodiversity loss also support the LULUCF regulation. This is because they promote the establishment of landscape features and soil protection, which are essential for carbon storage. Also, 24% of CAP direct payments are allocated to eco-schemes [13] that incentivise environment friendly farming practices, such as organic farming, agroforestry, or soil conservation (see Case study 1 on agroforestry).

Eco-schemes are voluntary for farmers and Member States have the flexibility to design and implement these. The CAP budget must allocate 40% to climate-relevant interventions and 10% to biodiversity objectives. At least 35% of CAP funding for rural development (second pillar) is dedicated to agri-environment management commitments, Natura2000 and Water Framework

[13] The CAP Regulation requires Member States to allocate at least 25% of their direct payments' allocations to eco-schemes. However, lower levels are permitted when Member States are spending particularly high proportions of their rural development funding on the environment and climate.

Directive payments, environmental and climate investments, and animal welfare. Rural development support can be used to finance farming practices with positive impact on the environment and the climate (agri-environment-climate measures), afforestation, agro-forestry systems, and forest restoration after natural disasters, as well as payments for conservation and payments for environmental and climate services from forests.

In addition, farmers receiving CAP support have to implement EU standards on 'Good agricultural and environmental conditions' (GAEC). Several GAECs promote CO_2 sequestration or protect carbon stored in ecosystems, such as the maintenance of soil organic matter and soil structure, the maintenance of permanent grassland, the protection of wetland and peatland, the obligation of bringing back a certain percentage of agricultural land into high-diversity landscape features or the ban on converting permanent grassland in Natura 2000 sites.

Member States outline in their CAP Strategic Plans (CSP), how they will allocate their CAP funding to different interventions to achieve the specific objectives of the CAP. The CAP is the most important source of EU funding for actions that protect and increase carbon sinks in the land sector. Meeting GAEC requirements benefits both carbon sinks and biodiversity.

Synergies with LULUCF

Under the new Common Agricultural Policy, Member States were asked to indicate in their CSP how green interventions would contribute to the long-term national targets. These targets are set out in the LULUCF Regulation and the ESR. Interventions such as eco-schemes or management commitments under rural development to incentivise paludiculture (productive use of wetlands and peatlands) on formerly drained organic soils, agroforestry, grassland management, and reforestation are mitigation measures with considerable co-benefits for biodiversity and ecosystem restoration. However, most Member States have not specified the impacts of these CSP interventions against the targets. Improved monitoring of GHG emissions and removals of CSP interventions would help quantify impacts better and achieve LULUCF targets, whereas in turn the implementation of the LULUCF Regulation could potentially build on experience and data gathered under the CAP.

3.2.2 Governance Regulation and National Energy and Climate Plans

Brief description

The **Governance Regulation** [14] requires Member States to monitor and report on status and planning related to the Energy Uni Climate Action. To that end, one of the key elements are the **National Energy and Climate Plans (NECPs)**. In the NECPs, for LULUCF, Member States need to document their targets and provide an analysis of the state of play. They should outline measures planned to reach their national legally binding targets for 2030 and provide projections to demonstrate that these measures will be adequate to reach their targets. In the case that outlined measures are insufficient, Member States need to propose additional measures and update projections. Draft updates of NECPs had to be submitted in 2023, followed by finalised updated NECPs in 2024. The next reporting round for NECPs will start in 2028.

Synergies with LULUCF

Within the NECPs ember States need to identify improvements for collecting information and monitoring needed for effective policy implementation in the LULUCF sector and specify how they plan to increase net removals [15]. The updated NECPs should also reflect the increased ambition of the LULUCF Regulation (see Chapter 4 for details). Member States should integrate

[14] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action (OJ L 328, 21.12.2018, p. 1–77)

[15] Commission Notice on the Guidance to Member States for the update of the 2021-2030 national energy and climate plans 2022/C 495/02 OJ C 495, 29.12.2022, p. 24–55.

mitigation, adaptation and nature restoration measures into their LULUCF and agriculture sectors. Concretely, updated NECPs should address planning and quantifying the following activities related to LULUCF [16]:

- "*Identification of the improvements for the system of information collection and monitoring needed for effective policy choices, design and implementation in the land use, forestry, and agriculture sectors (e.g., through satellite images). The system should include the need to ensure the effective implementation with respect to the objectives of protecting and restoring ecosystems; […]*
- *Increasing net removals in the land-use, forestry and agriculture sectors including through carbon farming, and long-lasting carbon storing materials (such as wood-based construction products), with a focus on integrated approaches such as nature-based solutions in order to also contribute to the objectives of ecosystems protection and restoration, as well as other environmental objectives (e.g., biodiversity, zero pollution, stopping natural resources depletion);*
- *Promoting and implementing energy efficiency measures related to biomass, including the supply of bio-based insulating materials.*"

The NECP process is an important planning tool for Member States as it can provide an overview of the relevant climate policies highlighting linkages between various policies. It can often serve as a useful platform for different Ministries, national authorities, NGOs and wider stakeholder groups to come together to discuss and align the national climate policies. NECPs can, provide important supplemental infer understanding trends in GHG emissions and removals in Member States. Detailed GHG inventories, as also regulated under the Governance Regulation, can also support the quantification of activities required in the NECPs.

In late 2023, draft updated NECPs submitted by Member States [17] have been assessed by the European Commission [18]. In its EU-wide assessment the Commission stated that the majority of the draft updated NECPs do not show sufficient ambition and action on land. Very few Member States showed a concrete pathway to reach their national net removal targets, or sufficient actions to assist farmers, foresters and other stakeholders in building sustainable business models in line with these targets. The aggregation of the LULUCF projections showed that the overall net removals would still lead to a gap of around -40 to -50 Mt CO_2eq compared to the 2030 overall EU value of -310 Mt CO_2eq. The final NECPs taking into account the tailored recommendations are due to be submitted by June 2024.

3.2.3 Effort Sharing Regulation

Brief description

The **Effort Sharing Regulation** [19] (ESR) establishes national targets for Member States for the reduction of greenhouse gas emission by 2030. These targets cover emissions from domestic transport (excluding aviation), buildings, agriculture, small industry, and waste. Emissions covered under the EU Emissions trading System and LULUCF emissions are not included. With these national targets Member States will collectively contribute to an emission reduction at EU

[16] Ibid.

[17] https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#national-energy-and-climate-plans-2021-2030

[18] Commission Staff Working Document Assessment of progress towards the objectives of the Energy Union and Climate Action Accompanying the document Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions State of the Energy Union 2023 Report (pursuant to Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action) SWD/2023/646 final

[19] Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013

level, in the ESR sectors, of 40% compared to 2005 levels. These targets are translated into annual emission limits for the years 2021-2030 for each Member State. For compliance under the ESR, Member States have to compare Effort Sharing emissions with their annual limits, quantified in Annual Emission Allocations (AEA).

Relation to LULUCF

For compliance under the ESR Member States can apply several flexibility mechanisms (see also section 4.3). One of these is the use of credits from LULUCF, within a certain threshold (ESR, Art. 7). If Effort Sharing emissions are higher than their annual emission limits, Member States can use up to 131 million credits over each of the 2021-2025 and 2026-2030 periods to comply with their national targets. National limits for the use of these credits are listed in ESR, Annex III. The ESR compliance framework is synchronised with the LULUCF Regulation and starts in 2027/28 and 2032/33.

3.2.4 Carbon Removal Certification Framework

Brief description

The recently adopted **Carbon Removal Certification Framework Regulation** [20] (CRCF) establishes a Union voluntary framework for certifying high-quality carbon removals and associated soil emission reduction generated by activities located in the EU. Building on best practices, CRCF requires carbon removals and soil emission reductions to meet a set of quality criteria (quantification, additionality, long-term storage, and sustainability) and rules for third party verification and certification. CRCF has been developed to facilitate and speed up the deployment of high-quality carbon removals from activities related to carbon farming, permanent carbon removals and carbon storage in products, while fighting greenwashing and harmonising rules in carbon certification markets. Supported by an expert group on carbon removals, the Commission will develop detailed EU certification methodologies to operationalise the quality criteria, considering the specific characteristics of the different carbon removal activities. The certification process will be managed on the ground by certification scheme recognised by the Commission.

The CRCF aims to facilitate the achievement of the EU's Nationally Determined Contribution (NDC) and its climate objectives, including the national targets set out in the LULUCF Regulation. While there is no direct link between the units certified under CRCF, which are based on a life-cycle assessment (LCA) methodology, and the accounting of carbon removals and soil emissions reductions towards the EU climate objectives, which are based on the relevant EU legislation and IPCC rules, the CRCF 'certificate of compliance' will contain relevant information for EU and national GHG accounting (e.g. amount of total removals).

Synergies with LULUCF

There are two dimensions to how the LULUCF Regulation and the CRCF are interlinked. Firstly, by providing harmonized MRV rules, CRCF can facilitate the upscaling and financing of carbon farming through the CAP, State aid but also voluntary carbon markets (VCMs). For instance, Member States can finance carbon farming projects that are certified under CRCF as a way to help achieving their LULUCF national targets. Corporations could also use CRCF carbon farming removals for neutralising residual emissions under their voluntary climate goals, thus contributing to increasing carbon removals in the EU.

Secondly, by collecting project level data, CRCF can help improving the quality of national GHG inventories. This can help the involved agencies in improving their methodologies and moving

[20] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals, 2022/0394 (COD)

their LULUCF reporting to higher Tier levels (see chapter 5.2). Improved national GHG inventories may eventually better capture the contribution of CRCF activities, thereby reinforcing the incentive for Member States to finance these projects. Upon entry into force of the CRCF, Article 17(3) the LULUCF Regulation requires the Commission to prepare a report on the possibility to include carbon storage products into the scope of the LULUCF Regulation. Where appropriate, the LULUCF Regulation will be revised. Moreover, more concrete methodologies for these products will be developed by means of delegated acts under the CRCF.

3.2.5 State aid rules for the agricultural and forestry sectors

Brief description

The revised **State aid rules for the agricultural and forestry sectors** align State aid with the EU's strategic priorities, in particular the CAP and the European Green Deal, as well as the Farm to Fork Strategy and the Biodiversity Strategy. The State aid rules include the Agricultural Block Exemption Regulation [21] (ABER) that exempts specific categories of aid from the requirement of prior notification [22] to and approval by the Commission if they fulfil certain conditions. In parallel, the Guidelines for State aid to the agricultural and forestry sectors and in rural areas [23] set the conditions under which the Commission assesses whether state aid measures that are not block-exempted are compatible with the single market.

The revision of State aid rules adopted at the end of 2022 has considerably extended the scope of the ABER and introduced new incentives for a change in agricultural practices beyond what is legally required, a higher incentive for forest ecosystem services, collective schemes, and result-based payments schemes, such as carbon farming schemes and a simplified procedure for the authorisation of state aid for measures co-financed under the CAP.

Synergies with LULUCF

Member States can quickly provide aid and steer domestic policies to deliver on LULUCF targets thanks to the wider possibilities to block-exempt national measures. These measures include those in favor of climate and environmental management commitments, such as result-based carbon farming schemes, and of forestry measures up to given thresholds. Moreover, new funding opportunities under the Guidelines, especially the additional incentive for forest ecosystem services beyond the mere compensation of income foregone or additional costs, contribute to upscaling and increasing uptake of carbon farming schemes and, similarly to CRCF, help Member States meeting their LULUCF targets.

3.2.6 Renewable Energy Directive

Brief description

The **Renewable Energy Directive** (RED) establishes the policy framework to promote renewable energy in the European Union. Following the initial RED I which set targets for renewable energy and energy efficiency in 2020, the Directive was extended as RED II in 2018 [24] encompassing the period 2021 to 2030. The recently revised RED III [25] aims at achieving an overall 42.5% share of

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[21] Commission Regulation (EU) 2022/2472 of 14 December 2022 declaring certain categories of aid in the agricultural and forestry sectors and in rural areas compatible with the internal market in application of Articles 107 and 108 of the Treaty on the Functioning of the European Union C/2022/9131 *OJ L 327, 21.12.2022, p. 1–81*

[22] Notification is the process by which Member States submit State aid measures to the European Commission for assessment before they implement them.

[23] European Union Guidelines for State aid in the agricultural and forestry sectors and in rural areas 2014 to 2020 *OJ C 204, 1.7.2014, p. 1–97*

[24] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) PE/48/2018/REV/1 *OJ L 328, 21.12.2018, p. 82–209.*

[25] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 PE/36/2023/REV/2 *OJ L, 2023/2413, 31.10.2023.*

renewable energy by 2030 with related national renewable energy targets and binding targets for the respective sectors. In pursuit of this goal, EU Member States have the option to complement this target with an additional 2.5% indicative top-up, allowing for the achievement of a 45% share. EU Member States need to design their strategies for meeting these targets in their National Energy and Climate Plans (NECPs, see below).

Synergies with LULUCF

RED III does not directly regulate LULUCF activities. However, the RED III provides that EU Member States must require economic operators, such as bioenergy producers, to demonstrate that the biofuels, bioliquids and biomass fuels used for achieving national renewable targets comply with EU sustainability criteria related to land use, GHG saving criteria and energy efficiency requirements. These sustainability criteria play a direct role in maintaining and enhancing carbon stocks under the LULUCF regulation. For instance, harvesting for bioenergy must be executed in a way that maintains soil quality and biodiversity and has to improve long-term production capacity of the forest. Moreover, in relation to these sustainability criteria, RED II defines high-carbon stock land. In its Article 29 (4) the Directive states that bioenergy from agricultural biomass from land that had high-carbon stocks in the past (before 2008) and explicitly mentioning wetlands, (i.e. land that is covered with or saturated by water permanently or for a significant part of the year), continuously forested areas (i.e. land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30%, or trees able to reach those thresholds in situ), and land with a tree canopy cover of between 10% and 30%. Under the LULUCF Regulation, such lands are subject to Tier 3 methods from 2030 onwards in accordance with the revised Annex V part 3 of the Governance Regulation.

3.2.7 Biodiversity Strategy and Nature Restoration Law

Brief description

In 2020, the European Commission adopted the **EU Biodiversity Strategy** [26] that contains specific commitments and actions to be delivered by Member States by 2030. These commitments include to legally protect a minimum of 30% of the EU land (i.e. an extension of the existing Natura 2000 areas) and sea, of which at least one third should be strictly protected, including all remaining primary and old-growth forests. Moreover, Member States should put in place effective restoration measures to restore degraded ecosystems, in particular those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters.

As part of the Biodiversity Strategy the proposal for a **Nature Restoration Law** (NRL) [27] establishes recovery measures that will cover at least 20% of the EU's land and 20% sea areas by 2030, and all ecosystems in need of restoration by 2050. It sets specific legally binding targets for nature restoration in each of the listed ecosystems - from agricultural land and forest to marine, freshwater and urban ecosystems. The NRL includes the target to restore 30% of drained peatlands under agricultural use by 2030 and 50% by 2050. Also, Member States should achieve an increasing trend in the stock of organic carbon in cropland mineral soils as well as the share of agricultural land with high-diversity landscape features such as hedgerows, trees and buffer stripes. For urban ecosystems, Member States should achieve an increasing trend in urban green areas until a satisfactory level is reached. Moreover, no net loss of urban green space and of urban tree canopy cover should occur by 2030 unless urban ecosystems already have over 45% of green space. In forest ecosystems, restoration measures should be implemented to enhance forest biodiversity and Member States should achieve an increasing trend in the indicators

[26] Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions. EU Biodiversity Strategy for 2030 Bringing nature back into our lives COM/2020/380 final.

[27] Proposal for a Regulation of the European Parliament and of the Council on nature restoration COM/2022/304 final.

standing and lying deadwood as well as the common forest bird index. Also, there should be an increasing trend in three out of the following five indicators: share of forests with uneven-aged structure, forest connectivity, stock of organic carbon in litter and the mineral soil, share of forest dominated by native tree species, tree species diversity. The resulting effect on CO_2 sequestration may be captured by reporting under the LULUCF Regulation.

Synergies with LULUCF

There are opportunities for Member States to meet climate goals set in the EU Climate Law by 2050 and the LULUCF land sink target in the LULUCF Regulation with a significant scaling-up of nature restoration. The NRL focuses especially on restoring ecosystems with a high potential for climate mitigation as it aims at scaling up nature-based carbon removals. Concretely the following synergies can be identified (Auberger and Noebel 2022):

- The EU GHG inventory of LULUCF sector emissions under the UNFCCC shows a net GHG sink of 249 Mt CO_2eq in 2019. Integrated scenarios estimate that the sink could be increased to a level up to -400 Mt CO_2eq or even -600 Mt CO_2eq by 2050, especially through reducing forest harvest intensity and restoring wetlands (Böttcher et al. 2021). Nature restoration is one solution in terms of tapping into this potential that can generate multiple co-benefits (Böttcher et al. 2021).
- Restoring peatland is recognized as a key GHG mitigation measure. Peatlands cover 3% of the agricultural area in the EU but emit 98 Mt CO_2 per year that correspond to 40% of reported net LULUCF removals (EU 2023). Rewetting peatland stops emissions from degraded peat, avoiding the loss of their huge carbon stocks and, under some circumstances, converts them into carbon sinks.
- National restoration plans will need to consider and work with the National Energy and Climate Plan and the national long-term strategy on climate.
- Protecting all remaining primary and old-growth forests which would be otherwise harvested also contributes to saving important forest biomass carbon stocks. Also, when Member States increase carbon stocks in litter and mineral soil, e.g. by reducing soil disturbances and changes in species composition, this contributes to the improvement of the forest sink.

Member States will have to apply IPCC Tier 2 methodologies from the inventory submission in 2028 onwards and Tier 3 methods for the estimation of GHG emissions and removals on land use units under restoration or protection from the inventory submission in 2030 onwards as outlined in Annex V part 3 of the Governance Regulation.

3.2.8 Forest Strategy and Forest Monitoring Law (Proposal)

Brief description

The new **EU Forest Strategy to 2030** [28] is an integral part of the European Green Deal and the EU Biodiversity Strategy for 2030. The Strategy builds on the multi-functional role of forests and creates a common framework for safeguarding EU forests, which is essential to achieve its climate and biodiversity targets. The new EU Forest Strategy aims to overcome the challenges related to climate change and biodiversity loss while promoting a climate-neutral economy by finding a sustainable balance between economic and environmental interests and unlock the full potential of EU forests. The Strategy provides an orientation for EU as well as Member State policies up to 2030. It contains several actions aimed at improving forest protection, sustainable

[28] Communication from the Commission t the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. New EU Forest Strategy for 2030. COM/2021/572 final.

forest management, forest data collection, and includes regulatory, financial, and voluntary measures.

As a key deliverable of the EU 2030 Forest Strategy, the Commission has adopted a proposal for a **Regulation on a monitoring framework for resilient European forests** [29], which is complementary to the proposed Soil Monitoring Law (see section 3.2.9).

The proposed Regulation mandates the Commission to set up a monitoring system in cooperation with Member States comprising (i) a geographically-explicit identification system for the mapping and localisation of forest units; (ii) a forest data collection framework and (iii) a forest data sharing framework. Such a monitoring framework will provide actors of the forest and forestry sectors open access to timely, accurate, consistent, transparent, comparable and complete information on the state and condition of forest ecosystems, promoting data-driven decision-making on forests, supporting new business models such as carbon removal certification and payments for ecosystem services and the development of a new market for providers of digital monitoring services.

Synergies with LULUCF

Forested land is the main contributor to net removals in the EU and can therefore play an essential role in meeting the commitments of European Climate Law. The EU-wide forest monitoring framework proposal will support the implementation of the LULUCF Regulation. It will facilitate standardised and comparable information, utilizing innovative Earth Observation solutions. This will enable Member States to report geographically-explicit data on forest land and monitor progress in climate adaptation and mitigation. Annual reporting on tree cover changes and forest disturbances can support Member States monitor and report of carbon stock changes. This reduces the administrative burden for Member States for compliance with EU obligations, in particular for Member States with smaller administrative capabilities.

3.2.9 Soil Strategy and Soil Monitoring Law (Proposal)

Brief description

The **EU Soil Strategy for 2030** [30] aims at an enhanced protection of soils in Europe. In 2023, the Commission proposed a **Soil Monitoring Law** [31] (SML) to protect and restore soils, to ensure that they are used sustainably and to achieve healthy soils in Europe by 2050. It establishes a monitoring framework for soils in the EU and defines sustainable soil management practices. The European mission "*A soil deal for Europe*" provides an important funding opportunity for soil health, such as a European soil monitoring framework or a network of living labs and lighthouse projects.

The proposed SML Directive will establish a robust and unified monitoring framework for all soils within the EU. This framework will enable Member States to implement measures aimed at restoring deteriorated soils, thereby promoting sustainable soil management as the standard practice in the EU. Member States are tasked with specifying the practices that soil managers should adopt and those that should be prohibited due to their potential to cause soil degradation.

[29] Proposal for a Regulation of the European Parliament and of the Council on a monitoring framework for resilient European forests COM/2023/728 final.

[30] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Soil Strategy for 2030 Reaping the benefits of health soils for people, food, nature and climate COM/221/699 final.

[31] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Soil Monitoring and Resilience (Soil Monitoring Law) COM/2023/416 final

Furthermore, Member States are required to identify potentially contaminated sites, conduct thorough investigations, and address any risks that pose threats to human health and the environment.

Synergies with LULUCF

An expectation of the proposed SML is that high-quality data on soils will become available and will increase the uptake, large-scale development, and success of new sustainable business models. This includes carbon farming as well as activities in forest management.

Regeneration of degraded soils back to a healthy condition would also serve the development and implementation of other EU policies and related plans and programmes, such as the LULUCF Regulation, the CAP and water management. The proposed SML will generate new data and assessment information on soil health and can thus also provide a service to improve land management under the LULUCF regulation.

The Governance Regulation (see above chapter 3.2.2) requires Member States to use geographically-explicit land-use conversion data and at least IPCC Tier 2 methods from 2028 onwards. The soil monitoring system includes the existing EU soil sampling programme LUCAS which is an important link between the SML and the LULUCF Regulation, as well as existing and new remote sensing products through Copernicus.

3.2.10 Regulation on deforestation-free products

Brief description

The **Regulation on deforestation-free supply chains** [32] (EUDR) was adopted in May 2023 and entered into force end of June 2023. It repeals the previous EU Timber Regulation. This regulation is designed to combat deforestation and forest degradation linked to EU consumption and production, particularly in the realm of agricultural commodities and related products. In the EU, emissions from conversion of forest land to other land uses are currently at 25 Mt CO_2eq per year that are addressed by the proposed regulation. A central feature of the regulation is the implementation of a mandatory due diligence procedure within the EU and in its supply chains. The regulation introduces a mandatory due diligence procedure: Relevant commodities and products shall not be placed or made available on the market or exported, unless (a) they can count as “deforestation-free”; (b) they have been produced in accordance with relevant legislation of the country of production; and (c) they are covered by a due diligence statement. This obligation applies both to operators and larger traders. The relevant commodities are timber/wood, soy, palm oil, cocoa, coffee and cattle, and products made from these (e.g., leather, chocolate, charcoal, printed paper etc.).

Synergies with LULUCF

The reduction of emissions from deforestation and degradation in the EU will directly contribute to the targets under the LULUCF regulation. Synergies between EUDR and the LULUCF Regulation also emerge from the databases that is required for both, assessing deforestation risks associated with products and annual emissions and removals form land use and land-use change and forestry. There are opportunities for improving the databases through data collection by operators and traders, similarly to CRCF (see above).

[32] Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010

3.3 How the LULUCF Regulation relates to other emerging mitigation technologies with land use relevance

Improving monitoring under the LULUCF regulation will increase accuracy in estimating emissions and removals of all sectors. This includes specialised activities that are particularly complex and not yet directly addressed by the above-mentioned EU policies, such as the accounting of biochar, BECCS, and blue carbon. The CRCF Regulation will develop EU certification methodologies to quantify carbon removals for these activities.

3.3.1 Biochar application to soils

Biochar is defined as a solid carbonised product created through thermochemical conversion by heating to above 300°C with limited air through a gasification or pyrolysis process. The impact of biochar on emissions and removals can be reported in the GHG Inventory, as well as the impact of related practices.

The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories provides guidance for the estimation of emissions and removals from biochar soil amendments, making it easier to report the impact of biochar (the estimating method does not need to be elaborated by the country anymore). However, the 2019 Refinement falls short of providing a Tier 1 method with default emission factors for the estimation of biochar soil amendments. Thus, Member States willing to account for biochar soil amendments need to develop representative country-specific emission factors for the biochar types used in their country (Tier 2) or more detailed activity data specifying the process conditions for biochar production, or the physical and chemical characteristics of the biochar applied (Tier 3).

Just like bioenergy accounting, carbon stock changes in soils associated with the use of biochar only tell part of the story. Emissions that occur along the biochar feedstock supply chain are estimated in other LULUCF categories or sectors. For example, the harvesting and use of wood biomass for biochar production is reported in the biomass pools of the relevant land-use categories. Emissions associated with the use of machinery for harvesting, transport, and non-CO_2 emissions from the pyrolysis of the biochar feedstocks are included in the energy sector.

3.3.2 Bioenergy with carbon capture and storage (BECCS)

Bioenergy with carbon capture and storage, or BECCS, involves capturing CO_2 from processes in combustion plants where biomass is burnt to generate energy. The captured CO_2 is subsequently stored in geological formations such as depleted oil and gas reservoirs or saline aquifers, which can result in negative CO_2 emissions.

The IPCC 2006 Guidelines make specific reference to carbon capture and storage (CCS) and provide methodological guidance for the reporting in national GHG inventories, in particular mandating plant-specific measurements and reporting. The negative emissions from geological storage and the positive emissions associated with CO_2 transport, injection in storage sites and any leakage from geological storage are to be reported separately in the energy sector. The IPCC Guidelines make no distinction between CCS using fossil or biomass fuel sources.

3.3.3 Blue carbon

Blue carbon is the carbon captured by marine organisms and stored in living and dead biomass as well as in organic compounds in the sediment (Reise et al. in press). A lot of blue carbon is stored in coastal ecosystems, such as mangroves, tidal marshes, and seagrass meadows. There is still limited information related to the amounts of carbon stored in these ecosystems, the quantification of impacts of human activities on such ecosystems and how damaged systems can be regenerated. The IPCC 2006 guidelines already include guidance for estimating and reporting of anthropogenic GHG emissions and removals from managed mangrove forests. The IPCC 2013 Wetlands Supplement and the IPCC 2019 Refinement complement guidance for tidal marshes and seagrass meadows. The reporting only covers management activities such as the construction of aquaculture ponds, drainage, extraction of soils or rewetting. It does not cover the natural GHG emissions and removals. Blue carbon is generally reported in the Wetland category, although a few exceptions may happen (see 2013 Wetlands Supplement p. 4.8).

So far, only Malta and France [33] report on blue carbon, specifically on tidal marshes as well as mangroves in oversea territories (Reise et al. 2024). One reason could be that methods for reporting GHG fluxes from coastal ecosystems as typically present in the EU are only provided in the 2013 IPCC Wetland Supplement, the use of which is authorized but not required by the LULUCF Regulation and the UNFCCC.

[33] There are mangroves in French Guyana. Moreover, methods for mangrove and seagrass restoration have been approved under the French Label Bas Carbone. For these reasons, France may soon be incited to report on these marine ecosystems.

4 Member State obligations under the LULUCF Regulation

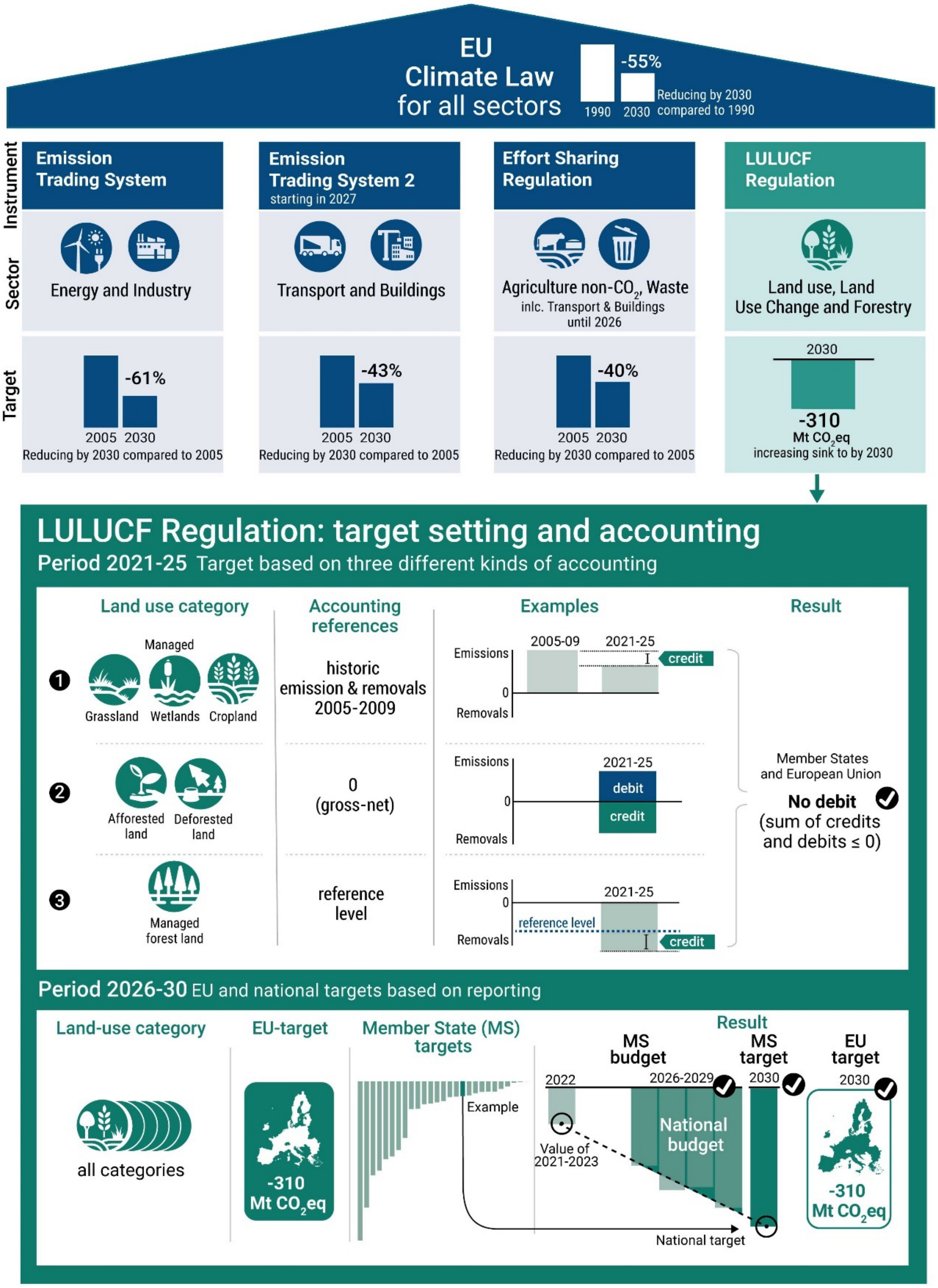
4.1 Coverage and reporting categories

The revised LULUCF Regulation sets out how land use will contribute to achieving the EU climate targets. The key revised target is to increase land-based net removals in the EU by an additional –42 Mt CO_2eq by 2030 as compared to the yearly average over the period 2016-2018. This results in the Union-wide target for net GHG removals of -310 Mt CO_2eq in 2030. The additional –42 CO_2eq target is distributed among Member States through individual targets in a way that requires each Member State to increase its climate ambition in their land use policies.

Member State commitments are implemented in two distinct periods:

- In the **period of 2021 to 2025**, each Member State needs to comply with the 'no-debit' rule. That means they need to ensure that within their LULUCF sector, accounted emissions do not exceed accounted removals. Annex 3 of this Handbook provides details of these **specific accounting rules** and the underlying approaches.
- In the **period 2026 to 2030**, the accounting towards targets is simplified:
  - The Regulation sets out **binding national 2030 targets for each Member State** encompassing all emissions and removals in the LULUCF sector reported in GHG inventories (Art. 4.3). The targets are specified in Annex IIa of the LULUCF Regulation.
  - From 2026 to 2029, there is a '**budget**' defined as the total aggregate net removals that are required to reach the target in 2030 (Art. 4.4). In practice, this is defined by a linear trajectory, with a start point in 2022 and end point in 2030.

Figure 8: Overview of EU climate policy architecture and Member States' obligations under the LULUCF Regulation



Source: Own compilation.

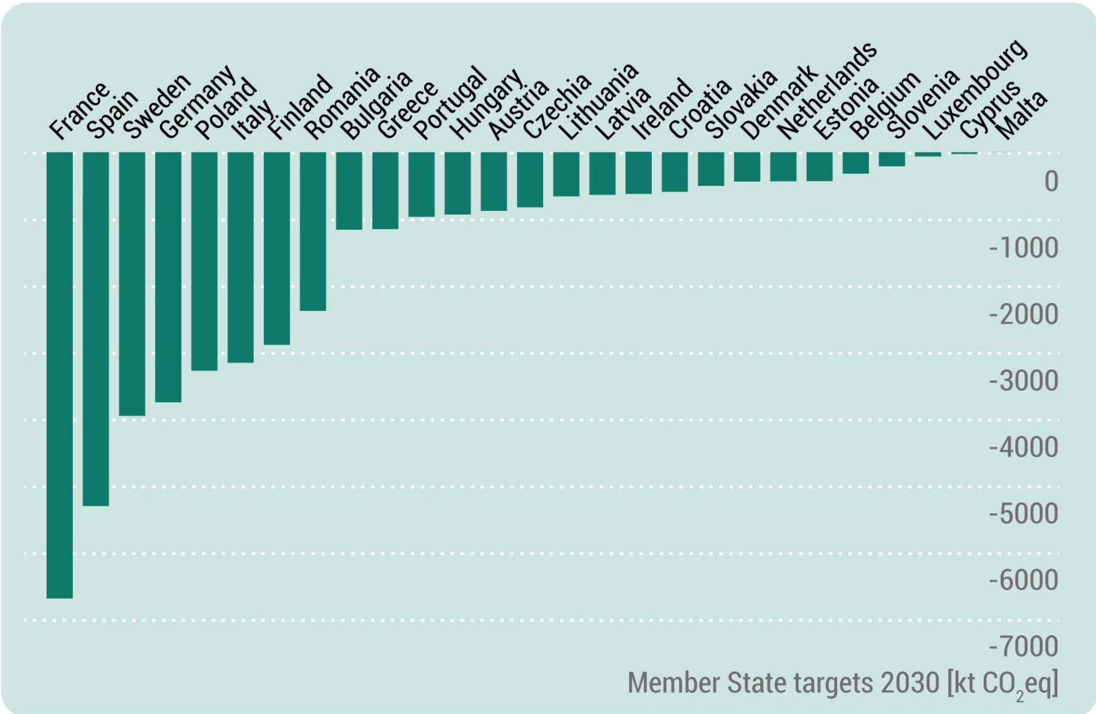
After 2025, the compliance against the targets is assessed directly through the GHG emissions and removals reported in annual GHG inventories that Member States already provide with their reporting obligations under the UNFCCC. Robust estimates of emissions and removals with high accuracy and timeliness will thus be needed to allow for a reliable assessment of progress towards targets.

4.2 National target and budget setting

4.2.1 From the Union target to national targets

To achieve the Union-wide target of -310 Mt CO_2eq an increase of the net sink by -42 Mt CO_2eq is required, compared to the yearly average of the period 2016 to 2018. The effort to achieve this additional carbon sequestration is shared between Member States. Each of them thus is incentivised to implement measures to enhance removals and reduce emissions from the LULUCF sector (Art. 4.3, Figure 9). The individual values of the net GHG removals in 2030 for Member States are based on (i) Member States' yearly average historic net removals from their GHG inventories for the years 2016, 2017 and 2018 and (ii) the countries' share of total EU managed land area**,** which was used to allocate the total increase in net removals to Member States (see calculation example in Figure 10). Not all Member States reported a net sink for the base years of the period 2016 to 2018; however, the individual targets require each Member State to increase their climate ambition in land policies.

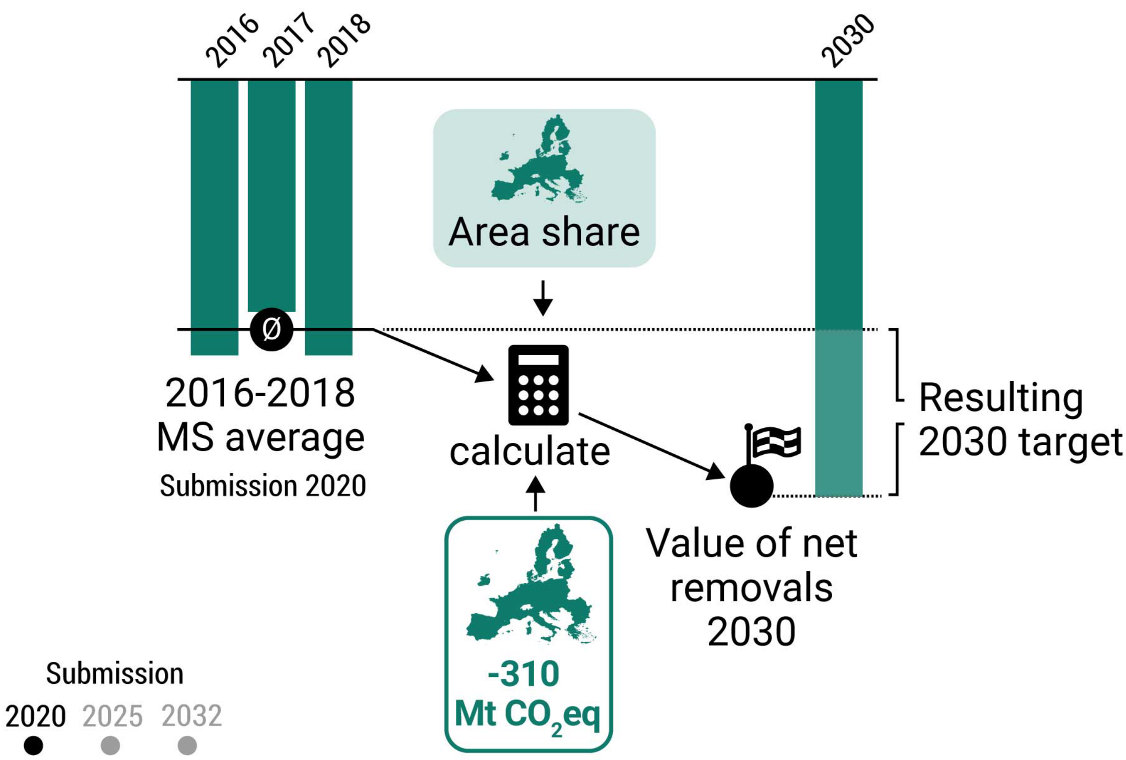
Figure 9: Member States' targets in 2030 under the LULUCF regulation



Source: Own compilation based on LULUCF Regulation (EU) 2018/841 amended by 2023/839, Annex IIa.

Figure 10 shows an example of target setting using this approach. The light green bar indicates the resulting national 2030 target (column C in Annex IIa of the LULUCF Regulation) which is equivalent to the length of the bar shown in Figure 9. This target is added to the average net GHG emissions or removals of the years 2016 to 2018 as reported in GHG inventory submission 2020 (column B in Annex IIa of the LULUCF Regulation) to achieve the value of the net GHG removals for the year 2030 (column D in Annex IIa of the LULUCF Regulation). The national target may change due to recalculations of the net removals or emissions for the years 2016-2018 that become necessary if changes in the estimation methods applied are occurring (see section 4.4, Figure 14).

Figure 10: Example of Member States' target calculation for 2030



Source: Own compilation.

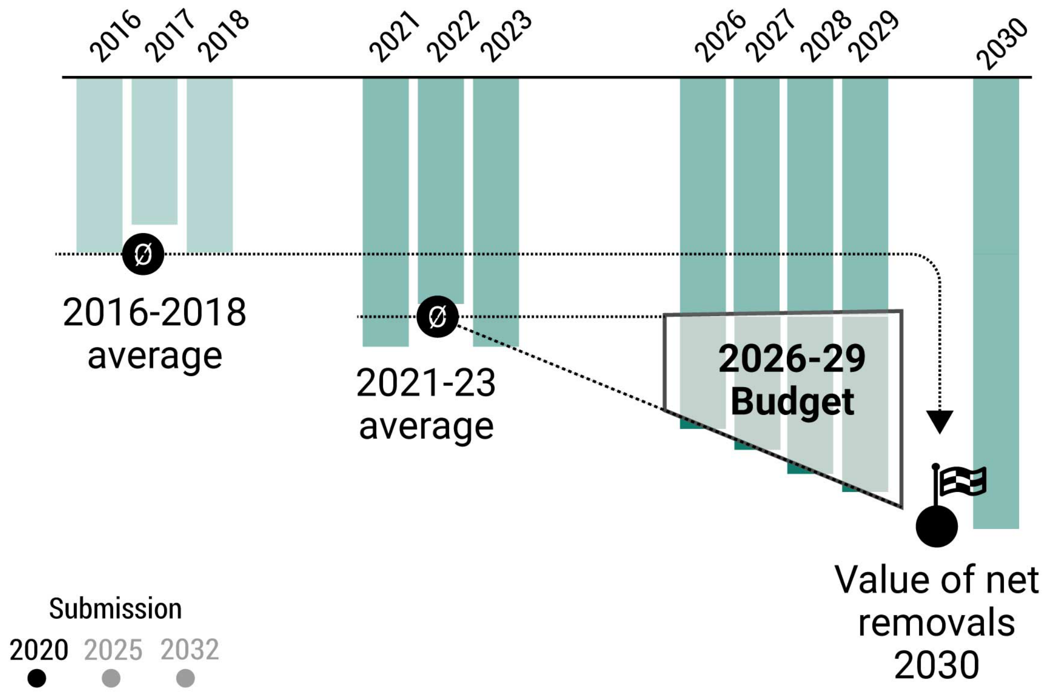
4.2.2 National budgets

For the years 2026 to 2029, net emissions and removals in Member States should stay within a **national budget** (Art. 4(4), Figure 11). The elements to calculate the budget are the following:

a. The average yearly net values of the GHG inventory data for the years 2021 to 2023, as reported in 2025.
b. The value of net removals for 2030, calculated as described above.
c. A linear trajectory starting in 2022 at the average value for the years 2021 to 2023 (see a. above) and ending at the 2030 target level of emissions and removals (see b. above). This trajectory delivers values for the years 2026, 2027, 2028, 2029.
d. Annual values calculated for the years 2026 to 2029 as set by the trajectory.
e. The sum of the annual values calculated for 2026 to 2029 gives the 2026-2029 budget.

The budget will be laid down in an implementing act, after a comprehensive review of the **GHG inventory submitted in 2025 (see also chapter 4.6)**.

Figure 11: Example of a Member States' budget calculation 2026-2029



Source: Own compilation.

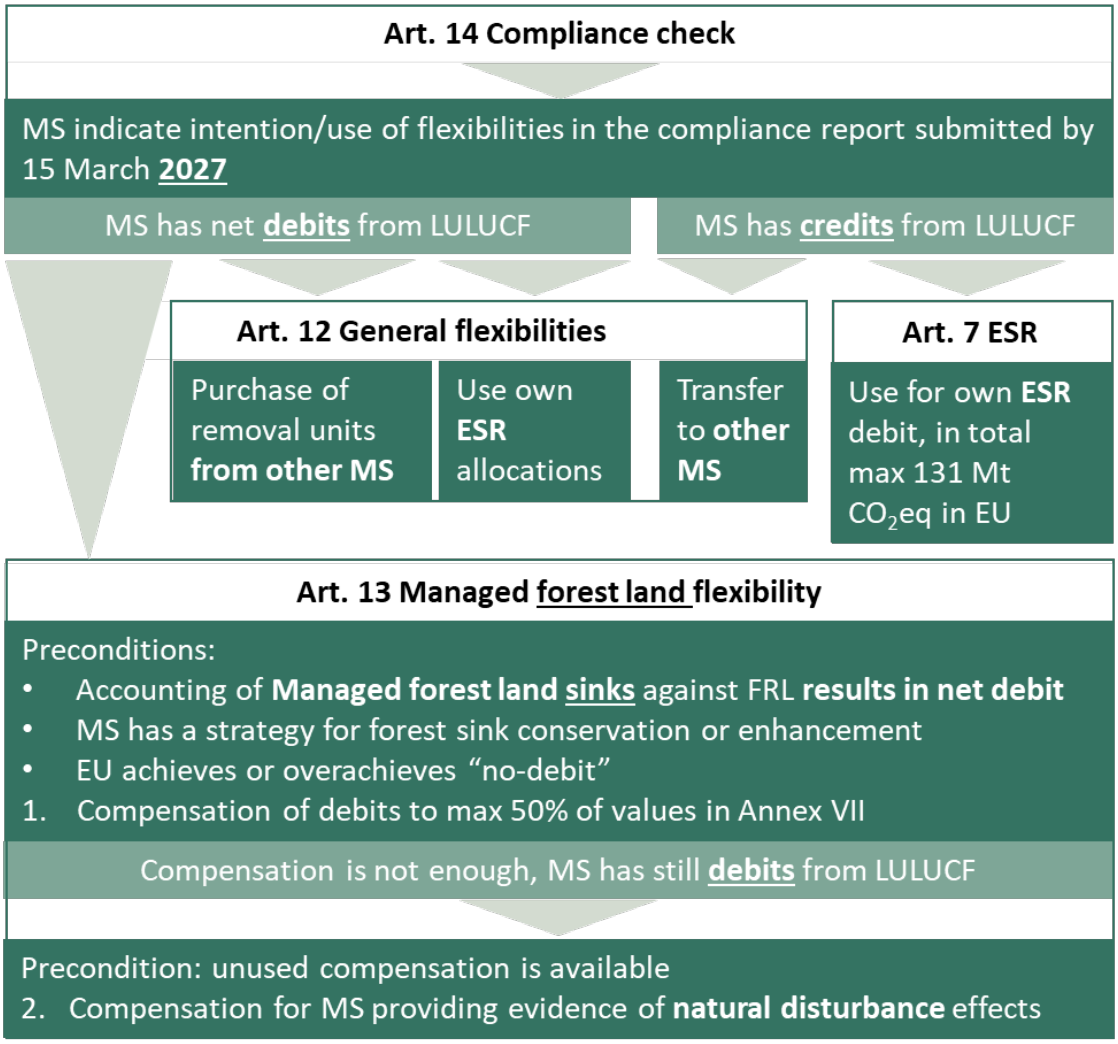
4.3 Flexibilities

There are several flexibilities Member States can make use of under the LULUCF Regulation (Figure 12, Figure 13). The **general flexibilities** are within the LULUCF sector among Member States and with the ESR. If a Member State does not meet its LULUCF target or budget, it can deduct annual emission allocations under ESR to LULUCF (Art. 12.1). If a Member State outperforms its LULUCF target and budget, it can transfer its LULUCF remaining overachievement to a Member State that needs it to meet its target (Art. 12.2). It might also use the LULUCF overachievement for compliance under the ESR. This amount is constrained per Member State and for all Member States to a maximum of 50% of 262 Mt CO_2eq by the ESR (Art. 7(1), Annex III), for each period (2021 to 2025, and 2026 to 2030).

For the years 2021 to 2025 Member States have access to the **managed forest land flexibility mechanism** (Art. 13). If a Member State fails to reach their 'no debit' commitment, and managed forest land results in net emissions (debit), that Member State may compensate the debit from sinks accounted for as emissions provided it has included measures to ensure conservation or the increase in forest sinks in their long-term strategies submitted under the Governance Regulation and emissions do not exceed removals in the Union as a whole. In addition, the compensation must not exceed 50% of the maximum compensation for the Member State as set out in Annex VII of the LULUCF Regulation.

In the event that a Member State's total emissions exceed total removals, and after using the compensation attributed to that Member State as set out in Annex VII of the LULUCF Regulation, any remaining emissions may be compensated up to an amount unused by other Member States of the full compensation for the period 2021 to 2025 set out in Annex VII of the LULUCF Regulation. Accessing this flexibility is conditioned upon the submission of evidence to the Commission demonstrating the impact of natural disturbances and the measures to be put in place to avoid or mitigate similar impacts in the future. If the demand for compensation exceeds the unused amount, the compensation will be proportionally distributed among duly justified requests by the Member States concerned

Figure 12: Overview and decision tree of options for the use of flexibilities under the LULUCF Regulation for the period 2021 – 2025.



Source: Own compilation based on LULUCF Regulation.

In addition, a **land use mechanism** (Art. 13b) for the years 2026 to 2030 can be used by Member States that do not meet their target, or budget, or both. There are a number of preconditions for making the flexibility available to Member States. These include that

- overall the **EU achieves its target**,
- Member State **exhausted flexibilities from Article 12**, and
- Member States **reported on measures** to protect their carbon sinks or enhance them in their NDCs.

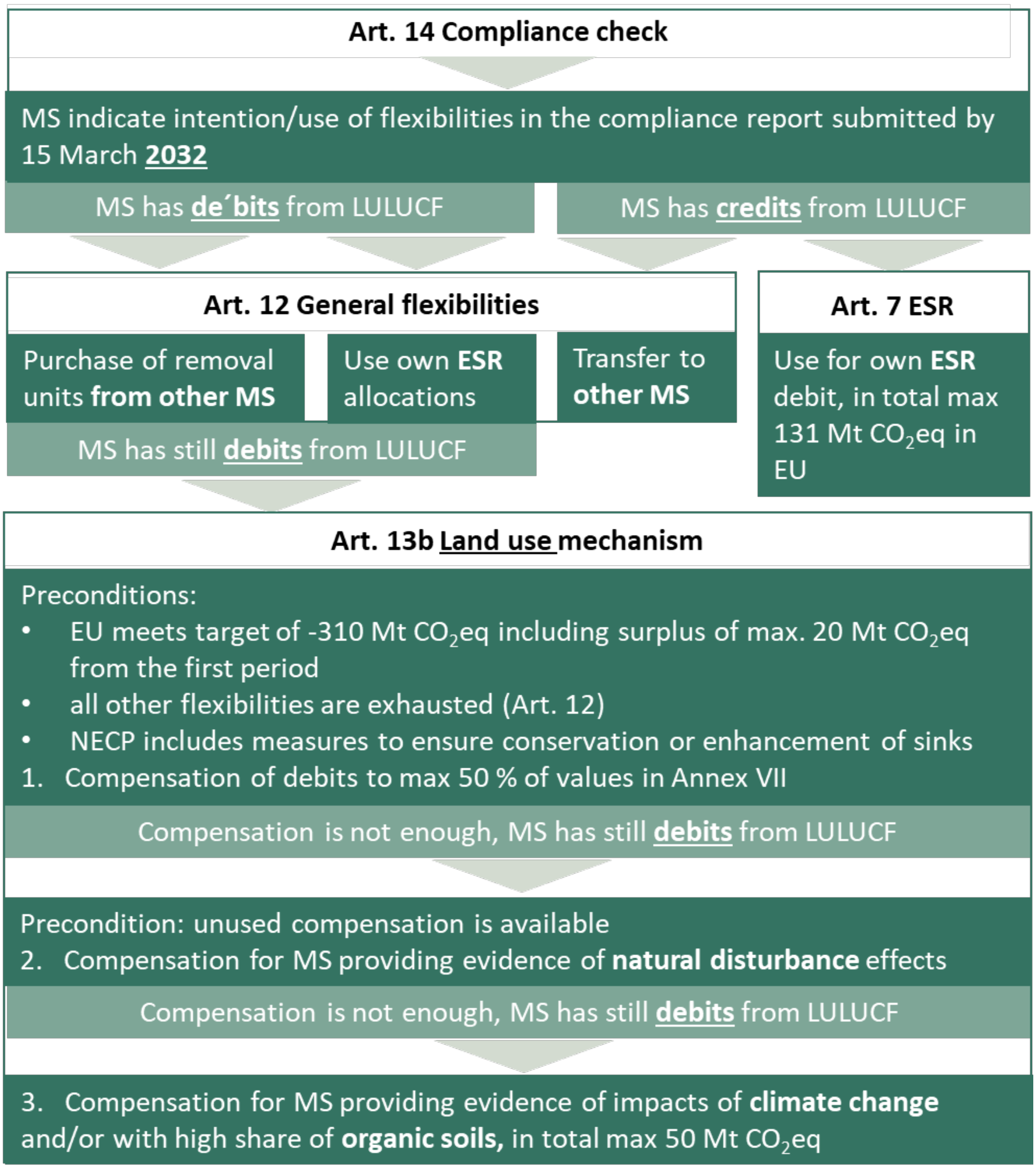
The flexibility is capped at 178 Mt CO_2eq. for all Member States, i.e. 50% of the national maximum amounts provided in Annex VII of the Regulation[34]. Different rounds of compensations are foreseen. The first round allows Member States fulfilling the conditions to compensate their debits without additional requirements. In case Member States cannot fully compensate their debit, more compensation is granted to Member States that provide evidence that debits occur due to impacts of natural disturbances. However, this second round only applies if there is unused compensation available under the mechanism. In a third round, Member States can compensate remaining debits up to another 50 Mt CO_2eq of unused compensation from other Member States of the years 2021 to 2030 if they either can provide evidence that these can be **attributed to climate change impacts** or arise because they have a higher **share of organic soils** compared to the EU average.

If the demand for compensation exceeds the maximum amount of 50 Mt CO_2eq, that compensation will be proportionally distributed among duly justified requests by the Member States concerned.

As for emissions that go beyond the control of a Member State, this Handbook provides information on how an attribution of emissions to natural disturbances and climate change impacts can be made in Section 5.5.

[34] Only up to 50% of the values provided in Annex VII compensation is granted under this mechanism for the period 2026-2030.

Figure 13: Overview and decision tree of options for the use of flexibilities under the LULUCF Regulation for the period 2026 – 2030.



Source: Own compilation based on LULUCF Regulation.

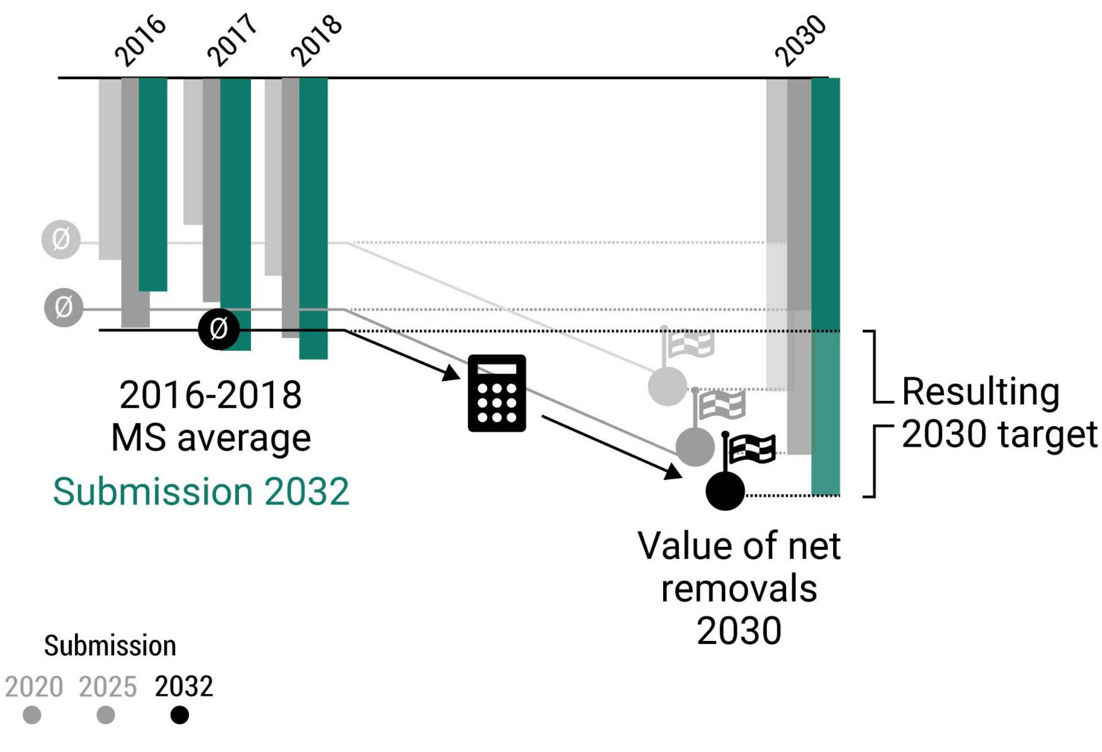
4.4 Compliance

Compliance with the LULUCF Regulation is assessed in 2027 for the period 2021-2025 and in 2032 for the period 2026-2030. In both years there will be a comprehensive inventory review (see chapter 4.6). For the first period, Member State and the EU compliance will be assessed against the ‘no-debit’ commitment in accordance with accounting rules (see Annex 3). For the second period, Member State and the EU compliance will be assessed against the targets set out in Annex IIa of the LULUCF regulation. Only after the compliance checks under the LULUCF Regulation have been completed in 2027 and 2032, the compliance cycle under the ESR will start. More information on the timing and action points for Member States can be found in section 4.7.

As shown in Table 1 and explained in chapter 4.2, GHG inventory data of different years is relevant for the calculation of Member States' budgets, the 2030 targets and compliance in both periods. For the calculation of compliance with both the 2030 target (Figure 14) and the budget for the period 2026-2029 (Figure 15), the **reviewed GHG inventory data submitted in 2032** will be used.

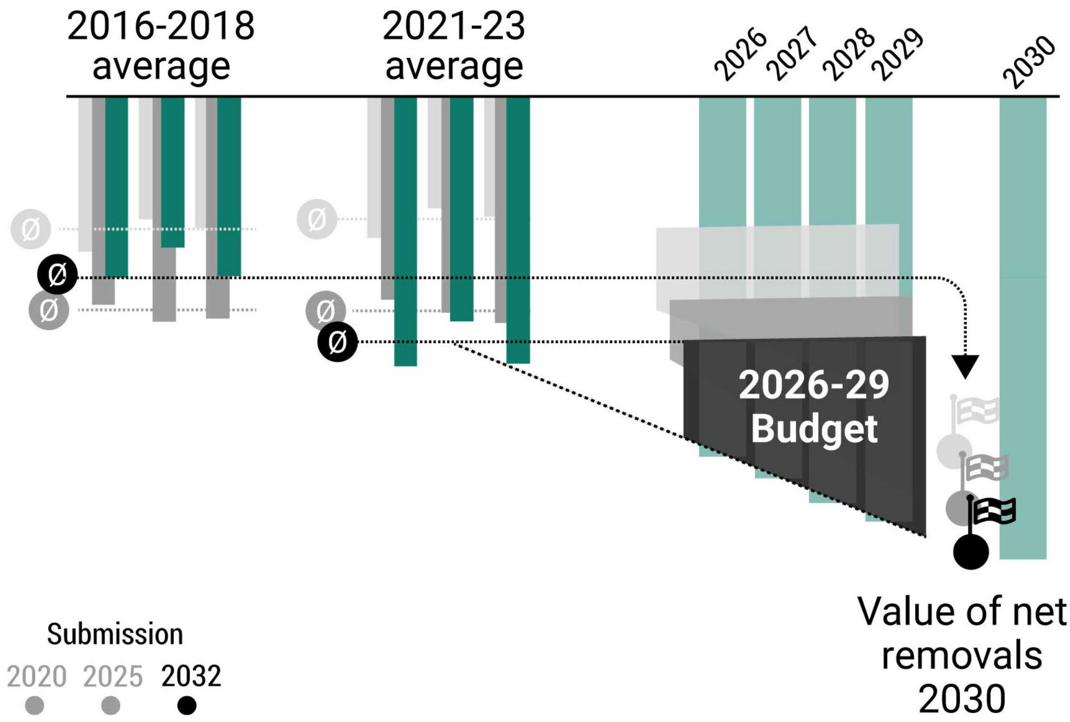
Member States are encouraged to update their methodologies and report using higher Tier methodologies to increase the accuracy and level of detail of their GHG inventories. Such changes can affect the consistency of inventory data used for assessing compliance, national targets and budgets and the Union's target. Therefore, **methodological adjustments**, can be applied by the Commission to ensure consistency. Practically, these adjustments reflect the difference of the average data from 2016 to 2018 between the 2032 inventory submission and the one of 2025, in which 2030 targets have been calculated for the linear trajectories (see Figure 14). The adjustments do not affect the Member State targets nor the Union target of -310 Mt CO_2eq in 2030 (Art. 14a). Instead, the Commission can adjust Member State inventory results (see example in Figure 14) to ensure that the compliance with the European total is still below -310 Mt CO_2eq, despite the overall change in the EU greenhouse gas inventory. This is achieved by using the original target share of this target between Member States (Art. 4 2) together with the methodological adjustment, or difference between the inventories as described above. A similar adjustment is applied in the checking of compliance for the budget (2026 to 2029). An example of compliance calculation in this situation is presented in Figure 15.

Figure 14: Example of Member State target calculation 2030 for compliance



Source: Own compilation. Note: Example of a calculation of the resulting target 2030 with a Member State target -2 Mt CO_2eq.

Figure 15: Example of Member State target calculation of the budget 2026-2029 for compliance



Source: Own compilation. Notes: Example calculation of Member State budget in the year 2032.

4.5 Methodological requirements

The LULUCF Regulation aims to enhance the accuracy and precision of the Member States' LULUCF inventories through the application of the IPCC concept of higher Tiers and through an enhanced monitoring of land-use change, using geographically explicit data.

Methodological improvements in GH inventories that increase the accuracy of reported emissions and removals from land are key for successful implementation of multiple EU policies. Under the LULUCF Regulation, targets as well as compliance assessment are now based on what Member States report in their GHG inventories. Improved monitoring of land will also be needed for achieving objectives related to protecting biodiversity, transforming food systems, protection of soils, as well as adaptation and climate resilience.

The current methodologies applied by many countries to report emissions and removals need to improve to allow for higher levels of accuracy, precision, and timeliness. Conveniently, recent technological developments, for example products from Copernicus Services and digitally collected data under the Common Agricultural Policy are now available and can help Member States in improving their monitoring and reporting of the land sector.

Using the best available methods, the national GHG inventories will be able to track changes, to reflect policies, and to track whether the targets are met. The best available methods will empower Member States to have a good knowledge of the developments in land sector and to apply measures and policies in a timely and effective manner. Higher Tiers increase the quality of the calculations, avoiding applying default assumptions for some sectors or subsectors. Using geographically-explicit monitoring of land use changes allows Member States to precisely track what is happening on the field. Combining high quality datasets in a geographically-explicit framework helps policymakers to have a comprehensive and detailed view of the evolution of carbon fluxes and assess the effect of their policies in a timely manner.

4.6 Inventory Reviews

A review consists of checking the quality of inventories. It is periodically conducted at European and international level by teams of experts. Each country's methods and results are reviewed following the key principles of transparency, accuracy, consistency, completeness and comparability. The reviews aim to check for the good application of IPCC guidelines, and that reporting requirements under UNFCCC, and EU legislation are met. The expert review teams examine data, methodologies and procedures used in preparing the national inventory. It pays attention to key categories, areas of the inventory where issues have been identified and recommendations made in previous reviews, progress in the implementation of the planned improvements, or where recalculations have occurred.

The updated LULUCF Regulation is accompanied by a specific review process. A comprehensive review is planned for 2025 to verify the greenhouse gas inventory data up to the year 2023 [35]. The average of the years 2021, 2022 and 2023 reported and reviewed in 2025 is considered the basis for setting the linear trajectories. Another comprehensive review is foreseen in 2027 and 2032, before the compliance check against Member States' targets is carried out.

These reviews are conducted by the Commission, assisted by the European Environment Agency (EEA) [36]. The EEA is responsible for performing quality assurance and quality control procedures in the preparation of the Union GHG inventory, compiling the inventory, and assisting in conducting the inventory review under Article 38 of the Governance Regulation.

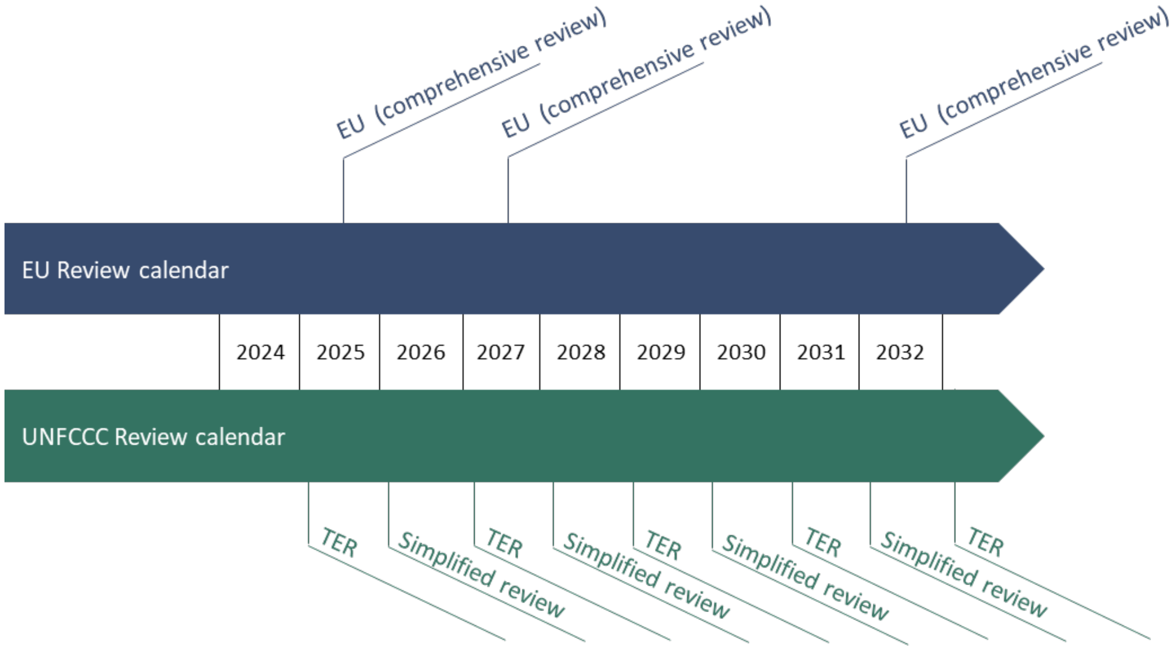
The comprehensive review shall include [37]:

- Checks to verify the transparency, accuracy, consistency, comparability and completeness of information submitted (see chapter 5.1, Table 2, for details on these principles defined by IPCC);
- Checks to identify cases where inventory data are prepared in a manner which is inconsistent with UNFCCC guidance documentation or Union rules (available IPCC Guidelines for Greenhouse Gas Inventories are presented in chapter 5.1);
- Checks to identify cases where LULUCF accounting is carried out in a manner which is inconsistent with UNFCCC guidance documentation or Union rules; and
- Where appropriate, calculating technical corrections necessary, in consultation with the Member States. (Note that such technical corrections after Art. 38 of the Governance Regulation may include technical corrections of the FRL after Art. 8(11) of the LULUCF Regulation but are addressing the entire GHG inventory, see also Glossary).

These reviews under the Governance Regulation are conducted in addition to UNFCCC review processes. Indeed, annual review of individual inventories of each Annex I Party became mandatory in a Decision by the Conference of the Parties in 2003 [38], this review process is just slightly modified in the framework of the Paris Agreement.

[35] REGULATION (EU) 2023/839 (27)
[36] See REGULATION (EU) 2018/1999 Article 42 Role of the European Environment Agency
[37] REGULATION (EU) 2018/1999: Article 38 Inventory review and Annex XXII of Implementing Regulation 2020/1208
[38] Decision 19/CP.8: UNFCCC guidelines for the technical review of greenhouse gas inventories from Parties included in Annex I to the Convention

Figure 16: Timeline for reviews under EU and UNFCCC. TER - Technical Expert Review.



Source: Own compilation.

Reviews in the framework of the Paris Agreement

In the framework of the Paris Agreement the review process is framed around the technical expert review (TER) [39].The TER of the Biennial Transparency Report (BTR) may be conducted in one of four different formats:

1. A centralized review is when the members of a technical expert review team conduct the review from a single, centralized location. During a centralized review, a single technical expert review team could review several Parties.
2. An in-country review is when the members of a technical expert review team conduct the review in the country of the Party undergoing a technical expert review. In-country visits will be scheduled, planned, and take place with the consent of, and in close coordination with, the Party subject to review.
3. A desk review is when the members of a technical expert review team conduct the review remotely from their respective countries.
4. A simplified review of a Party's national inventory report involves the secretariat undertaking an initial assessment of completeness and consistency with the Modalities, Procedures and Guidelines, consistent with the initial assessment procedures. A review of the findings of this initial assessment will form part of the consequent technical expert review of the Party's national inventory report.

A Party's national inventory report submitted in a year in which a biennial transparency report is not due shall be subject to a simplified review. A follow-up of the findings of the simplified review will form part of the technical expert review in the subsequent year.

The TER is followed by a facilitative, multilateral consideration of progress (FMCP) undertaken with respect to the Party's efforts under Article 9 of the Paris Agreement and the Party's respective implementation and achievement of its NDC. Both TER and FMCP are key elements of the enhanced transparency framework.

[39] 18/CMA.1 Modalities, procedures, and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, paragraph 151

4.7 Steps for the implementation of the LULUCF Regulation

Table 1 shows the relevant steps for the implementation of the LULUCF Regulation up to 2032.

Table 1 Timeline for LULUCF Regulation

Year(s)	Articles	Content	Relevance
2023-2032	Gov. Reg., Art. 26(2), Art. 26(4)	**MS**: Annual reporting of GHG inventory data for the LULUCF sector; in each inventory submission in year y, the most recent year is year y-2; by 15 January preliminary data, by 15 March final data; by 31 July approximated data for year y-1	Base information for target setting process and compliance
2024; 2026; 2028-2031	Gov. Reg., Art. 37 (4a)	**COM (EEA)**: Annual initial checks of submitted LULUCF inventory data and targeted verification of relevant historic inventory data, without a comprehensive review	Check for larger deviations (beyond 500kt) and ensure consistency
2024	LULUCF Reg. Art. 17(2)	**COM**: Report on the operation of the LULUCF Regulation (within six months of the first global stocktake)	Report to the European Parliament and the Council on the operation of the Regulation
2025	Gov. Reg., Art. 38, LULUCF Reg. Art. 4(5)	**COM**: Comprehensive Review of GHG inventories data	Calculation of linear trajectory and budget 2026-2029 for Member States by means of implementing acts
2027	LULUCF Reg. Art. 14	**MS**: 15 March: Submission of compliance reports by Member States for the period 2021-2025, including the intention to use flexibilities	Calculation of LULUCF numbers 2021-2025 and draft accounting results for the 'no-debit' rule
2027	Gov Reg, Art. 38, LULUCF Reg. Art. 14	**COM**: Comprehensive Review of GHG inventories data. Assessment of technical corrections to Forest Reference Level (FRL) and eventual recalculations of FRL.	Calculation of final LULUCF numbers 2021-2025 and final accounting results, need for the use of flexibilities
2027	LULUCF Reg. Art. 14	**MS + COM**: Compliance check 2021-2025 and use of flexibilities	Registry transactions, Compliance check 2021-2025

Year(s)	Articles	Content	Relevance
2032	LULUCF Reg. Art. 14	**MS**: 15 March: Submission of compliance reports by Member States for the period 2026-2030, including intention to use flexibilities	Calculation of LULUCF numbers 2026-2030 and draft results
2032	Gov Reg, Art 38, LULUCF Reg. Art. 14	**COM**: Comprehensive Review of GHG inventories, to calculate average net emissions and removals 2016 to 2018. Calculation of methodological adjustments and final cf. 2030 EU wide and Member State targets. Report prepared by the Commission.	Calculation of final LULUCF numbers 2026-2030, need intention to use of flexibilities
2032	LULUCF Reg. Art. 14	**MS + COM**: Compliance 2026-2030 and use of flexibilities	Registry transactions, Compliance check 2026-2030

Source: Own compilation.

5 Guidance for improving monitoring and reporting for effective policies

5.1 Improving monitoring and reporting for effective policies

Attaining the EU's 2030 climate target and achieving climate neutrality in 2050 relies on reducing emissions and increasing removals from the land sector. Policymakers across all Member States therefore need to be able to design targeted policies and incentives that allow the land sector to exploit carbon removals and emission reduction potentials. The design and adjustment of these policies requires more timely and more accurate monitoring systems that allow tracking of improved land management practices and their impact on carbon stocks (see Sections 1.1.2, 3.2 and 5.6.2). The LULUCF Regulation places a strong emphasis on **improving the quality of monitoring and reporting** because it is**:**

a) a prerequisite to compliance checks against the targets it sets;
b) a necessity for the integration with other policies (see Section 3.2);
c) an essential tool to support informed decision-making by policymakers.

GHG inventories contain information on the **level** of emissions and removals in each year and on the **trend** of emissions and removals across the time series of inventory years. Estimating emissions and removals in the LULUCF sector requires accurate measurement of the land areas associated with a specific land use and with land-use changes (**activity data**) and the sequestration and emission factors linked to these land uses and management types (**emission factors**). **Standardised methodologies** for estimating emissions and removals from LULUCF are provided by the IPCC (2006 IPCC Guidelines, the 2013 IPCC Wetland Supplement and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories).

IPCC Guidelines for Greenhouse Gas Inventories

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) are the basis for reporting GHG emissions and removals in the EU and under the UNFCCC. They specify the mathematical equations of the method, information on emission/ sequestration factors and other parameters relevant for the method, and sources of activity data (e.g. land areas in the land use sector). Methods are provided at different levels of detail and complexity (see Section 5.2 on Tiers), allowing inventory compilers to estimate all emissions and removals source categories even with limited resources and focus their improvement efforts on those categories that contribute most significantly to national GHG emissions and removals and to the emission trends.

The IPCC continuously works on improving methods for GHG inventories. In 2013, it issued the 2013 IPCC Wetlands Supplement (IPCC 2014), which includes methodologies to estimate emissions from more types of wetlands previously not covered, for rewetting of peatlands, and provides updated and more specific emission and sequestration factors, and other methodological elements.

The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (referred to as 2019 IPCC Refinement, IPCC 2019) also updates and supplements the 2006 IPCC Guidelines. Monitoring technologies related to remote sensing significantly advanced in the LULUCF sector. This recent technological progress and how it can be used for improved inventories is addressed in the 2019 IPCC refinement. For soil organic carbon, the 2019 IPCC

Refinement added a methodology for biochar amendments to mineral soils and improved guidance for soil models.

Member States are required to ensure that the data provided are accurate, complete, consistent, publicly accessible, comparable and transparent (Article 5(1) of the LULUCF Regulation). Table 2 explains what is meant by these six quality criteria – the so-called TACCCP principles.

Table 2: The TACCCP principles from Article 5(1), quality criteria for GHG inventories

Quality	Description (IPCC 2006 guidelines, volume 1, Introduction)
Transparency	There is sufficient and clear documentation such that individuals or groups other than the inventory compilers can understand how the inventory was compiled and can assure themselves it meets the *good practice* requirements for national greenhouse gas emissions inventories.
Accuracy	The national greenhouse gas inventory contains neither over- nor under-estimates so far as can be judged. This means making all endeavors to remove bias from the inventory.
Completeness	Estimates are reported for all relevant categories of sources and sinks, and gases. Geographic areas within the scope of the national greenhouse gas inventory are covered. Where elements are missing their absence should be clearly documented together with a justification for exclusion.
Consistency	Estimates for different inventory years, gases and categories are made in such a way that differences in the results between years and categories reflect real differences in emissions. Inventory annual trends, as far as possible, should be calculated using the same method and data sources in all years and should aim to reflect the real annual fluctuations in emissions or removals and not be subject to changes resulting from methodological differences.
Comparability	The national greenhouse gas inventory is reported in a way that allows it to be compared with national greenhouse gas inventories for other countries. This comparability is ensured by the use of the reporting guidance and tables and use of the classification and definition of categories of emissions and removals.
Publicly available	This sixth principle is an addition of the LULUCF Regulation to the IPCC original TACCC principles. Its meaning is not detailed in the Regulation but given the emphasis on interoperability with other databases and geographic information systems in both the LULUCF and Governance Regulations, the intent of the co-legislators is to go beyond publishing the inventory report and datasheets towards geographic portals where inventory data is accessible at a fine spatial resolution.

Source: Own compilation.

To adapt to differences in data availability and capacity, methodologies are provided at different levels of complexity. For the representation of land areas, these levels are called ‘Approaches’; and for estimation methodologies, they are called ‘Tiers’ (Figure 17). A key objective of the LULUCF Regulation is to help Member States move towards higher Approaches and higher Tiers.

Figure 17: Complexity of monitoring method: Approaches and Tiers

Tier 3 **High res. data (e.g. model)**	Not applicable	Modelled data combined with LUC matrix (not necessarily spatially dis-aggregated)	Geo-information at high-resolution, detailed time series, country-specific disaggregated data based on inventories and/or models
Tier 2 **Country specific values**	National area statistics, combined with country-specific values – typical 1st improvement	Annual LUC stats, combined with country-specific values	Geo-information, time series, country specific values – good coverage, detailed analysis
Tier 1 **IPCC default values**	National area statistics, combined with IPCC default values – basic entry level	Annual (or annualised) LUC stats presented as national matrix – applied using default IPCC values	Geo-information, time series, default values – weak, but better than App 1 and 2
	Approach 1 **National statistics**	**Approach 2** **Land Use Change matrix**	**Approach 3** **Geo-tracked**

Reduced Uncertainty

Improved Coverage and Representation

Source: EC 2016.

The enhanced monitoring for LULUCF mandated by the Regulation is necessary to improve countries' knowledge and control of the emissions and removals occurring in the land sector. Enhanced monitoring for LULUCF using geographically-explicit datasets, in particular, allows the implementation of high-resolution calculations (see for example Case study 2 on high resolution maps and policies in Denmark), although the resolution is ultimately limited by the resolution of all activity data, emission factors, calculation parameters and specific information needed for different areas.

Case study 2: High resolution maps for efficient incentives and norms in Denmark

Environmental policies are often based on a benchmark: a maximum level of pollution allowed a threshold above which further action is subsidized, etc. Improving the local relevance of the benchmark increases the cost-efficiency of a policy. Denmark has already applied this rationale to two environmental policies: peatland rewetting and nitrogen limits.

Read more on Case study 2.

Enhancing monitoring is possible through three complementary ways:

- **Better use of high quality and high-resolution available datasets**, using national and European datasets that provide geographically-explicit information useful for the calculations. Interoperability is key, to facilitate use of these datasets and allow for analysis using combinations of datasets about land use, biomass, soil, forest, agriculture, nature protection, nature disturbances. A geographically-explicit framework for calculation allows such use of relevant datasets in a consistent manner,

- **Enhanced calculation methods**, with higher Tiers implying the use of very detailed parameters (accuracy of pools, complexity of equations, dependency on time),
- **Higher spatial and temporal resolution of calculation**, with a geographically-explicit approach allowing the calculation to reflect differences in parameters and management in different zones.

These three ways for enhancing LULUCF monitoring are complementary: a geographically-explicit approach for the monitoring of land use change areas is only of limited use if Tier 1 assumptions are used for the carbon fluxes calculations. The intent of the LULUCF regulation is to provide a consistent set of methodological principles to help countries move to higher-resolution and more accurate calculations, which use already available high-quality datasets, and can monitor LULUCF emissions and removals at a scale that reflects impacts of land management and policy implementation.

In the following Sections, practical tips and examples are provided on how to meet the requirements of the LULUCF Regulation regarding Tier levels (5.2), geographically-explicit information or Approach 3 (5.3), interoperability of inventory data (0), natural disturbances (5.5), tracking progress towards the target (5.6), and projections of GHG emissions and removals (5.7).

5.2 Tier levels

5.2.1 What does the LULUCF Regulation say?

The LULUCF Regulation aims to precisely monitor policies and actions as well as their impacts on GHG emissions. Its reporting-based targets also requires accurate and timely estimates of greenhouse gas emissions and removals. Member States are especially encouraged to use advanced technologies available under Union programmes, such as Copernicus, and national high-quality data. This ambition is in line with other European strategies: the EU Biodiversity Strategy for 2030, the communication of the Commission of 20 May 2020 on a Farm to Fork Strategy for a fair, healthy and environmentally friendly food system, the New EU Forest Strategy for 2030, the EU Soil Strategy for 2030. This is why the LULUCF Regulation establishes stringent methodological requirements that improve the accuracy of reported information. The calculation methods in the LULUCF Regulation are classified according to Tier levels in line with the IPCC guidelines:

- **Tier 1** methods (the default method) use readily available statistical data and default emission factors from the IPCC Guidelines. The Tier 1 emission factors also assume typical processes on land areas for certain regions. This method is often not very accurate for emissions and removals from land use and land use changes.
- **Tier 2** methods (the intermediate method) are similar to Tier 1 in terms of methodologies, but default emission factors are replaced with country-specific emission factors developed on the basis of knowledge of the types of processes and specific conditions that apply in the country for which the inventory is being developed. This method should lead to an improvement of estimates over Tier 1 because default values proposed for Tier 1 are based on a large spectrum of references that are not always representative of each Member States.
- **Tier 3** methods (the most detailed method) are more complex, they encompass country-specific methodologies based on measurement data at high level of resolution and repeated measurement campaigns (e.g. National Forest Inventories, Soil inventories). Tier 3 methods can also entail specific modelling approaches calibrated and validated for the country against measurements (e.g. soil models,

biomass models or models for harvested wood products). This method will lead to an improvement of estimates over Tier 1 and 2 because it may better reflect the temporal dynamics and fill in the data gaps that may exist with lower methods. However, where a model is used, a lack of attention paid to validation can lead to lower accuracy compared with lower tiers.

From the 2028 GHGI submission onwards, the LULUCF Regulation requires the application of at least Tier 2 methods for all managed land categories and emission sources. From the 2030 submission onwards, the LULUCF Regulation requires the application of Tier 3 methods for most forest land, grassland, and wetlands.

More specifically, estimating carbon fluxes from the following land areas will require Tier 3 methods for all carbon pools (the comprehensive list of area definitions is provided in Regulation 2018/1999 Annex V Part 3 amended by Regulation 2023/839):

- Land use units with high carbon stocks, in particular areas of undrained wetlands, forests and wooded lands (as defined in Article 29(4) of the Renewable Energy Directive II);
- Land use units under protection, restoration or identified in need of restoration, especially:
  - Areas with high biodiversity value including primary forests, species-rich natural forests and wooded lands, protected areas, natural grasslands and species-rich grasslands as defined in Article 29(3) of the Renewable Energy Directive II);
  - Sites under Habitats Directive [40];
  - Sites under Birds Directive [41];
  - Sites under Water Framework Directive [42];
  - Sites under the Flood Directive on the assessment and management of flood risks [43].
- Land use units facing high future climate risks, especially:
  - Areas affected by natural disturbances under the LULUCF Regulation (Paragraphs 5 and 6 of Article 13b);
  - Areas identified with high risks and subject to climate-related disaster reduction actions in the national adaptation strategy in Member States.

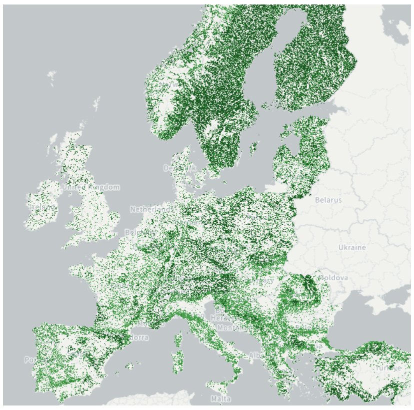
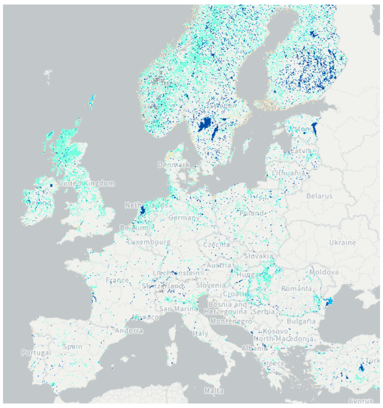
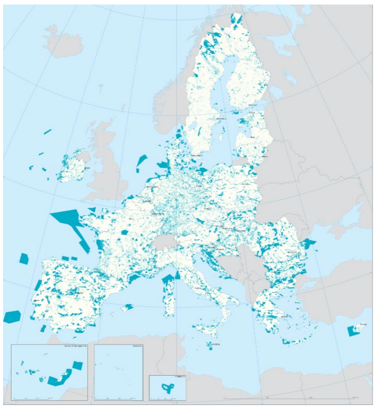
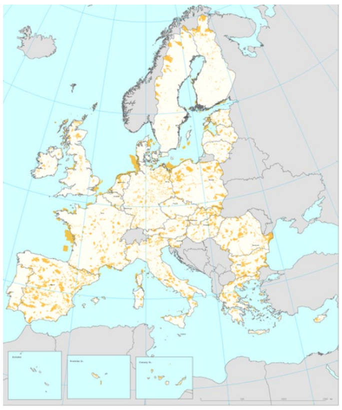
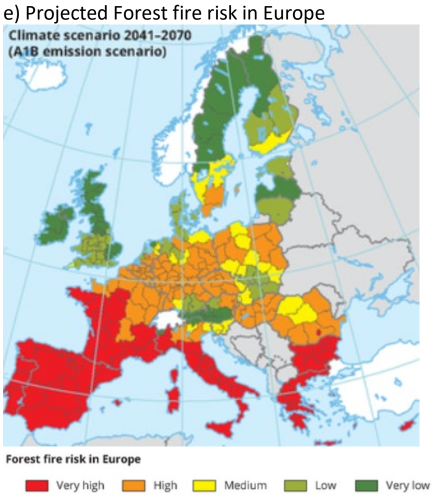
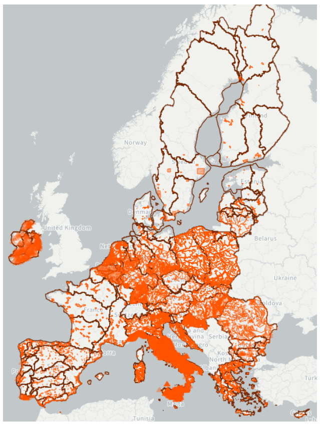
The consideration of all these criteria indicates that a large area of lands will require Tier 3 methods. Substantial areas meeting these areas (e.g. undrained wetlands) are currently considered as ‘unmanaged’ under UNFCCC reporting and their emissions and removals are therefore not estimated. The Regulation still allows not to report the emissions and removals in unmanaged land.

Nevertheless, if a Member State applies Tier 3 methods generically for a reporting category (e.g. forest land remaining forest land, wetland remaining wetland), then the requirement will be fulfilled for the aforementioned land areas too.

It is also specified that, if lands represent less than 1% of the area of managed land reported by the Member State, Tier 3 methods are not expected, and Tier 2 method can be kept avoiding multiplying efforts for very small cases.

[40] Directives 92/43/EEC and 2009/147/EC
[41] Directive 2009/147/EC
[42] Directive 2000/60/EC
[43] Directive 2007/60/EC

Figure 18: Lands potentially subject to Tier 3 methodologies [44]

<table>
<tr><td rowspan="2">Example of land use with high carbon stocks</td><td>a) European forest map
Forest Type 2018, Europe
</td><td>b) Wetland concentration in Europe
Water & Wetness status 2018, Europe
</td></tr>
<tr><td>Source: https://land.copernicus.eu/en/products/high-resolution-layer-forest-type/forest-type-2018</td><td>Source: https://land.copernicus.eu/en/products/high-resolution-layer-water-and-wetness</td></tr>
<tr><td rowspan="2">Example of land use under protection, restoration</td><td>c) Habitats Directive sites
</td><td>d) Bird Directive zones
</td></tr>
<tr><td>Source: EU27 - Habitats Directive — European Environment Agency (europa.eu)</td><td>Source: EU–27 - Birds Directive sites — European Environment Agency</td></tr>
<tr><td rowspan="2">Example of land use facing high future climate risks</td><td>e) Projected Forest fire risk in Europe
</td><td>f) Flood risk areas
</td></tr>
<tr><td>Source: https://www.eea.europa.eu/data-and-maps/figures/projected-forest-fire-risk-in-europe</td><td>Source: https://discomap.eea.europa.eu/floodsviewer/</td></tr>
</table>

[44] Note that more accurate maps often exist at Member State level.

5.2.2 What are the benefits of reporting using higher Tiers?

The Regulation initiates a virtuous cycle between better policies and better inventories (see, for example, Sections 3.2.1 and 3.2.2). Moving to Tier 2 will help to estimate the impact of many practices (in particular in carbon farming) that are not reflected in a GHG inventory elaborated with Tier 1 methodologies. Higher Tiers would capture the following practices:

- Promotion of good practices in forestlands (e.g. improved forest management),
- Promotion of good practices in croplands (e.g. catch crops, crop rotations, intermediate crops amendments, limitation of soil erosion, limitation of soil compaction),
- Promotion of good practices in grasslands (e.g. hay management, grazing),
- Creation or protection of agroforestry systems,
- Planting or protection of trees outside forests,
- Planting or protection of hedgerows,
- Planting of grass strips, etc.

Measurement-based Tier 3 will become increasingly important as climate change overhauls the existing knowledge on the GHG budget of agricultural and forestry practices. Provided that they are properly and regularly validated, Tier 3 models may bring the additional benefit of distinguishing the impact of legacy effects, current policies, and natural effects. Tier 3 models can also be used for projections and other purposes (see Case study 3 and Section 3.2.6). But most importantly, the combination of Tier 3 models and quality, annual measurements will help a timely and accurate reporting of emissions and removals, two essential features for effective and reactive policies (see also section 5.6.2 on timely reporting).

Case study 3: A verified and timely Tier 3 model serving multiple purposes beyond the inventory in Canada

Like many countries, Canada was confronted with the challenges of timely reporting and the combining of multiple datasets for estimating forest emissions and removals. To address these challenges, Canada developed the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). It is a complex Tier 3 model that can be used for other purposes and by other stakeholders (e.g. projections, harvest strategy, fire prevention). **Read more on Case study 3**.

5.2.3 Current state of monitoring and reporting by EU MS

Moving to higher Tiers will represent a different challenge for each Member State depending on the current state of their GHG inventory. Indeed, there is a wide disparity between the use of methodologies by EU countries as analysed by a recent assessment commissioned by EEA [45]. The use of Tier 3 methods covers about a quarter of all reported emissions and removals and is attributed to just a handful of countries. A significant proportion of land and carbon pools is still covered by inventories using a Tier 1 methodology.

[45] Brooks et al. (2023): Methodologies Applied by European Countries to Calculate LULUCF Emissions and Removals. Report commissioned by EEA.

Based on the state of inventories in 2023, the most challenging issues on Tier levels are expected for the following cases:

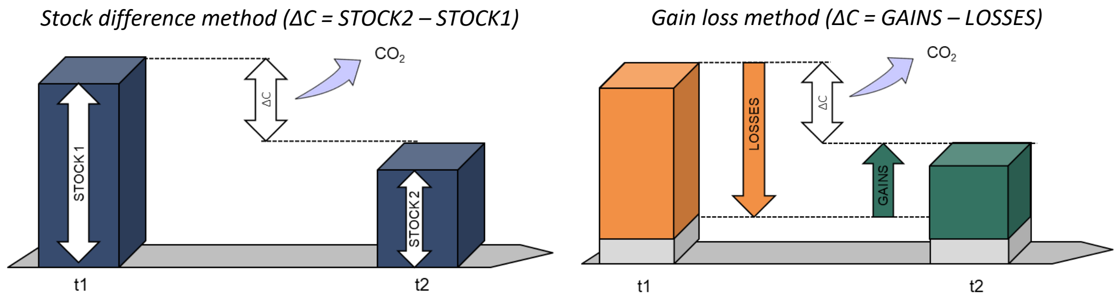
- Reporting of emissions/removals on mineral soils: Tier 1 is often used and sometimes assimilated to the assumption that the soil organic carbon pool is in equilibrium, which is not in line with the 2006 IPCC Guidelines (Figure 20). The order of magnitude of unreported emissions and removals has been estimated to be around 45% of the current net LULUCF balance (Bellassen et al., 2022).
- Reporting of emissions/removals on organic soils: most Member States use a Tier 1 methodology. The use of country-specific parameters is limited to a few cases, for instance with the estimation of the depth of the water table for calculating emissions from drainage.
- Reporting of emissions/removals of biomass on cropland and grassland: Member States are using a wide range of methods to estimate biomass in cropland and grassland. Most of them qualify for a Tier 2 but rarely for a Tier 3. Dynamic data is rarely available and generally there is a lack of experience in monitoring trees outside of forests. In addition, few systems are capable to tracking management practices.
- Reporting of emissions/removals on wetlands: for all subcategories, emissions are most often reported as either 'not occurring' or 'included elsewhere'.
- Reporting of emissions/removals on settlements or other lands: most Member States report emissions and removals associated with land conversions, a handful of countries apply country-specific methods to settlements to estimate carbon stock changes.
- Reporting of non-CO_2 emissions: a few countries have developed country-specific emission factors and methodologies but most of them use default emission factors and apply Tier 1 methodologies.

Overall, examining all categories and excluding those reported as included elsewhere or not occurring, 37% categories are estimated using a Tier 1 methodology, 34% using Tier 2, and 5% using Tier 3. The remaining 24% are reported as not applicable or not estimated. Despite only making up 5% of the categories, Tier 3 estimates account for 23% of the total emissions and removals estimated in the LULUCF sector. The proportion of emissions covered by Tier 2 methodologies accounts for 62% of emissions, with Tier 1 methodologies accounting for the remaining 15%.

5.2.4 How to move to higher Tiers?

With the new Regulation, Member States must upgrade their methodologies towards higher Tiers. To exemplify the effort it may represent, it is useful to begin with the basic methodologies for LULUCF: the Tier levels are closely linked to the equation used. In LULUCF, nearly all estimates are based on carbon stock variations, either using the 'stock difference method' or the "gain loss method" (Figure 19).

Figure 19: The two main methods of estimation in the LULUCF sector



Source: Own compilation.

Depending on land categories and carbon pools, one or the other method is prioritised. Note that these methods do not directly correspond to a level of Tier, but rather to general approaches to retrieve annual carbon fluxes. The qualification as Tier 2 will depend on the parameters used.

While Member States will unavoidably face methodological and data availability challenges in respecting the requirements of the Regulation on higher Tiers, in many cases, existing data and scientific work already give good basis for inventory implementation. For instance, existing analysis of the LUCAS soil survey already provide Tier 3 measurement-based estimates of soil carbon changes in cropland remaining cropland and grassland remaining grassland for the 2009-2018 period for all Member States (Rosa et al. 2023).

To help Member States to improve gradually and avoid being overwhelmed by the challenge of moving to higher Tiers, key carbon farming practices at the European levels have been listed in the Communication on Sustainable Carbon Cycles (see Section 3.2.2). Further prioritisation of nationally relevant carbon farming practices will also help.

Moving from Tier 1 to Tier 2

Considering the current state of methodologies applied in Member States and the high level of ambition of the LULUCF Regulation, many Member States will have to move from Tier 1 to Tier 2 for many sources and sinks. The IPCC guidelines indicate calculation methods that are considered Tier 2 when certain parameters used for the emission factors are country-specific. Thus, a mix of IPCC default parameters and country-specific qualifies as Tier 2, as implied by the following quote from the IPCC guidelines:

"A Tier 2 method is an extension of the Tier 1 meth*od that allows an inventory to incorporate country-specific data. It is good practice for countries to use a Tier 2 method, if possible, even if they are only able to better specify certain components of the Tier 1 method. For example, a compiler may only have data to derive country-specific reference C stocks, which would then be used with default stock change factors to estimate changes in soil organic C stocks for mineral soils."* (IPCC 2019, 2019 Refinement vol. 4, p. 2.38)

Figure 20: Example of methods by Tier level, land use and pool

Land use category/Pool	Biomass	Dead organic matter	Soil organic carbon
Forestland remaining forestland	T1: [Gain-loss method] +D T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]	T1: 0 T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]	T1: 0 T2: [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]
Cropland remaining cropland	T1: [Gain-loss method] + D T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]	T1: 0 T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]	T1: [Stock-difference method] + D T2: [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]
Grassland remaining Grassland	T1: 0 T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]	T1: 0 T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]	T1: [Stock-difference method] + D T2: [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]
Wetland remaining Wetland	Distinction between peatlands and flooded lands but no split related to carbon pools in the 2006 IPCC guidelines. The following methods are assumed:		T1: 0 T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]
Settlements remaining Settlements	T1: 0 T2: [Gain-loss method] + CS T3: [Stock-difference method] + CS	T1: 0 T2: [Gain-loss method] or [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]	T1: 0 T2: [Stock-difference method] + CS T3: [Model-based method] or [Measurement-based method]

Legend:

- [Gain-loss method] Gain-loss method
- [Stock-difference method] Stock-difference method
- [Model-based method] Model-based method
- [Measurement-based method] Measurement-based method

T1: Tier 1
T2: Tier 2
T3: Tier 3
D: with default parameters
CS: with country-specific parameters
0: Carbon stock changes are assumed to be zero

Source: Own compilation based on IPCC 2006.

Ideally “country-specific” emission factors that replace IPCC default emission factors should be derived from national measurements as long as it can be argued that they are more accurate in the specific context of the country. Nevertheless, country-specific emission factors can also be derived from a sub-sample of European or international databases. This is particularly useful in the context of the LULUCF Regulation implementation. In particular for soils, SoilGrids or the LUCAS soil survey may be used for more refined analysis. Averaging all plots with similar climate and soil conditions can be relevant, even if they are located in a neighbouring country, or using statistical analysis to identify the plots which are most comparable with the targeted conditions (e.g. Schneider et al., 2021). The LUCAS soil survey, national soil measurements or inventories, and downloadable soil maps can be used to derive country-specific values, or a proxy of them for at least stocks of reference or land use change ratios (see Bellassen et al. 2023). There are thus different ways to implement Tier 2 methodologies. For cropland, the 2019 Refinements even offer a different kind of Tier 2 method, consisting in a simplified process-based model (2019 Refinements vol4, p. 2.15-2.26).

The case of non-CO_2 gases

The UN reporting framework for GHG inventories before the adoption of the Paris Agreement and its Enhanced Transparency Framework used the Common Reporting Format (CRF) tables for the provision of quantitative information on GHG inventories. These templates requested information on non-CO_2 gases at a level of disaggregation that barely allowed a transparent understanding of what significant sources of non-CO_2 emissions were.

The LULUCF Regulation and the UNFCCC Common Reporting Tables (CRT) under the Paris Agreement now request information on non-CO_2 gases at a further disaggregated level. Since the reporting of non-CO_2 gases has traditionally received less attention, Member States may now encounter difficulties in providing the information on non-CO_2 gases at the level currently requested.

To overcome potential barriers associated with this refined disaggregation, Member States may consider:

- apportioning emissions weighted by land use categories using expert knowledge and any available data source (e.g. the majority of wildfires occur in areas categorized as forest or grassland remaining forest or grassland, or most of the Nitrogen inputs are devoted to agricultural lands or occasionally to increase forest wood production);
- exploring the use of regional or international data series (e.g. European Forest Fire Information System) to extrapolate information at country or regional level considering the areas and management practices to which the data apply, and which drive carbon oxidation or emissions of non-CO_2 GHGs from the sources.

Moving to Tier 3

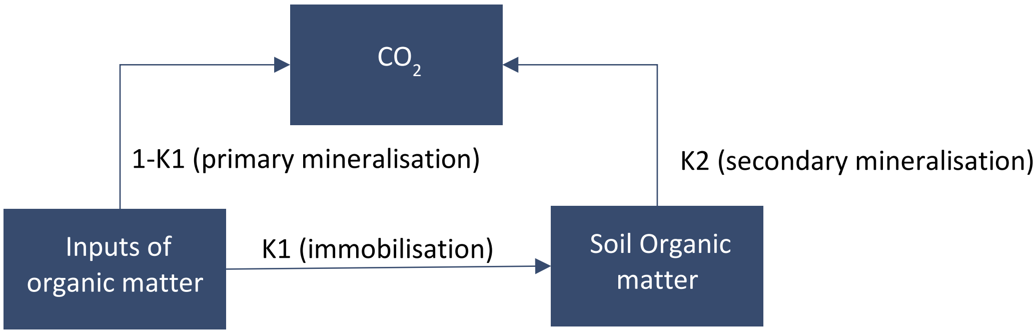
As mentioned above, Tier 2 will not be sufficient for managed wetland, forest land, protection sites, restoration sites, and areas under climate risk, as the revised Governance Regulation requires a Tier 3 method from the 2030 inventory submission onwards. Tier 3 methods cover two different approaches: measurement-based methods and model-based methods.

Measurement-based methods mobilize repeated inventories which samples are repeatedly collected on a high number of sites. A measurement-based Tier 3 approach (repeated inventory) is the only method which allows to meet reporting requirements without tracking key land management practices. But in practice, even with a measurement-based Tier 3 approach, monitoring of key practices is important for policy makers as far as they are the levers that the government can pull and track. In addition, tracking key land management practices allows for a better stratification, and thereby improves the precision of the measurement-based estimates.

In model-based methods, the models generally involve decay functions and carbon transfers between different organic matter pools. For the soil carbon pool, for example, they may simulate soil carbon changes based on site conditions and carbon inputs such as weather data, soil type, litter input (which is derived, for example, from forest inventory and harvest statistics data). Note that models can be simple and yet allow for policy-relevant reporting, as long as they can be calibrated and verified using reliable and representative national data.

To better understand what models are, the example of a simple model (Henin-Dupuis, 1945) may help. This model is based on single pool of organic matter in the soil and the consideration of immobilisation and mineralisation with empiric kinetic parameters.

Figure 21: Principle of a simple model for soil carbon dynamics



Source: Own compilation based on Hénin and Dupuis 1945). K1: Percentage of organic matter provided by an amendment, remaining in the soil after one year, and which thus supplies the stock of stable organic matter (humus). K2: Percentage of soil organic matter lost annually per mineralization.

This model considers only one pool in the soil, whereas the heterogeneity of organic matter justifies the consideration of several dynamic compartments. This is often what is considered in more complex models such as Yasso07, C-Tool, Roth-C, CBM-CFS3 and others that are now used.

In principle, one of the advantages of a model over a measurement-based estimate is that it allows the disentanglement of the effects of climate, management practices, and differences between different models in the estimated national or regional totals. This feature can be exploited both to better understand the effect of past policies and to project the effect of future ones. However, in-depth knowledge of the model and the implementation of several counter-factual simulations are necessary to exploit this advantage. Ensuring that the model is and remains capable of reproducing independent measurements is also a challenging and time-consuming task, demanded for good reasons by the IPCC guidelines (Bellassen et al. 2023). Therefore, reasonable resources need to be allocated for model application and for model testing in order to reap the benefits of a model-based Tier 3 approach. If this is not feasible, a Tier 2, where allowed by the Regulation, or a measurement-based Tier 3 is preferable.

Non-issue: how to ensure time-series consistency when moving to higher Tiers?

A common worry when moving to higher tiers is to ensure time-series consistency. Time-series consistency indeed requires attention, but it should not prevent a methodological improvement or the use of a more reliable data source. As the IPCC Guidelines put it (IPCC 2019 vol. 1, p5.5), "Both methodological changes and refinements over time are an essential part of improving inventory quality.". Otherwise, one would remain stuck with the generally poor data available in for the 1990s. Chapter 5 of the volume 1 of the IPCC Guidelines provide a list of pragmatic techniques and concrete examples on how to ensure time-series consistency: overlap, surrogate data, interpolation, trend extrapolation, and non-linear trend analysis. It also leaves room for "other techniques" when none of the above techniques can be satisfactorily implemented. This is the case for total standing volume in forests in the Polish NIR: because the old and new data sources do not overlap, a mix of surrogate data and trend extrapolation is used, whereby the pre-2009 data is "recalibrated" upwards to meet the extrapolated trend of the post-2008 data over a few years prior to the change in monitoring technique. A similar calibration approach is described in Case study 4 for France, to combine data with high accuracy but low time resolution (forest inventories) and data with high time resolution but lower accuracy (harvest statistics).

Case study 4: Combination of data and a simple model to increase time resolution in the French inventory

As many countries, France has an efficient forest inventory which provides accurate estimates of tree growth, harvest and mortality. The associated drawback is a coarse time resolution which hinders appropriation of the reported data by policy makers. To bridge this gap, a simple model combining 5-yearly forest inventory data with annual statistics was developed, allowing meaningful annual estimates which, among others, reflect dramatic events such as storms in the time series. **Read more on Case study 4.**

5.3 Geographically-explicit monitoring

5.3.1 What does the LULUCF Regulation say?

Moving to geographically-explicit monitoring is one of the necessary paths to enhanced LULUCF monitoring. 'Geographically-explicit monitoring' refers, in this context, to the use of spatial datasets, such as land-cover maps, for the assessment of land-use and land-use change areas in the calculation of the LULUCF sector. This means that information is available on gross land-use changes and on the location of these conversions. Several types of data can be relevant to develop this information: vector or raster land-use/land-cover maps, grid-based hybrid maps, permanent sampling points.

The aim of the Regulation, moreover, is to promote a broader perspective where all calculations of the LULUCF sector are performed at a high resolution, with a policy-relevant geographically-explicit framework. This means that information on carbon stocks and fluxes should also be assessed in a manner consistent with the identification and monitoring of land-use change areas such as conversion of forest to cropland or settlements. Indeed, geographically-explicit monitoring of land use areas is not sufficient in itself to ensure a higher resolution, accuracy and policy relevance of the LULUCF GHG inventory compilation; the key element here is to ensure the application of appropriate data in the monitoring system, for example identification of where conversion of land from forest (so-called deforestation) is taking place, compatible with the parameters chosen by Member States for forest definitions. Carbon calculations, using higher Tiers and using timely and pertinent spatial datasets, should ideally be developed with the same monitoring system in mind. However, while not sufficient in itself, geographically-explicit monitoring of land-use areas is a necessary condition to ensure that LULUCF inventories are benefiting from the highest-quality methods and datasets. That is why the original Regulation, in its Annex V, introduced a methodological requirement: "*Member States shall use geographically-explicit land-use conversion data*".

What does it mean for the inventory compiler?

Within the framework of the Regulation, moving towards geographically-explicit monitoring implies the use of digital cartographic datasets, or repeated measurements of digital, high density permanent sampling plots, for land-use change monitoring and for estimating carbon fluxes related to land use, land use change and forestry.

The requirement on monitoring does not mean that it is a requirement applied to the granularity of information in the GHG inventory reporting. The concept of enhanced geographically-explicit monitoring is to apply monitoring approach and calculation methods at subnational levels not only at administrative level (such as regions), but at high-resolution, which can reflect landscape units (e.g. agricultural parcels or sets of parcels; forest patches; urban zones, natural vegetation areas, etc.). Existing spatial datasets can provide information on land-use, biomass, soils, management, etc. at this level of detail. Ideally, this enhanced geographically could help providing results at relevant subnational levels.

This geographically-explicit framework of the LULUCF monitoring must be applied already to GHG monitoring under the Regulation for the reporting year 2021, i.e. with the submission 2023. A difficulty in this is that all time series reported for UNFCCC reporting shall be consistent, even though there is no high-quality land-use change data for past periods.

For the monitoring of land use and land-use change, in particular, each country should therefore select the most suitable dataset or apply a multi-source approach to use several datasets. The requirement to use geographically-explicit land use datasets does not impose a specific data format, such as 'wall-to-wall', raster, or continued sampling. What is intended is that such data remains interoperable with other datasets to facilitate carbon calculations at high spatial resolution.

This requirement for a geographically-explicit approach must also be considered when moving to higher (see the section 5.2 related to higher Tiers). This means that the inventory calculations of both areas and carbon fluxes will benefit from the use of geographically-explicit data. The methodology applied for GHG estimates must reflect the difference in management, s environmental conditions, of each specific zones, and use the geographically-explicit data that gives information for each specific area. Use of generic assumptions, national factors and parameters should be avoided in order to compile high-resolution estimates. The IPCC provides guidance on how to stratify land-use categories, how to monitor land-use change, and how to overcome data gaps.

For the monitoring of management practices and changes in management, countries can rely on IPCC's proposed parameters, on national values, or on European datasets. For example, the ongoing project LAMASUS [46] will propose land management classes for forest, cropland, grassland urban areas back to 2000.

What does it mean for the policy community?

Although the Regulation does not require the reporting of maps, the policy community benefits directly from the application of a geographically-explicit monitoring of LULUCF:

- First, this approach ensures that the current local situation regarding carbon sinks and LULUCF emissions and removals in general are monitored as precisely as possible.
- Second, this approach ensures that national and sub-national policies, as well as changes in management in the field, are well integrated within the calculations, taking into account differences between zones.
- Third, policy design can be based not only on national estimates and statistics but also on and understanding of the spatial distribution of impacts, thanks to geo-location, maps, and results at higher spatial resolution.
- Fourth, the use of geographically-explicit data facilitates the integration of satellite imagery and other annualized datasets that improve timeliness of estimates.

[46] Land Management for Sustainability Project https://www.lamasus.eu/

- Fifth, geographically-explicit monitoring can help transparency and understanding of final results through maps and other visual representations.

Is this requirement different from IPCC's Approach 3?

To better understand what is expected within the Regulation, it is important to highlight that "*the use of geographically-explicit land-use conversion data*" is a requirement aimed at facilitating the use high-quality datasets, and at performing calculations at provided resolution to reflect the differences between areas, the implementation of policies on the field, and to use land management information for different zones.

To help inventory compilers, it remains useful to explain that this requirement of the Regulation refers explicitly to the IPCC guidelines on land representation. The IPCC Guidelines (IPCC 2006, Volume 4, Chapter 2, Section 3.3) defines three approaches for land representation, which set how information on areas of land use and land use change is obtained.

- Approach 1 is applied when no information on land use conversion is available, only total areas of land use categories for one or several years.
- Approach 2 is applied when information on land use conversion is available, allowing the derivation of a land-use change matrix for specific periods of time, without knowing the location of these changes.
- Approach 3 is applied when conversions are geographically tracked.

The 2019 Refinement to the IPCC Guidelines provides more information, particularly for Approach 3, on data collection: sampling, survey, and wall-to-wall datasets. It also provides guidance on how to combine multiple data sources while ensuring consistency.

The regulation requirement to use geographically-explicit data for land use monitoring is a more precise requirement than the requirement to apply IPCC's Approach 3. Indeed, to reap the benefits expected of geographically-explicit monitoring of land use conversions, mapping, or very high resolution (spatially and temporally) sampling is needed (see for example Case study 8 on France's where the spatial resolution is 0.5 ha and the temporal resolution is annual). Moreover, to achieve the level of detail required to detect any such land use conversion, the spatial resolution of the data (such as the Minimum Mapping Unit for vector wall-to-wall products) must be consistent with the minimum value for forest area as defined by each Member State in its GHG inventory (and Annex II of the Regulation). In practice, the appropriate IPCC guidance therefore focuses on 'wall-to-wall' (vector, or raster-based) mapping, or continuous dense sampling, likely supported by information from Earth Observation as well as ground-based sampling. These methods provide the most cost-effective and technically available solution to achieving the Regulation's objective of enhancing monitoring.

The Regulation objective is mostly to encourage the use of geographical data that ensure higher resolution of monitoring and reporting of areas, emissions, and removals. Therefore, to implement the Regulation requirements, countries are invited to develop the most relevant and accurate method that can use one or several geographically-explicit datasets. Such an approach can combine, for example, NFI continuous geo-referenced point sampling data with other land use and land-use change datasets.

To apply geographically-explicit monitoring, geographically-explicit data needs to be available. Many products and services exist. However, making them fit with inventory specifications and expectations remains complex. The next sections explain how to make choices appropriate for the task set out in the Regulation.

5.4 Interoperability

Enhanced monitoring is possible through improved calculation methods, higher spatial resolution of calculation and better use of high quality and high-resolution available datasets. Ensuring interoperability between various datasets and the LULUCF calculation and policy framework is key to make sure that all relevant information useful for emissions and removals estimates can be used. Without interoperability, LULUCF inventories cannot easily benefit from high quality datasets that describe and track change in land-use, in carbon stocks and in land management.

That is why the regulation encourages Member States to ensure interoperability between the land monitoring for LULUCF inventories and other relevant spatial databases, related to areas with high carbon stocks, subject to protection or restoration, or with high climate risks, and covered by different European or national legislation texts.

Interoperability supports the reusing of datasets, avoiding duplicative investments in data gathering and can help to solve related policy problems, for example when assessing the possible co-benefits or conflicts between mitigation, adaptation, and biodiversity measures. Some datasets describing and tracking changes of forest, or wetlands, can be produced with a protection or restoration goal, but can also be beneficial to LULUCF inventories. In the same way, the Regulation requests LULUCF datasets, produced at first for GHG reporting, to be interoperable with other environmental datasets so that LULUCF information can be used for other purposes.

5.4.1 What does interoperability mean?

Interoperability describes the characteristic of a product, or system, to work with other products or systems. In the context of LULUCF geographically-explicit monitoring, interoperability means that relevant datasets are designed in a way that allows them to be combined for analysis. The Regulation requirement of interoperability is addressed to the national LULUCF inventories, as datasets. The inventories need to be designed in a way that ensure their interoperability and comparability with other datasets. The reported LULUCF dataset must enable and facilitates exchanges with other relevant geographically-explicit databases. Moreover, such enhanced interoperability will also facilitate public accessibility and understanding.

5.4.2 What should policy officers do?

Ensuring interoperability implies that data producers are aware of the final use of their data within the framework of LULUCF monitoring, reporting and verification system, and within the associated policy framework. Policy officers in charge of supervising LULUCF reporting systems can help data producers and national greenhouse gas inventory compilers and other LULUCF policy officers to share their needs and requirements.

Exchanges between data producers, public data portals, scientific and academic communities, and LULUCF monitoring and reporting communities should be facilitated at national level – and regional, European and even international levels – by policy officers. Doing so, more datasets and high-quality information, as well as Tier 3 modelling tools, can be disseminated to LULUCF communities that can integrate them into the LULUCF monitoring and reporting framework.

Verification processes, such as quality assurance checks, can be developed by policy officers using external datasets that are not yet used in the LULUCF inventories, when such datasets are relevant and comparable in quality and resolution to the datasets used in the inventory. Using such datasets to challenge LULUCF inventories will further push for more interoperability, as requests for data comparison and comparability will emerge.

National authorities can also encourage the implementation of consistent definitions, conceptual frameworks, resolution requirements, metadata transparency, public availability, etc. An example of such development is the INSPIRE Directive. The creation of public portals for geospatial data display and download also helps to promote interoperability.

5.4.3 What are the advantages of interoperability of LULUCF datasets?

Member States should ensure interoperability while developing the geographically-explicit approach for the land-use and land-use change monitoring. With this approach, multiple spatial datasets, such as land cover maps, cadastral areas, forest maps, LPIS etc., can be compared and even integrated to monitor land use changes as accurately and precisely as possible, benefiting from the complementarity of each data.

Developing interoperability of LULUCF datasets with other datasets directly helps to increase synergy with other environmental policies and helps LULUCF inventories to take into account areas with high climate challenges, areas with high carbon stocks, subject to protection or restoration, or with high climate risks. Comparing the results of LULUCF inventories and maps of such areas can be helpful:

- First, to take into account the management and land cover specificities of these areas into the methodology used in the LULUCF inventory.
- Second, to explore how land use and land use change, and their associated emissions and removals, affect differently these areas with high climate challenges or under specific management or protection targets,

The request that the LULUCF inventory are designed to be interoperable with other datasets from related policy area will facilitate the synergy of climate and other environmental policies. To do so, the Regulation provides a list of other data sources that could directly be used with LULUCF datasets as long as interoperability is ensured. These other data sources are listed within the Annex V to the Governance Regulation, Part 3, and are related to the mapping of areas with high carbon stocks, subject to protection or restoration, and with climate risks. Systems monitoring soil carbon stocks are also listed.

5.4.4 How to enhance interoperability of LULUCF datasets?

The following concrete steps and advice serve enhance interoperability of LULUCF datasets:

- **Adopt standardized formats**: the use of standardized file formats for LULUCF inventory data, for intermediate results and final reported results facilitates reuse for other purposes. Such formats include CSV, JSON, or GeoJSON for tabular and spatial data.
- **Use metadata standards**: always specify metadata. Include information about data sources, processing methods, and any assumptions made during the inventory compilation. This is essential to allow other policy or scientific officers to use LULUCF datasets. Clear geographic and thematic perimeters (e.g. inclusion or not of natural areas, overseas territories) must be indicated in the metadata.
- **Unique Identifiers and versioning of datasets**: LULUCF officially repo**rted data can be difficult** to understand for stakeholders not familiar with the requirements of this framework. Creating easy-to-use and to understand datasets, with clear versioning and documentation, while assigning unique identifiers to each dataset, is also key to ensure interoperability.
- **Documentation and definitions**: land use definitions, spatial referencing, geographical perimeters, temporal boundaries, etc. should be clearly explained. A

data dictionary that defines each variable, field, and their units, in the dataset is also useful.

By following these steps, a country can enhance the interoperability of LULUCF inventory datasets, making them more accessible and usable in conjunction with other environmental datasets.

5.4.5 National portals for maps comparison

One of the most effective ways to make environmental data available is to use geographic portals. They can provide access to cartographic data from many areas and therefore offer the possibility of cross-referencing them from a spatial and sometimes temporal point of view.

Several Member States have already created a national portal allowing the visualisation of different geographic datasets (see Case study 9) national or European, covering different environmental topics (land cover, forests, agriculture, fires, etc.), in line with their national geographic agency [47]. Even though datasets have very different spatial and temporal resolution; and use different definitions for land categories (e.g. for the forest areas), a centralized system allows users to display this geospatial information and to extract some insights. For example, extracting information related to the land use sector (areas of land use change, or even carbon fluxes) on protected areas can help policymakers in assessing whether the protection status is effectively contributing to reducing emissions and increasing sinks. Inventory compilers can use such overlay of geospatial data to enhance land use monitoring and the calculation of carbon fluxes, taking into account levels of management consistent with these protected areas. Interoperability is a way to facilitate access to geospatial data that can feed the land use sector inventory, policy assessment and development, and other stakeholders' needs.

Case study 9: National portal in Italy

To visualize priority areas for the LULUCF monitoring and mitigation actions, various environmental geospatial products are available from national, European or international products. In this case study, we present Italy's national portal that displays such maps. **Read more on Case study 9**.

Such portals allow agricultural policy staff to share information about CAP data (such as LPIS maps), forestry monitoring agencies to share information about NFI data, nature protection agencies and national parks to share information about protected areas, etc. While greenhouse gas emissions inventory compilers can share information about land use change monitoring and carbon fluxes. Such a portal could also include geographically-explicit information related to LULUCF inventories, such as the land-use and land use change maps. In France, a tool is under development to visualize, process and analyse land use information used in the LULUCF inventory and other maps or satellite imagery.

Having all the information in one place facilitates assessing the links, synergies, and trade-offs between LULUCF actions and reporting, and other environmental policies. However, some of these datasets, depending on the country, are still treated as confidential and are not always available to carry out analyses in conjunction with LULUCF inventory datasets. National authorities should promote the availability of geospatial data and ensure interoperability so that

[47] See for example Germany (https://www.geoportal.de), France (https://www.geoportail.gouv.fr) or Spain (https://visualizadores.ign.es)

analyse combining LULUCF datasets and other information is easier for policy and science officers (see e.g. Case study 10).

Case study 10: Using national data sources to improve knowledge on drained organic soil emissions in Austria

Agricultural use of organic soils contributes substantially to GHG emissions from organic soils. The Austrian Environment Agency addresses these questions in a project aiming to improve the estimates of drained organic soils in the Austrian National GHG Inventory. **Read more on Case study 10**.

5.4.6 What are the benefits of geographically data in monitoring?

Geographically-explicit monitoring offers several key advantages:

- **Timeliness and focus on implementation tracking**. The use of geographically-explicit monitoring facilitates the use of relevant datasets that provide timely information on land-use, biomass stocks, land management, etc. Such datasets include remote sensing products or Common Agricultural Policy information such as GSAA). The use of datasets that provide information on recent years, and the fact that calculation considers different parameters (e.g. soil management or inputs, carbon stocks, biomass harvest rates, or other relevant information) for different areas, ensure that LULUCF monitoring is able to track the implementation of policies on the field and to estimate their impacts.
- **Facilitating the development of action on priority areas**. With geographically-explicit monitoring, emissions and removals can be calculated for specific zones, using their specific information. Monitoring of priority areas can therefore be ensured via the use of their actual management practices, their soil, biomass and other carbon pools characteristics; and their land-use change dynamics. In protected areas, the evolution of emissions and removals is often linked with the implementation of the protection policies. Ensuring that, for example, forest degradation from anthropogenic disturbance is no longer occurring; or that wetland restoration is effective, are examples of the advantages of such enhanced LULUCF monitoring for general environmental tracking.
- **Improve synergies and opportunities to consolidate reporting with other relevant policy areas.** Geographically-explicit approaches facilitate the use of other geographical datasets, even when they deal with other thematical areas, as it is indeed easy to compare two datasets by overlapping them, as long as one remains aware of differences in spatial, thematical and temporal resolutions. Other such datasets may include LPIS, soil carbon stock maps, NFI, buildings and roads, biomass maps, etc. Data used for LULUCF reporting can also be useful for other reporting framework or policy assessment, and vice versa. This synergy between LULUCF monitoring ant other policy areas (such as Forest, soil, biodiversity, etc.) is achieved using interoperable datasets.

In addition, this requirement has two indirect effects:

- **A level-playing field in Europe**. Currently, Member States apply different approaches and a mix of approaches for land representation, using different national and European datasets. The requirement for geographically-explicit monitoring can contribute to the creation of a level-playing field in Europe whereby all Member States are equally equipped to implement climate mitigation policies– e.g. targeting priority areas – and host carbon farming projects (see for example Case study 5 on farm-level GHG assessments and their link with national monitoring and policies in France). Ultimately, the requirement for geographically-explicit monitoring also facilitates that the contributions of all Member States to the European LULUCF target are assessed with comparable resolution.

- **Enhanced transparency and verification.** The use of geographically-explicit land-use conversion data may ensure an improvement of not only monitoring and reporting, but also verification. Even though the Regulation does not require the reporting of maps data sets, the application of geographically-explicit approach will facilitate the usage of cartographic results (areas, emissions and removals) at different scales. Spatial data allows easier checks since it can be displayed on Geographical Information Systems and compared to other maps, aerial imagery or even participative feedbacks.

Case study 5: Farm-level GHG assessments and their link with national monitoring and policies in France

Over the past few years in France, farmers have received incentives to define the GHG budget of their farm and identify climate mitigation levers through numerous channels. However, the synergies with the national GHG inventory and public policies are still underexploited. **Read more on Case study 5.**

5.4.7 How to move to geographically-explicit monitoring?

The initial step applied by countries is the gathering of spatial datasets that accurately monitor land uses, land-use changes, land characteristics and land practices. The Regulation assumes that a combination may be required [48].

It is recommended that the geographically-explicit datasets used are open source and available on national INSPIRE Portals, following the terms of the Inspire Directive. Within the framework of the 2020 European strategy for data [49], the GreenData4All initiative led to a legislative proposal [50] revising the INSPIRE Directive, and the Directive on Public Access to Environmental Information. Its aim is to update and further develop existing rules under the INSPIRE Directive on the sharing of environmental geospatial data to make them consistent with recent cross-cutting digital data initiatives and legislation and to facilitate the flow of public data into the context of the implementation of the EU Green Deal.

The following Sections provide insights on the collection and selection of relevant geographically-explicit datasets and give examples of Member States that have developed geographically-explicit approach for land monitoring (see also Annex 4). Emphasis is put on datasets which are readily available for all Member states. This list is, of course, far from exhaustive. Other geographically-explicit data exist at national (e.g. NFIs using permanent

[48] Reg 2018/1999 Annex V Part 3 as amended: "Member States are encouraged to explore synergies and opportunities to consolidate reporting with other relevant policy areas and strive towards greenhouse gas inventories which allow for interoperability with relevant electronic databases and geographic information systems".
[49] https://digital-strategy.ec.europa.eu/en/policies/strategy-data
[50] https://op.europa.eu/en/publication-detail/-/publication/17a95a78-d49e-11ee-b9d9-01aa75ed71a1/language-en

sample plots on all land use categories; OSO in France or SIOSE-Sistema de Información de Ocupación del Suelo de España- in Spain) or international (e.g. Global Forest Database) levels. On national level there are many datasets available within all Member States. The selection of the right dataset and combination of it (see Case study 6) is crucial for the monitoring.

Case study 6: Assessing time series of forest cover dynamics in Romania

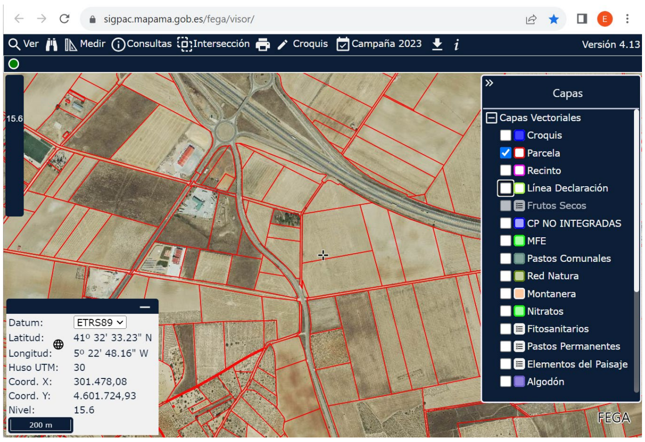
A discrepancy of 500,000 ha in forest area in Romania was found when comparing national legal forest maps and National Forest Inventory information. The case study describes how Romania has set up a multi-data integration system to assess time series of forest cover dynamics more accurately. **Read more on Case study 6.**

EU-scale data available for all Member States

Land parcel identification systems (LPISs)

A LPIS is a geographical dataset that helps to record [51] the annual land use of all parcels for which a subsidy from the Common Agricultural Policy is requested. Only agricultural land is captured. Each Member State is responsible for the development and maintenance of their LPIS, which is often publicly accessible e.g. via the INSPIRE portal following the terms of the INSPIRE Directive (see box below) and will be further supported by the upcoming GreenData4All initiative which aims to enable more data sharing between private & public sectors with the general public [52]. Government-mandated climate reporting agencies should have systematic internal access to them. Since LPIS is set up by each Member State, a diversity of approaches exists concerning its implementation. LPISs will typically provide high-resolution and good-quality data on the types of cropland and grassland that can be used directly as activity data or land-use information in the geographically-explicit monitoring.

Figure 22: Screenshot of SIGPAC (Spanish portal for LPIS data)



Source: Spanish Ministry of Agriculture, Web map service SIGPAC.

INSPIRE: data for data sharing

[51] Together with the Integrated Administration and Control System (IACS) of the CAP.

[52] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13170-GreenData4All-updated-rules-on-geospatial-environmental-data-and-access-to-environmental-information_en

The 2007 INSPIRE Directive 2007/2/EC [53] creates a legal framework for promoting the sharing and use of geospatial data related to environmental policy and activities that may impact the environment within the EU. It includes 34 themes for data sets, among them land cover, land use, soil characteristics, as well as habitats and biotopes. Member States are required to share their data sets and to provide accompanying metadata. To ensure interoperability and facilitate harmonization, Member States are also required to follow common implementing rules. The standardization of metadata to describe the datasets, achieved through INSPIRE was key to facilitate inventorying and searching of data. The INSPIRE Geoportal is the main access point to the data sets. It provides several ways to accessing data, for example by themes, priority data sets by legislation, environmental domain or country, and high value data sets.

The Open Data Directive ((EU) 2019/1024) defined six categories of high-value datasets, which if made available have the potential to generate socio-economic benefits, for example through cross-border data applications and services. The categories include geospatial datasets as well as earth observation and environment datasets. Two high-value geospatial data sets for example are the Geospatial aid application (GSAA) and LPISs, which contain the spatial data components of the Integrated Administration and Control System under the CAP (Regulation (EU) 1306/2013) and can provide useful information for improving methods applied on croplands. Public authorities are required to make these datasets available free of charge, in a machine-readable format by February 2025. As of now, coverage of EU Member States on the Geoportal is not complete.

While some data sets may also be available via other channels, for example at the national level, the advantage of INSPIRE is that all data are available in one place. This facilitates sharing of data between administrative branches and different level of governments as well with the public. The Geoportal provides access to the data in the languages of the EU Member States. In the future, data relevant for the forest monitoring and soil monitoring legislations is also expected to be available through the INSPIRE Geoportal, as well as data from the Copernicus ROSE-L mission, which will provide information at 10m resolution useful estimating biomass on land.

Geo-Spatial Aid Application (GSAA))

GSAA is related to the Common Agricultural Policy and is a part of Integrated Administration and Control System (IACS). GSAA is an electronic application form based on a geographic information system that allows beneficiaries to spatially declare the agricultural parcels of the holding. GSAA data is referenced to the parcels delivered in the LPIS. There again, the type of activity data which can be retrieved from GSAA varies between countries. In Denmark for example, afforestation subsidies recorded in IACS are used as activity data for the monitoring of afforestation areas. Agro-Environmental and Climatic Measures (AECMs) recorded in IACS, as well as the new Eco-Schemes, could provide activity data for some management practices, provided that these practices receive CAP support.

Copernicus Land Monitoring Service (CLMS)

The Copernicus Land Monitoring Service (CLMS) [54], is one of the six operational Copernicus services, providing operational Earth Observation based products on various elements of Land Cover and Land Use (among others), free and open for all users. Although the main focus of the available data is on biophysical parameters and land cover products, there are also elements of land use. Among others, the following Copernicus products can contribute to improved geospatially-explicit mapping and monitoring of activity data (or proxies to activity data):

[53] European Commission (2007): Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). European Commission. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32007L0002.
[54] https://land.copernicus.eu

- Land-use changes:
  - A highly accurate pan-European land cover map (CLC+ Backbone), available for 2018, with an update for 2021 available by the end of 2023, and then updates every 2 years [55] with a 10m resolution (but without specific change layers).
  - Maps of vegetation (10-20m resolution) and vegetation change (20m resolution, tree cover and forest, grassland) [56]
  - Note that the High-Resolution Layers (HRL) have a 3-yearly update cycle from 2012 up to 2018 which is increased to yearly updates from 2018 onwards. Additionally, a new, also yearly crop type layer will complement the HRL portfolio (currently in production). However, it needs to be considered that the products normally become available only 10 months to 2 years after the reference year.
  - Long time series of land use and land cover change: Corine Land Cover (CLC)
  - CLC present limitations when used to derive land-use change matrices for LULUCF inventory. First, minimal mapping units are coarse (5 ha to 25 ha, depending on categories and on whether stable or change polygons are drawn). This spatial resolution is often not precise enough to track forest patches that meet official national forest definitions, or to track small-scale urban sprawl phenomenon. Its temporal resolution is also limited when it comes to the objective of timeliness of inventories, since it is only produced with an update frequency of 6 years. CLC is available for the reference years 1990, 2000, 2006, 2012 and 2018 with respective change products for 1990-2000, 2000-2006, 2006-2012 and 2012-2018.
- Hedges, agroforestry, trees outside forests: small woody features maps, available for 2015 and 2018 (5m raster product).
- On burnt area: the global component of the CLMS has burnt areas in their portfolio [57] and there is also a global fire monitoring element of the Copernicus Atmosphere Monitoring Service [58].

As a part of the new CLC (named CLC+) [59], the CLMS is currently developing tailor made 100m grid products that try to approximate LULUCF activity data categories, the so-called LULUCF instances. These combine the afore-mentioned land cover and land use data produced in the frame of CLMS in a web-application/database (CLC+ Core). Within the CLC+ Core system, all input datasets (e.g. 10m raster products) will get aggregated to 100x100m. The output also has a 100x100m resolution. This is also the case with, for example, CLC+ LULUCF Instances. CLC+ Core is also available for countries to use, and additional training can be offered in 2024. First instances prototypes became available in 2023.

Further Copernicus products like European Forest Fire Information System (EFFIS) can be found in Annex 4. ICF (2019) proposed for example a critical review of Copernicus datasets in regard to their relevance for the LULUCF inventory purposes.

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[55] https://land.copernicus.eu/pan-european/clc-plus/clc-backbonehttps://land.copernicus.eu/pan-european/clc-plus/clc-backbone

[56] https://land.copernicus.eu/en/products/high-resolution-layer-tree-cover-density, https://land.copernicus.eu/en/products/high-resolution-layer-forest-type, https://land.copernicus.eu/en/products/high-resolution-layer-dominant-leaf-type and https://land.copernicus.eu/en/products/high-resolution-layer-grassland

[57] https://land.copernicus.eu/global/products/ba

[58] https://atmosphere.copernicus.eu/global-fire-monitoring

[59]https://land.copernicus.eu/en/products/clc-a-new-generation-land-information-system-for-europe https://land.copernicus.eu/en/products/clc-a-new-generation-land-information-system-for-europehttps://land.copernicus.eu/en/products/clc-a-new-generation-land-information-system-for-europe

LUCAS soil survey

LUCAS [60] (Land Use and Land Cover Survey) is a harmonized survey dataset on land cover and land use that extends over the whole of the EU's territory. Data is gathered through direct ground observations made by surveyors on sample points. The data collected by LUCAS provides harmonized information for studying a range of socio-environmental challenges, such as land take, soil [61] degradation or biodiversity. Data on land-use is available for 2006, 2009, 2012, 2015, 2018 and 2022.

The LUCAS soil survey provides soil data, and in particular carbon concentration and bulk density. The data is available for a sub-sample of the LUCAS points for years 2009, 2015, 2018 and 2022. This survey, possibly combined with national soil measurements or inventories, and downloadable soil maps, can be used to derive country-specific values for at least carbon reference stocks and emission factors associated with land-use changes (see Bellassen et al. 2023 for details).

Existing analysis of the LUCAS soil survey already provide example of Tier 3 measurement-based estimates of soil carbon changes in cropland and grassland for the 2009-2018 period for all Member States (Rosa et al. 2023).

Other possible data sources

Some of the above-mentioned datasets can be used directly without extensive pre-processing etc. Beyond these, other datasets are available which can be and in some instances are being used in national GHG inventories. However, some of the dataset listed below need extensive processing before they can be used as input for the monitoring, e.g. airborne imagery or other satellite data, and some are not available in all Member States.

Airborne datasets

Airborne imagery provides a higher resolution and timely data and can be used for a variety of geospatial applications (see European Association of Aerial Surveying Industries (EAASI) [62] It is amongst other used often by countries for the LPIS update and controls or is used for the LUCAS survey. In addition, aerial imagery can be used with ground-based data, other geospatial data or CLMS products to detect land cover and land use changes. For example as airborne imagery provide timely data spatial assessments of natural hazards like storm damage in forest areas can be performed. In case of available historical data changes can also be tracked back. Besides that, airborne imagery and can also be used for estimating digital surface models (Achard et al. 2008).

National Forest Inventories (NFIs)

National Forest Inventories (NFIs) have been developed separately by countries with different approaches to cover the information needs about forest at the national level. They are empirical assessment of forest resources, based in particular on plot measurement of trees. NFI methods reflect the country-specific conditions and interests. Some NFI are based on permanent sampling points that can be used as the basis or as an element of a geographically-explicit monitoring of LULUCF. NFIs are often the key forest monitoring system at national level, and they assess different variables useful for LULUCF inventories: land-use areas, land-use change, growing stocks of living biomass, dead biomass, increment, mortality and harvest rates, etc. Their methods are evolving to integrate new data and techniques such as remote sensing, Lidar, etc. Harmonisation efforts have been conducted during the 1990's and the 2000's to ensure better comparability between European NFIs. European NFIs are the base of EFISCEN-Space, a

[60] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=LUCAS_-_Land_use_and_land_cover_survey

[61] https://esdac.jrc.ec.europa.eu

[62] https://www.eaasi.eu/

geographically-explicit projection modelling tool of forest development in Europe at the forest stand level driven, under realistic forest management conditions. The model functionality can be extended to cover aspects such as carbon in biomass, soil and harvested wood products, among other indicators.

Copernicus Satellite constellation [63, 64]

The Sentinel satellites are part of the European Copernicus program to monitor the Earth. The satellites include six different missions. For example the Sentinel-1 provides radar data, Sentinel-2 provides high-resolution multispectral imagery for monitoring land cover or Sentinel-4 is dedicated to monitor air quality. Data from the Copernicus Sentinel constellations is freely available and is e.g. Sentinel-1 and -2 time-series is used as input to produce the CLMS HRL VLCC products.

Landsat Program

The Landsat Program consists of a series of Earth-observing satellite missions jointly managed by NASA [65] and the U.S. Geological Survey (USGS) [66]. Since 1972, Landsat satellites have continuously acquired images of the Earth's land surface and provided an uninterrupted data archive to assist land managers, planners, and policymakers in making more informed decisions about natural resources and the environment with a 30m resolution.

EuroGeographics

EuroGeographics [67] is an independent international not-for-profit organisation representing Europe's National Mapping, Cadastral and Land Registration Authorities and facilitates access to official, reliable, comparable and verifiable geospatial data from them. Open Maps for Europe (OME) is a new online service that provides free to use maps from more than 40 European countries. The datasets are created using official map, geospatial and land information from official, national sources. The new OME2 project, co-funded by the European Union, builds on its success by developing a production process and high-value, large-scale pan-European prototype [68].

National digital maps of land use, topography, cadastre, and other data sets

National digital maps of land use, topography, cadastre, protected areas [69], peatlands, buildings, transport networks and other landscape features can also be useful for a geographically-explicit monitoring of land-use and land-use change. Such datasets can help to determine a detailed land-use map. However, to consistently track land-use changes, specialized data about land-use and/or land-cover change, such as national or European land-cover and land-cover change products, can be more relevant.

Various other international, European, national or local geographically-explicit datasets can be used as primary or secondary source for the LULUCF monitoring, describing land use, land cover, biomass density, carbon stocks, etc.

Further, there are many private companies with a focus on EO data, satellite imagery and mapping. Many of them are members of EARSC (European Association of Remote Sensing Companies) [70].

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[63] https://www.copernicus.eu/en/about-copernicus/infrastructure-overview/discover-our-satellites
[64] https://atmosphere.copernicus.eu/sites/default/files/FileRepository/Events/Press-tour/Space_for_Copernicus.pdf
[65] https://landsat.gsfc.nasa.gov/data/
[66] https://www.usgs.gov/landsat-missions/data
[67] https://eurogeographics.org/
[68] https://www.mapsforeurope.org/
[69] In Sweden for example: https://skyddadnatur.naturvardsverket.se/
[70] https://earsc.org

National and international soil data

Many Member States have either a soil inventory or one campaign of soil carbon measurements that are comparable to the LUCAS soil survey (see above) and can either replace or complement it. In addition, several soil carbon maps are easily accessible online (e.g. SoilGrids).

Other non-cartographic datasets that can still be useful in a geographically-explicit monitoring

Some other datasets can provide useful information regarding LULUCF activity data and calculation parameters, such as agricultural practices, but are not cartographic products. However, when combined with geographically-explicit monitoring of other parameters, they can provide the basis to a high-resolution calculation of emissions and removals, especially when such statistical datasets provide subnational levels of detail.

Farm Accountancy Data Network (FADN)

FADN [71] is a European database originally focused on farm accounts (products, costs, profits, …) in Euros, although it is evolving towards data on physical amounts in tons or number of animals, with the objective of performing environmental assessments. It is updated annually and covers only a representative sample of farms.

The European FADN can already provide activity data on the extent of organic farming in hectares. The national FADNs usually contain more data than that sent to DG Agri for the European compilation. This data can sometimes be the source of activity data for a relevant practice regarding soil organic carbon. The Italian FADN for example contains data on the amounts of organic inputs to agricultural soils. Whether your national FADN contains useful information on activity data for soil organic carbon monitoring is to be assessed on a country-by-country basis.

In the Farm to Fork strategy, the Commission had announced its intention to convert the Farm Accountancy Data Network (FADN) into a Farm Sustainability Data Network (FSDN). It is now acted with the Regulation (EU) 2023/2674 of the European Parliament and of the Council of 22 November 2023. This initiative expands the scope of the current EU farm data collection network to include data on their environmental and social practices.

Agricultural census

There is no aggregated agricultural census at the European level. However, most Member States conduct an exhaustive agricultural census or similar non-exhaustive surveys at variable frequencies (3-15 years). Similarly to national FADNs, there is to be a country-by-country assessment of whether your agricultural census contains useful information for deriving activity data. One may hope to find activity data on food standards (e.g. organic, geographical indications), the number of hedges or agroforestry plots, the crops and the management practices applied, etc.

Farm practices surveys

There is no aggregated farm practices survey at the European level. However, most Member States conduct such surveys on a small sample of farms or fields at variable frequencies (5-15 years). Similarly to national FADNs, there is to be a country-by-country assessment of whether your farm practices survey contains useful activity data. One may hope to find activity data on the amounts of organic inputs to soils, the number of hedges or agroforestry plots, the extent of cover crops, etc.

[71] https://agriculture.ec.europa.eu/data-and-analysis/farm-structures-and-economics/fadn_en#conversiontofsdn

Choice of geographically-explicit data

Some countries such as Portugal, the Netherlands, Czechia, Slovakia, and Luxembourg rely on vector maps to consistently track land use over time. It means that each piece of land that changes at one time must be delimited with a new polygon. Such a map can be derived from cadastral data or can be a national land-use product; it must meet the following conditions:

- Have a sufficient spatial resolution that can allow to accurately track land-use change and that is compatible with the national definition of forest land.
- Have a nomenclature (number of classes and their definitions) that is precise enough to be translated into IPCC categories or national subcategories and reflect carbon stock changes.
- Have several years covered, to propose evolution of the dynamics of land-use changes.
- Have a high degree of consistency in polygon boundaries between editions of the dataset, in order to avoid topological and geometric artefacts. Indeed, the opposite could lead to a high detection of 'false changes'. To do so, products that are specifically designed to track changes consistently over time are to be prioritized. For example, Corine Land Cover or Urban Atlas provide change maps that only highlights actual, verified polygons of change.

Other countries, such as Germany and France, use another system. They created a systematic grid over the country and use the central points (centroid) of each cell to collect the information. This approach relies on a underlaying raster with standardized grid cells as the mapping unit instead of polygons of variable shapes and sizes. To facilitate the integration of multiple datasets by intersection of maps and these grid cells, Germany and France have chosen to use centroids instead of raster cells. This helps to integrate multiple datasets, with different spatial or thematic resolution. It also helps to avoid polygon boundaries problems and limits related artefacts.

Each Member State can develop an approach that fits the national and/or European dataset that is the most relevant, as long as geographically-explicit data is used.

Non-issue: how to ensure time-series consistency and local relevance when increasing spatial resolution?

A common worry when moving to input data with higher spatial resolution is to ensure time-series consistency. As for moving to higher Tiers (see section 5.2.4), the recommendations from the IPCC Guidelines apply and allow to improve monitoring without being hampered by the inconsistency with the previous data source. Case studies 7 and 8 provide examples of how this has been implemented in two Member states.

Case study 7: The vector maps of Portugal

Portugal has developed its own land use and land-use change map that is a good example of a geographically-explicit approach to monitoring areas for the LULUCF inventory with a temporal consistency. This case study also presents Portugal's method to cover past periods**. Read more on Case study 7.**

Case study 8: The combination of multiple geographically-explicit data on a grid for France

This case study presents how France implemented a new geographically-explicit method to move from approach 2 to approach 3 for land representation. This method combines several national and European datasets within a high-resolution grid, using hierarchy rules and correspondence between nomenclatures**. Read more on Case study 8.**

Another common worry is the local relevance of the estimate. For example, the carbon balance of forest land biomass may be estimated as a regional average in the GHG inventory, and assigning this regional average to every plot of forest in the region can be seen as misleading and hiding spatial heterogeneity. Yet, one could argue that this assignment does not affect the regional estimate, and that it is likely to increase its number of users by being provided directly through a single, inter-operable and geographically-explicit, portal. In all cases, whereas the usefulness of displaying GHG emissions estimate at very high resolution can be debated, the case for high resolution input data is strong, if only for the estimates related to land-use changes.

5.5 Natural disturbances

5.5.1 Why are natural disturbances relevant for the LULUCF Regulation?

The land sector is affected not only by management decisions of humans but also by natural processes. Extreme events such as windfalls from storms, insect outbreaks or fires in forests can significantly affect the GHG inventories of countries in single years. GHG inventories reflect natural disturbances in different ways, depending on the size and type of disturbance. Disturbance events may have impacts on both carbon removals and CO_2 and non-CO_2 GHG emissions. The following types of events typically occur in the EU:

Drought events reduce CO_2 removals. This is because they negatively affect tree growth and increase tree mortality. Changes in growth and mortality are documented through National Forest Inventories (NFI). However, they are only carried out every five or ten years and do not capture interannual events. Some countries therefore revisit a fraction of the NFI sample plots annually, e.g. 20% for a full cycle after 5 years, to get information about changes in forest growth conditions in between inventory cycles. Drought events do not necessarily directly lead to high emissions. However, such emissions might occur through drought-induced disturbances such as insect and pest outbreaks.

Insect outbreaks reduce CO_2 removals and can potentially lead to high emissions. Insects can reduce forest growth, kill individual trees or even entire forest stands. Dying and dead trees might be harvested through salvage logging and thus may in part enter the HWP pool. However, timber quality is often reduced. Similarly to droughts, NFIs and harvest statistics record such events if they affect tree growth significantly over several years or killed and removed. At landscape level effects on forest carbon stocks might be levelled out by reduced harvest of living trees due to market effects.

Forest fires reduce CO_2 removals and can potentially lead to high emissions. Emissions occur from burning litter and understory in case of less intensive fires or from burning of tree biomass if the fire is more intense. Stand-replacing fires where entire trees burn are less frequent in EU but might occur more in the future. Forest fires are already monitored in a timely manner in many countries, either using national statistics or remote sensing data (see, for example, Section 5.3.3).

Windfalls from storm events reduce CO_2 removals and can potentially lead to high emissions. Storms damage trees by breaking the stem or uprooting. Windfalls are often followed by insect outbreaks as storm-damaged trees are less resilient. The damaged trees might still be used for products. However, often timber quality is reduced. Similarly, to the impacts of insect outbreaks, at landscape level effects on forest carbon stocks might be levelled out by reduced harvest of living trees due to market effects. The impact of windfalls also tends to show up in GHG inventories only with a delay of several years.

Over the last decades, natural disturbances have been increasingly putting pressure on European forests. Their impact was estimated to amount to 16% of the annual harvest in Europe over the last 20 years (Patacca et al. 2023). Wind is the most important disturbance agent (46% of unplanned harvest), followed by fire (24%) and insect outbreaks (17%). Natural disturbances lead to additional unplanned harvest, e.g. as salvage logging, meaning that dying or dead trees are removed. Large scale disturbance events can thus lead to market implications such as decreasing timber prices that often have a dampening effect on total harvest amounts realised in a country or region. Damaged wood, however, is often not suitable for use as sawn wood and therefore rather used for energy, pulp production or wood-based panels. This has also implications for carbon storage in wood products and possible substitution effects (Verkerk et al. 2022).

There is often a **relationship between managemen**t **choices and natural disturbances**. Therefore, opportunities exist to reduce natural disturbances through adapted forest management. Changes in forest composition, e.g. mix of tree species, vertical and horizontal structure of stands etc., can reduce forest fires, windthrows, insect and fungi pest outbreaks. For example, converting forests from single-species coniferous forests to mixed forests, including broad-leaved trees species, will increase forest resilience. However, adaptation measures need time to be implemented and time before they have an effect on forest resilience. Moreover, there are also long-term implications for the availability of other ecosystem services, such as wood supply of certain assortments. Finally, measures can only be implemented at certain phases of forest stand development. But there are also important synergies between mitigation and adaptation measures. For example, greater tree-species diversity can increase forest growth and, at the same time, increase the resilience of forests to natural disturbances (Verkerk et al. 2022).

The LULUCF Regulation defines **natural disturbanc**es as "*non-anthropogenic events or circumstances that cause significant emissions*". Their occurrence is assumed to be "*beyond the control of the relevant Member State*" and cause emissions that the Member State is not able significantly to limit. The inclusion of natural disturbance emissions in the accounting bears the **risk of large debits** from these events for affected countries but also the EU as a whole. The LULUCF Decision, therefore, allowed countries to exclude emission peaks caused by natural disturbances from the accounting (EC 2013). The provision was first introduced as an option during the second commitment period under the Kyoto Protocol, when accounting of forest management activities became mandatory.

5.5.2 What does the LULUCF Regulation say?

Exclusion of emissions from extreme events in managed forests during the period 2021 to 2025

The revised LULUCF Regulation allows for the exclusion of a limited amount of emissions from natural disturbances **on afforested land and managed forest land** in **the period 2021 to 2025**. Art. 10 and Annex VI of the Regulation provide details on how such events can be identified and how the exclusion is done. The basic rules and calculation steps are the following (for more details, see also the text box below):

First, a country needs to identify whether an 'extreme event' has occurred. To detect extreme events, a country's usual level of emissions from natural disturbance events is recorded based on past data. This level is called the '**background level**'. It represents the emissions that have occurred without any extreme events and is calculated based on the average emissions from natural disturbances between 2001 and 2020. Unusual outliers, i.e. years with high emissions, are excluded from these historic records.

The background level serves then as a benchmark for what are considered 'normal' levels of emissions from natural disturbances in a country. For extreme events, the difference to the background levels needs to be sufficiently large. Therefore, a certain extra amount (called **margin**) is added to the background level to **account for uncertainties**. If, according to the GHG inventory of the years 2021 to 2025, emissions from natural disturbances in one year are higher than the background level plus the extra margin, it is considered an 'extreme' event. These emissions can be left out of the total emissions count.

While in the short-term extreme events cause reduced CO_2 removals and high emissions, depending on type and severity, they can be followed by substantial **CO_2 removals from the regeneration of forests after disturbance**. Removals occur, e.g., when trees naturally regenerate after a fire, new forest stands are planted, or the biomass of remaining trees increases after an insect outbreak due to increased nutrient, water and light availability. For a **balanced accounting** it is important that such removals are not counted as climate mitigation contribution if emissions from the loss of biomass have been excluded earlier.

The exclusion of emissions from extreme events therefore comes with some additional rules specified in Annex VI of the Regulation.

The areas in which the events took place need to be known and a **documentation is required that shows that CO_2 removals on these areas after the event are excluded, too**. The exclusion of removals on areas affected by extreme events for which emissions have been excluded from accounting needs to be ensured for the remaining compliance period, i.e. until 2025.
Moreover, **emissions from harvesting, salvage logging or deforestation** after the disturbance event and emissions from prescribed burning on the disturbed land areas **cannot be excluded**.

The requirement of a balanced accounting makes implementation of the provision on natural disturbances technically demanding. Since emissions from harvesting and salvage logging cannot be excluded, it is likely that the requirements for an exclusion are met especially by large fire events that a) cause high emissions in a single year and b) less likely allow for salvage logging due to the damaging effect.

Areas affected through fire events are relatively easily detectable through remote sensing technologies (e.g. Emilio Chuvieco et al. 2019; Leblon et al. 2012). Such technologies can help documenting geographical location but also an attribution to disturbance type and driver (Julius Sebald et al. 2021). More challenging is the estimation of related emissions and tracking of subsequent regrowth that requires terrestrial information such as National Forest Inventory data (Castagna et al. 2023). However, despite the challenges, the option to exclude emissions from extreme events is an important instrument for countries in which such events can easily exceed normal years of emissions and removals by an order of magnitude.

Documentation of natural disturbances required to make use of managed forest land flexibility

Natural disturbances and the documentation of emissions caused by them are also relevant for other parts of the LULUCF Regulation. Member States that are willing to use the **managed forest land flexibility** in the period 2021-2025 offered by Art. 13 – i.e. to compensate a debit under managed forest land by a credit in other Member States (see Section 4.3 of this Handbook) – will also need to provide documentation on the impact of natural disturbances. Specific information required by Art. 13 includes the "*identification of all land areas affected by natural disturbances in that particular year, including their geographical location, the period and types of natural disturbances." Article 13 refers also to Annex VI that specifie*s rules for the calculation of the background level (see above). In fact, the background level approach here is used to provide evidence that natural disturbances are responsible for higher emissions not with the aim to exclude emissions from extreme events but to compensate a debit resulting from accounting forest sinks that are reduced by these events against the forest reference level.

Data sources for providing such evidence can be similar to the ones referred to above. These include remote sensing-based products and statistics that are collected by international data bases such as the European Forest Fire Information System (EFFIS) [72]. The Database of European Forest Insect and Disease Disturbances (DEFID2) [73] collects and makes available geospatial records of insect and disease disturbances in European forests (Forzieri et al. 2023). Similarly FORWIND [74] provides geospatial data on wind disturbances in Europe (Forzieri et al. 2019).

In contrast to the exclusion of extreme events based on Art. 10, Article 13 is also relevant for natural disturbances that cause a reduction of forest growth and thus reduced CO_2 removals such as drought events. However, due to their naturally wider spread compared to, e.g., forest fires, a delineation and geographical location identification is much more challenging.

Other information required by Art. 13 is a description of measures the Member State undertook to prevent or limit the impact and rehabilitate the lands affected by those natural disturbances.

Compensation of emissions from climate change impacts on managed land during second compliance period

The second compliance period does not allow for an exclusion of emissions from extreme events. However, similarly to the "managed forest land flexibility" of the period 2021-2025, Member States that provide evidence to the Commission concerning the **impact of natural disturbances** are eligible for compensation under the **land use mechanism** (Art. 13b, see Section 4.3 of this Handbook). Like the managed forest land flexibility the land use mechanism requires "*evidence concerning the impact of natural disturbances calculated pursuant to Annex VI*". Potential sources of information for such documentation are discussed above. Art. 13b, additionally demands evidence on "*the long-term impact of climate change resulting in excess emissions or diminishing sinks that are beyond their control.*" This evidence involves a **quantitative assessment of climate change effects on net emissions or net removals** for the affected area. Compared to the documentation of natural disturbances for applying Art. 10 and Art. 13 for accounting under the first compliance period 2021 to 2025, Art. 13b requires an attribution of these disturbances to climate change.

Scientific literature shows that recently increased disturbance activity in temperate forest ecosystems across the globe can be attributed to warmer and drier climate conditions (Sommerfeld et al. 2018). It can thus be expected that a warming climate could lead to large-scale disturbances in temperate forest ecosystems in the future (Seidl et al. 2017; Allen et al. 2010). Such an attribution at the country level requires extensive modelling of climate change impacts on vegetation. The attribution to single events is even more challenging. This is especially true due to the high spatial variation of site conditions that exacerbate but also buffer climate change effects as well as the influence of management on natural disturbances that can

[72] https://effis.jrc.ec.europa.eu/
[73] https://jrc-forest.pages.code.europa.eu/defid2r/
[74] https://doi.org/10.6084/m9.figshare.9555008

hardly be disentangled for individual events. Member States can, however, document changes of climate characteristics relevant for the LULUCF sector, including aridity, mean temperatures, mean precipitation, frost days, and the duration of droughts, explicitly referred to by the Regulation. Such data need to cover at least the period 2001 to 2025. Scientifically reviewed projections and observations for the period 2026 to 2030 should be included. Such records can at least be used to identify statistical relationships between occurrence of disturbances and observed changes in climate. Ideally, Member States can make use of models used for GHG reporting that include climate sensitivity and natural disturbances. An example is the CBM-CFS model already applied by a number of Member States (see Case study 3).

5.6 Tracking progress

5.6.1 What does the LULUCF Regulation say?

For the achievement of the EU wide LULUCF target, it is important to regularly check the progress towards the target. This includes an overview of the extent to which Member States are making progress in relation to their national targets, especially whether existing and planned policies and measures seem sufficient for national target achievement. In addition, it is important to keep an overview of the intended use of flexibilities.

The Governance Regulation sets common rules for the planning, reporting and monitoring with regard to the progress to national LULUCF targets. In the National Energy and Climate Plans (NECP), Member States have to submit information about:

- their national commitments in the field of LULUCF emissions and removals,
- how they are planning to contribute to the EU target,
- policies and measures in place and those which are planned, and
- projections with existing and planned policies and measures.

For the use of the land use mechanism (Art. 13b) it is mandatory to report in the NECPs about ongoing or planned specific measures to ensure the conservation or enhancement, as appropriate, of all land sinks and reservoirs, and to reduce the vulnerability of the land to natural disturbances.

The biannual National Energy and Climate Progress Reports (NECPR) helps tracking progress to national and EU wide targets. For these, Member States must submit information on the role of removals and historic and projected LULUCF emissions.

Table 3 lists the dates for the respective reporting of NECPs and NECPRs and other existing elements to track ambition and progress towards LULUCF targets.

European Commission and EEA annually report about progress towards EU-wide and national targets in the Climate Action Progress Report and the Trends and Projections Report. Every two years, the European Commission assesses in detail, based on NECPRs, the progress made at Union level towards meeting the objectives of the Energy Union and the progress made by each Member State towards meeting its objectives, targets and contributions and implementing the policies and measures set out in its NECP. If inconsistencies are detected with policy developments in Member States related to the overarching objectives of the Energy Union, the Commission issues recommendations to a Member State.

Table 3: Timeline for reporting related to LULUCF Regulation

Year(s)	Articles	Content	Relevance
2018, 2028, …	Gov. Reg, Art.9	Draft National Energy and Climate Plans (NECP)	Reporting on commitments, projections and planned use of flexibilities
2019, 2029, …	Gov. Reg, Art.3 and 4,	National Energy and Climate Plans (NECP)	Reporting on commitments, projections and planned use of flexibilities
2023, 2033, …	Gov. Reg, Art.14	Draft Update of National Energy and Climate Plans (NECP)	Reporting on commitments, projections and planned use of flexibilities
2024, 2034, …	Gov. Reg, Art.14	Update of National Energy and Climate Plans (NECP)	Reporting on commitments, projections and planned use of flexibilities
2023, 2025, 2027, …	Gov. Reg, Art.17, Impl. Reg. (EU) 2020/1208 Annex XXV; Impl. Reg (EU) 2022/229	National Energy and Climate Progress Reports (NECPR)	Reporting on commitments, achievements, projections and planned use of flexibilities
Annually	Gov. Reg, Art.29; Art 34; Art. 35	Climate Action Progress Report of the European Commission;	Assessment of progress to targets on EU and Member State level, recommendations to Member States
Annually	Impl. Reg. (EU) 2020/1208 Annex XVIII	Information on intended LULUCF compliance transfer, as part of the reporting on intended use of the flexibilities under the ESR	Total quantity of intended transfers, and more information on intended use
Annually	Impl. Reg. (EU) 2020/1208 Annex XX	Reporting on accounted emissions and removals, Information on emissions and removals from natural disturbances	Net emissions and removals separately for each subcategory

Source: Own compilation based on LULUCF Regulation.

5.6.2 Timely reporting and the trade-off with accuracy

A timely reporting of emissions estimate is a key condition for its policy relevance. If accurate information on GHG emission and removal estimates are delayed, the effectiveness of policies cannot be assessed. The 2032 compliance check of the LULUCF Regulation is a particularly demanding example of timeliness: whether a Member State has met its 2030 target will be assessed based on the GHG inventory submitted in 2032.

This creates a difficult trade-off with accuracy as many national data from surveys (e.g. biomass stocks from NFIs, soil carbon content from soil surveys) are currently acquired in 5 to 10 years intervals, with the consequence that with current methods, the accurate number for the inventory year of 2030 will only be reliably estimated in all Member States around 2042 [75]. Clearly, this conundrum cannot be fully avoided, and timely estimates are likely to remain less accurate compared later estimates. However, at least three avenues can be explored to improve the trade-off between timeliness and accuracy:

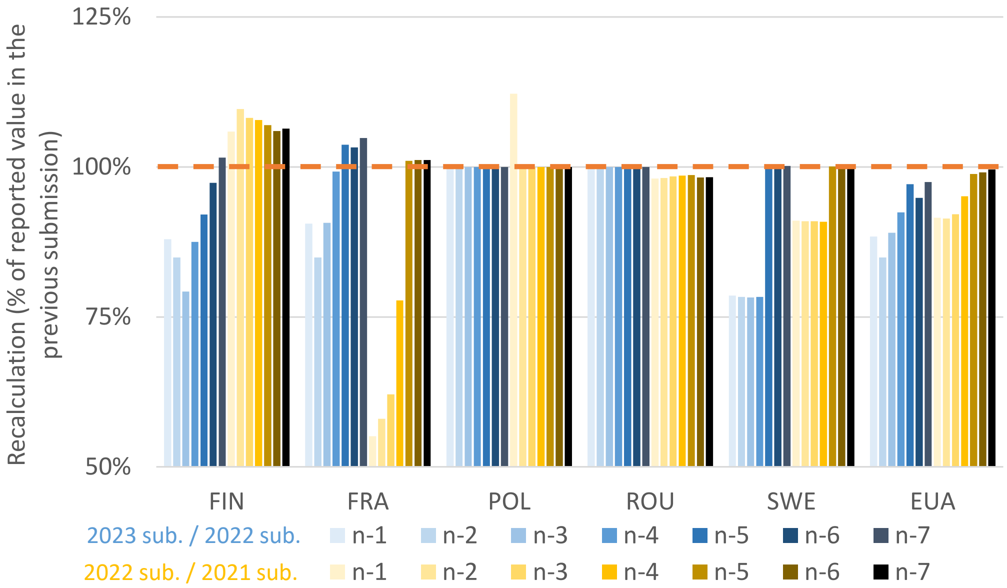
- **Member States can make greater use of remote sensing data** which tends to be timelier. This avenue is well on its way for activity data on land use. Extending it to the above-ground biomass pool could become possible in the years ahead, although for the time being it is an ambitious objective set by research projects. For the soil carbon pool, however, there is little hope of remote sensing estimates in the near future.
- **Member States should synchronize data acquisition with the most pressing policy deadlines**. The CLC+ LULUCF Instances for example, which will provide EU-wide maps of all LULUCF land-use categories every year, aim for a release timing which would be compatible with the use of the 2024 map for the 2024 inventory submitted in February 2026. National Forest Inventories typically have long return cycles. As a result forest inventory data for assessing compliance in 2032 might date from almost a decade earlier. This requires integration of remote sensing assessments that can be conducted more frequently, or specific inventories in between classical inventory cycles based on a sub-grid that record information relevant for GHG reporting.
- **Member States need to combine model and data and pay more attention to model verification**. Inventory compilers have always had to combine data and models for recent years for which final data is not available at the time of reporting. As argued, this combination will still be needed in the foreseeable future. The models can be very simple projections or extrapolations, following the 2006 IPCC Guidelines (volume 1, chapter 5), or more complex ones (see case studies on the Canadian and French approaches to combine model and data for timely reporting of forest emissions). Timely reporting, and the 2032 compliance check in particular, will require a greater emphasis on model verification from inventory compilers and reviewers, even if the model is a simple extrapolation (see box below on verifying extrapolated values in current GHG inventories). This can be achieved by calibrating and verifying the model over the time-series of already reported values for key pools and land categories.

[75] In the worst case, a 10-years inventory cycle starts in 2030, is completed by the end of 2039, and takes 1-2 years to be processed and appear in the 2042 inventory submission.

Verifying extrapolated values for timely reporting

Inventory compilers have always had to combine data and models for recent years for which final data is not available at the time of reporting. They used to pay little attention to the verification of these projections for the most recent years, on the sound rationale that these values would be recalculated once actual data became available. As a result, reported values for recent years can be substantially biased. In two out of the five largest contributors to the European forest sink, as well as in the EU as a whole, reported values for recent years were revised downwards by 10-40% for recent years (Figure 23). For example, if there had been a European target for year 2019 checked in 2021, the budget for living biomass in forest land – by far the largest contributor to the total LULUCF budget – might have been assessed as compliant on the basis of extrapolation even if it actually exceeded the target by 22%. Note that except for Finland in 2022, the reported values are stable in all these examples up to year n-5. In other words, most GHG inventories currently stabilize their estimates for living biomass in forest land after seven years (Figure 23).

Figure 23: Recalculations of removals from living biomass in forest land remaining forest land



Source: Own compilation, based on GHG inventory data submitted to the UNFCCC.

Values below 100% indicate that the forest sink has been revised downwards in the more recent inventory submission. Only the five Member States with removals higher than 20 $MtCO_2$/yr. in 1990 are displayed here, as well as the EU as a whole (EUA). "n-x" indicates the reported year, n being the last reported year in the most recent submission (e.g. 2021 for the 2023 submission).

5.7 Projections

5.7.1 What does the LULUCF Regulation say?

Projections used to be an important element in the LULUCF Regulation, through the Forest Reference Levels used for accounting of emissions and removals from managed forest land. But even after 2025, when accounting will no more be based on reference levels, projections will remain directly or indirectly involved in three instances:

- Most directly, “scientifically reviewed projections” are required for Member States willing to use the “land-use mechanism” flexibility (Article 13b, see section 5.5.2);
- Indirectly, but most crucially, because in 2032, compliance for the 2026-2030 period will largely rely on projections, as GHG inventory estimates tend to stabilize only seven years after for living biomass in forest land remaining forest land (see section 5.6.2);
- Indirectly through the Governance Regulation which calls for projections to be provided and updated by Member States in their National Energy and Climate Plans every five years (see section 3.2.2). Although there are no specific requirements about these projections, they are expected to be broadly consistent with GHG inventories.

5.7.2 How to efficiently produce projections?

Detailed guidance on projections is beyond the scope of this Handbook. However, specific guidance has been elaborated by the JRC for the Forest Reference Levels (Forsell et al., 2018) that can serve as a reference for national experts responsible for projections and GHG inventories in the Member States. Ultimately, projections are necessarily a modelling exercise, ranging from very simple to very complex. The models applied can be very simple projections or extrapolations, following the 2006 IPCC Guidelines (Volume 1, Chapter 5), or more complex ones (see Case study 3 and Case study 4 on the French and Canadian approaches to combine model and data for timely reporting of forest emissions). Assessing model accuracy is an important task for the application of such tools for GHG projections (e.g. Bellassen et al. 2023).

6 Opportunities for overcoming institutional and financial barriers to improved monitoring

The previous Section focused on technical opportunities and challenges and provided ways and examples on how to seize the opportunities and overcome the challenges. This section similarly presents common institutional and financial barriers and examples of opportunities to be seized in this area.

6.1 Overcoming institutional barriers

6.1.1 Challenges for Member States

A variety of stakeholders, including departments, agencies and ministries in the public administration at national level are typically involved in data collection, processing, reporting, and verification of the LULUCF inventory. The key stakeholders are:

- The national government, generally the ministry in charge of the environment, is responsible for overseeing and submitting the GHG inventory and its LULUCF Section to the UNFCCC and the EU.
- The national inventory agency is the designated body which actually prepares the GHG inventory. It may be a department of the ministry or a separate entity.
- Statistical agencies provide socio-economic and land-use (activity) data that are essential for estimating emissions and removals in the LULUCF sector. An example is statistics on wood harvest, sales, and use. The two cornerstone data providers tend to be the National Forest Inventory and the Agricultural Statistics Department, which again can be integrated in a ministry or separate agencies. Remote Sensing and GIS experts tend play an increasing important role in utilizing satellite data and geospatial tools to monitor land cover changes and carbon stocks.
- Scientific and research institutions contribute to the development of methodologies, data collection tools, and research studies related to carbon stocks, land use, and carbon sequestration. Scientific literature is a major source for improving emission factors by providing country specific estimates.
- Financial institutions may provide funding for projects related to mitigation measures but also improved monitoring and are thus essential for advancing reporting methodologies and generation of additional and continuous data.
- Institutional barriers between stakeholders involved in compiling GHG inventories can hinder effective collaboration and data sharing. These barriers can arise from differences in mandates, priorities, data access, and reporting requirements, which are likely to occur given the number of entities involved. Researchers producing data and estimates of GHG fluxes may not communicate them to the agencies in charge of GHG reporting, while these agencies might fail to involve academic researchers in their quality assurance process. This drives up administration costs and hinders the full exploitation of all available information for reporting purposes.
- Effectively integrating public and private finance for carbon farming projects under the Carbon Removal Certification Framework opens opportunities for better data and co-funding of activities, but also demands protocols, guidance, and data exchange systems for farm or forest level carbon removal data. For agricultural

operators undertaking carbon farming projects, the LPIS system is an important link. For projects developed in forests and peatlands, such data interfaces rules will need to be developed.

Compiling the LULUCF Section in the GHG inventory in compliance with the LULUCF Regulation and the UNFCCC reporting requirements typically requires one to three full time positions, on top of resources needed for subcontracting work by data providers within the country (other agencies or universities). It is therefore a substantial part of the total cost of compiling a GHG inventory, which has been estimated at around 0.5-0.8 M€/yr., excluding costs associated with necessary primary data collection usually implemented by other agencies for other purposes (Bellassen et al. 2015).

An example of how r coordinated science can support processes for improving GHG reporting is presented in Case study 11.

Case study 11: The role of coordinated science for improving GHG reporting

Ireland has experienced a fast evolution of methodology of the reporting of GHGs from grassland and wetlands that was influenced by a close collaboration between the communities of GHG reporting and research. A basis for this is the involvement of GHG inventory staff members in research projects as discussed by this case study. **Read more on Case study 11.**

6.1.2 Opportunities for Member States initiatives

To overcome institutional barriers within and across Member States, the following strategies can be applied.

Member States need to define **clear roles and responsibilities** for each stakeholder group. It needs to be ensured that government agencies, statistical bodies, and inventory agencies have well-defined mandates and clear reporting obligations. Coordination and collaboration between agencies need to be promoted at the national level to harmonize data collection efforts and minimize duplication of work. This can also involve mechanisms for **resolving disputes** or disagreements among stakeholders. These mechanisms should be fair, transparent, and impartial. Promoting **transparency** in reporting by sharing methodologies, assumptions, and data sources used in GHG inventories can enhance trust among stakeholders and allows for independent verification. **Cooperation** with privately recognised CRCF schemes, international organizations and neighbouring countries with the aim of sharing data, aligning reporting methodologies, and sharing best practices can also support national processes. In general, integration of CRCF and other private operator driven climate mitigation actions and results into inventories requires investments, but also offers opportunities for wider collaboration with the private sector and facilitation of innovation and additional skills and funding.

A typical reason why data producers fail to provide timely and adequate data to the inventory compilers is that the usefulness of the GHG inventory is not obvious to them. At least two types of actions can be implemented at Member State level to overcome this barrier.

Firstly, **re-use the inventory results** in contexts other than EU or UNFCCC reporting. A common and typical example is the production of projections. National projections of GHG emissions in all sectors are required every five years under Governance Regulation, and more generally, ministries and public agencies regularly order sectoral or sub-sectoral projections for various purposes. The data and tools mobilized for the GHG inventory are often close to those used in prospective studies and the inventory team and its data providers are therefore ideally positioned to make these projections (see Canadian case study 3 for a specific inventory tool). Other opportunities for the re-use of inventory work include the provision of reliable emission factors for mitigation projects or for the GHG budgets of public and private entities. The more inventory results and tools are used, the more other governmental agencies will be convinced of the importance of cooperating and funding the inventory.

Secondly, **involve data providers, private sector schemes and projects, and scientists in these other uses** of inventory results. For example, joint responses to ministerial calls for projections are a good opportunity to meet more frequently and thereby better understand one another's needs and constraints. In addition, the joint production of these projections showcases the competence of all partners in the consortium. Member States should provide incentives and recognition for stakeholders that actively contribute to accurate and comprehensive LULUCF reporting. Recognizing and rewarding good practices can motivate cooperation.

Case study 12: Iceland's improvement group: institutional arrangements for advancing GHG reporting

Iceland still lacks country specific data for applying higher tier methodologies and approaches, especially for grasslands, croplands and wetlands. A case study presents how the country established an "improvement group" for advancing GHG reporting. **Read more on Case study 12**.

6.1.3 *Opportunities for EU-wide initiatives*

Annual LULUCF workshops

There are a number of existing workshops that can help addressing institutional barriers in Member States:

- **Technical support workshops**: The JRC organizes annual technical workshops on latest developments in scientific methods and monitoring strategies. They address emission inventory experts.
- **Emission inventory support workshops**: These are workshops organized by EEA to present results and insights of the quality control and review activities as well as inventory compiler experience with the practical and technical challenges when compiling the annual emission inventory. The event allows Member States to reflect on potential improvement or practical solutions when compiling their national emission inventories.
- **Policy exchange workshops**: These are organized by EEA under the EIONET umbrella and with support from the European Commission. They address policy makers outside the legal setting and offer opportunities to exchange ideas for and results from land use policies that address LULUCF sector emissions and removals. Topics include mitigation, adaptation, and links with environmental impacts.

Other possible opportunities

Other possible ways at EU level to overcome institutional barriers could include:

- **E-learning and seminars to stimulate exchanges of good practices between MS**. There is an uneven distribution of institutional capacity, LULUCF file history, capacity to follow negotiation and Subsidiary Body for Scientific and Technological Advice

(SBSTA) networks, relevant national university level training and domestic knowledge bases among Member States. While not a revolutionary recommendation, a LULUCF reporting master class could be envisioned. It should be web-based, produce and host webinars and organise hackathons on specific problems and issues. The online community could be hosted by the LULUCF help desk mentioned below and could be linked to the LULUCF Review process and SBSTA negotiations.
One need to cover would be a basic introduction to LULUCF MRV and accounting for newer staff (to shorten the time needed to build capacity and skills) both in political systems, the wider expert groups and junior inventory staff. Another would be the front-end, exploratory investigations of detailed issues for experienced inventory compilers.

- **Establish an EU level LULUCF reporting help desk and portal hosted by the EEA.** Given the complexity of the collaboration as well as potential conflicting interests, establishing best practices and lessons learned is an important step towards improving monitoring and reporting. This is true both on the organizational level, the Member State level, and on the EU level. In order to both collect and distribute best practices and lessons learned, the EU could establish a LULUCF help desk that could offer just-in-time support to all Member States and all involved organizations and thus speed up the adoption of an efficient monitoring mechanism. Such a help desk and data repository could gather best practices and offer training, a data and study repository, and share all of it with the implementing staff in each Member Sate. This is primarily a top-down approach that can be supplemented with input from EEA, JRC and MS.
- **Building skills and understanding through participation to the UNFCCC review process**. A great learning opportunity is to study the LULUCF inventories of other Member States or Annex 1 parties. In this way, different approaches, detailed data processing, or modelling decisions may inspire GHG inventory teams for their own country.

  Although Member States are regularly encouraged to send experts to Bonn for UNFCCC review, trivial issues such as funding the travel costs of experts can, in some cases, prevent the participation of some countries. Covering these minor expenses at EU level could be an effective solution.

  Furthermore, the solution could be expanded to ensure the participation of independent reviewers in all reviews. The participation of independent reviewers – non-members of an inventory team such as scientists, NGOs, etc. – to the review process achieves the double objective of bringing new ideas into the process and of limiting conflicts of interest. This external participation would require the Commission to be in charge of recruiting them, to avoid interference by Member States. Commission staff could also be part of this pool of independent reviewers.

6.2 Opportunities for cooperation between Member States

6.2.1 Cooperation on emission factors

The cooperation of Member States on the implementation of LULUCF regulation currently seems to be limited. Inventory compilers and other LULUCF experts meet regularly in expert groups, but cooperation seems focused on presentations and informal discussions in these meetings. The history of presentations at the annual LULUCF workshops organized by JRC illustrates this limited cooperation. Despite high attendance (e.g. 115 attendees in 2023, more than half of them physically present) and the high quality of presentations and discussions, there are no joint presentations by Member States: of 43 presentations on ongoing improvements by Member States since 2015, none has been a joint presentation between two or more Member States and a single presentation covered a project involving two Member States, the MediNet project, mentioned in Case study 10.

The most common form of cooperation is a rather passive one, namely the use by one Member State of a country-specific emission factor elaborated by another – usually neighbouring – Member State. For example, Estonia uses Sweden's emission factors for soil carbon changes in land converted to settlements.

This practice is totally compatible with the IPCC Guidelines and qualifies as a Tier 2 method, provided that a) the neighbouring country (in this case, Sweden) likely has a comparable situation for the given emission factor and b) the neighbouring country's emission factor was itself obtained in line with the IPCC Guidelines. Justifying these two points requires at least a thorough reading of the neighbouring country's National Inventory Report, and possibly some informal exchanges with its inventory team.

6.2.2 Cooperation between Member States: are the opportunities worth the effort?

In principle, Member States could work synergistically towards the development of national/regional emission factors, the processing of similar activity data, etc. The opportunities for bilateral cooperation are, however, likely limited by the country-specific nature of most raw datasets, which will likely necessitate a country-specific adjustment of a jointly designed processing method in most cases. In addition to this 'internal' difficulty, one should not neglect the administrative burden of funding a joint expertise or research project involving more than one country. Given the above, it is perhaps not surprising that deeper bilateral cooperation has not developed despite the usefulness of regular exchanges between Member States at the JRC LULUCF workshop or other venues.

On the other hand, cooperation at the European scale on the **processing of European databases** or on the development of national/regional emission factors **seem much more promising**. The **benefits are higher, as the outcomes would be useful** to all Member States, and the administrative costs may be lower as the EU already has institutions and funding mechanisms to oversee or carry out the necessary work (e.g. EEA, JRC, DG Research).

6.3 Overcoming financial barriers

Member States face funding challenges when it comes to preparing their LULUCF GHG inventories and implementing continuous improvements to deliver high quality information. Data collection, which is essential to provide nationally-specific information is costly and time-intensive. Currently, most Member States have data gaps related to soil carbon, contribution to uncertainties for estimating the emissions and removals from the soil carbon pool and enhancing the role of soils for achieving climate targets.

Another challenge faced by Member States is ensuring continuity in their GHG estimates when improving methodologies. Depending on the methodology used, for example for land representation, the effort to integrate better available data can be relatively high. Over time capacity building and knowledge transfer also pose challenges when it comes to improving the methodologies used for preparing the GHG inventory and ensuring continuity over time. Member States need to dedicate sufficient resources, to ensure they have a continuous pool of reliable experts to carry out the work. The following table provides an overview of potential sources of funding from different EU programmes.

Table 4: Overview of potential sources of funding from different EU programmes

Programme	Type of project	Description
LIFE	Strategic Integrated Projects (SIP)	Projects that implement, on a regional, multi-regional, national or transnational scale, environmental or climate strategies or action plans developed by Member States' authorities and required by specific environmental, climate or relevant energy legislation or policy of the Union, while ensuring that stakeholders are involved and promoting coordination with and mobilisation of at least one other Union, national or private funding source.
LIFE	Standard Action Projects (SAP)	Projects, other than strategic integrated projects, strategic nature projects or technical assistance projects, which pursue the specific objectives of the LIFE programme.
LIFE	Technical Assistance Projects (TA)	Projects that support the development of capacity for participation in standard action projects, the preparation of strategic nature projects and strategic integrated projects, the preparation for accessing other Union financial instruments or other measures necessary for preparing the upscaling or replication of results from other projects funded by the LIFE programme, its predecessor programmes or other Union programmes, with a view to pursuing the LIFE programme objectives set out in Article 3; such projects can also include capacity-building related to the activities of Member States' authorities for effective participation in the LIFE programme.
Horizon	EU Missions	EU Missions are a coordinated effort by the Commission to pool the necessary resources in terms of policies and regulations, as well as other activities. They also aim to mobilise and activate public and private actors, such as EU Member States, regional and local authorities, research institutes, farmers and land managers, entrepreneurs, and investors to create real and lasting impact. One of the five missions is the SOIL Mission [76], through which funding can be made available to improve the monitoring of soils.
Technical Support Instrument (TSI)	Technical Assistance (TA)	The Technical Support Instrument (TSI) is the EU programme that provides tailor-made technical expertise to EU Member States to design and implement reforms. The support is demand-driven and does not require co-financing from Member States. The technical support is provided in a wide range of policy

[76] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/soil-deal-europe_en#funding-opportunities

Programme	Type of project	Description
		areas, including but not limited to climate action, digital transition, and health. Member States can also request support to prepare, amend, implement, and revise their national recovery and resilience plans under the Recovery and Resilience Facility.
COST Actions	Interdisciplinary research network that brings researchers and innovators together to investigate a topic of their choice for 4 years	COST (European Cooperation in Science and Technology) is a funding organisation for research and innovation networks. Their actions help connect research initiatives across Europe and beyond and enable researchers and innovators to grow their ideas in any science and technology field by sharing them with their peers. COST Actions are bottom-up networks that boost research, innovation and careers.

Through Copernicus, user uptake actions can be implemented as follows [77]:

- The user uptake action proposals of the consortium partners are submitted to the European Commission in the annual work programme (WP);
- WP must be approved by the European Commission;
- Specific Grant Agreements (SGA) containing approved actions of the WP are prepared and submitted to the EC;
- SGA must be approved by the EC;
- Start of the approved SGA including its actions;
- An action can be carried out by consortium partner(s) alone or together with external entities. The EU funds an SGA with max. 85%. Calls for proposals are published on CINEA's website and the European Commission's Funding & Tenders portal.

Examples of Life projects with contributions to improving GHG inventories for participating countries are presented in Case studies 13 and 14.

Case study 13: Life project MediNet

Moving to higher tiers often requires moving from default emissions factors and parameters, using more relevant values from national or regional studies. This case study presents how a regional project covering European Mediterranean countries developed information on carbon stocks and fluxes for living biomass in cropland and grasslands to improve the LULUCF monitoring in this region with specific ecological conditions. **Read more on Case study 13.**

[77] https://www.copernicus-user-uptake.eu/

Case study 14: Building a national system to monitor land-use over time in Croatia: the LIFE CROLIS project

Croatia needed to develop a geographically-explicit approach for land monitoring. This case study presents a LIFE-funded project that is aimed at creating such approach, using different earth observation products. The creation of a national land-use change timeseries has many policy implications for Croatia. **Read more on Case study 14**.

7 Conclusions

The LULUCF Regulation sets removal targets for each Member State's LULUCF sector by 2030 and requires enhanced reporting of these removals through higher Tiers and geographically-explicit data.

Achieving the ambitious targets proposed by the LULUCF Regulation will require the **design, implementation and evaluation of effective and integrated policies** to address emissions and removals from land. **Enhanced reporting** will support policy making and help assess compliance. Using **best available methods**, national GHG inventories will empower Member States to have a good understanding of developments in the land sector and to apply measures and policies in a timely and effective manner. Concretely:

- **Higher Tiers** use national data instead of default assumptions and **increase the accuracy of the estimates**.
- **Geographically-explicit monitoring** of land use change allows Member States to **track precisely** what is happening on the field.
- The combination of high-quality data sets in a geographically-explicit framework **helps policy makers to have a comprehensive and detailed view** of the evolution of carbon stock changes and to **assess the impact of their policies** in a timely manner.

To underline this higher purpose of the LULUCF Regulation, emphasis is placed on its **interaction with other European policies** that it will support (see section 3.2). Better GHG inventory tools can already be used for the national projections required by the Governance Regulation, as illustrated by the case study of the Canadian inventory tool for forests (see section 5.2.4). Geographically-explicit monitoring and publicly available data can support projects under the **Carbon Removal Certification Framework** and its national counterparts, or the Eco-Schemes and other **Common Agricultural Policy instruments**, as illustrated by the case of peatlands in Austria (see section 5.4.5).

Enhancing LULUCF reporting is a technical and organisational challenge. With this in mind, the Handbook has been designed to provide guidance on how to meet the technical requirement and examples of data sources (see section 5). Enhancing monitoring also requires **human resources and creative thinking** within inventory teams, as well as strong and operational links with other stakeholders, from **data providers to policy makers**. Examples of institutional and financial resources to consider and how to overcome potential barriers are provided in section 6.

To improve reporting on LULUCF, it is essential that **data collectors and policy makers to work closely together.** Ideally, countries will put in place the institutional arrangements that create a reinforcing positive feedback loop, whereby enhanced reporting supports mitigation actions and policies, and the implementation of these policies and actions generates additional data and mobilises resources to further expand GHG reporting activities.

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Annex 1: Case studies

Case study 1: 'Tree-deserts' in Europe and their future carbon-capture potential

According to UNFCCC rules, LULUCF reporting from grassland and cropland should include the impact of trees and other woody vegetation. Trees on agricultural land in the EU have significant biomass production, which is not consistently recorded in the GHG inventories of Member States. Nor are Trees outside forests consistently reported in the GHG inventories of Member States. Data collected by FAO for the 5-yearly Forest Resource Assessment often lacks data in the categories of "Other wooded land" or "Other land with tree cover", and, even when provided, only records areas with trees extending 0.5 ha.

Scope for large-scale afforestation in the EU is limited by the need to conserve agricultural land, yet agroforestry allows isolated trees, hedges, and tree lines to be established on land which remains in agricultural production, while increasing the carbon content and soil-fertility.

Agroforestry has significant potential to contribute to the EU LULUCF target by 2030. EURAF [78] calculates that there are 95.2 Mha of cropland and pastureland in the EU-27 that are devoid of trees, and 117.9 Mha with less than 10% tree crown cover. Bringing these areas to the 10% tree crown cover threshold would mean planting 11.2 Mha of agroforestry (or 750,000 ha/a between 2025 and 2040). Assuming an average sequestration rate of 5 t CO_2/ha/a for

[78] European Agroforestry Federation, http://euraf.isa.utl.pt/about/agroforestry-europe

agroforestry on mineral soils, including both above and below ground sequestration, 56 Mt CO_2 could be sequestered over the lifetime of the trees - which is typically 20-40 years.

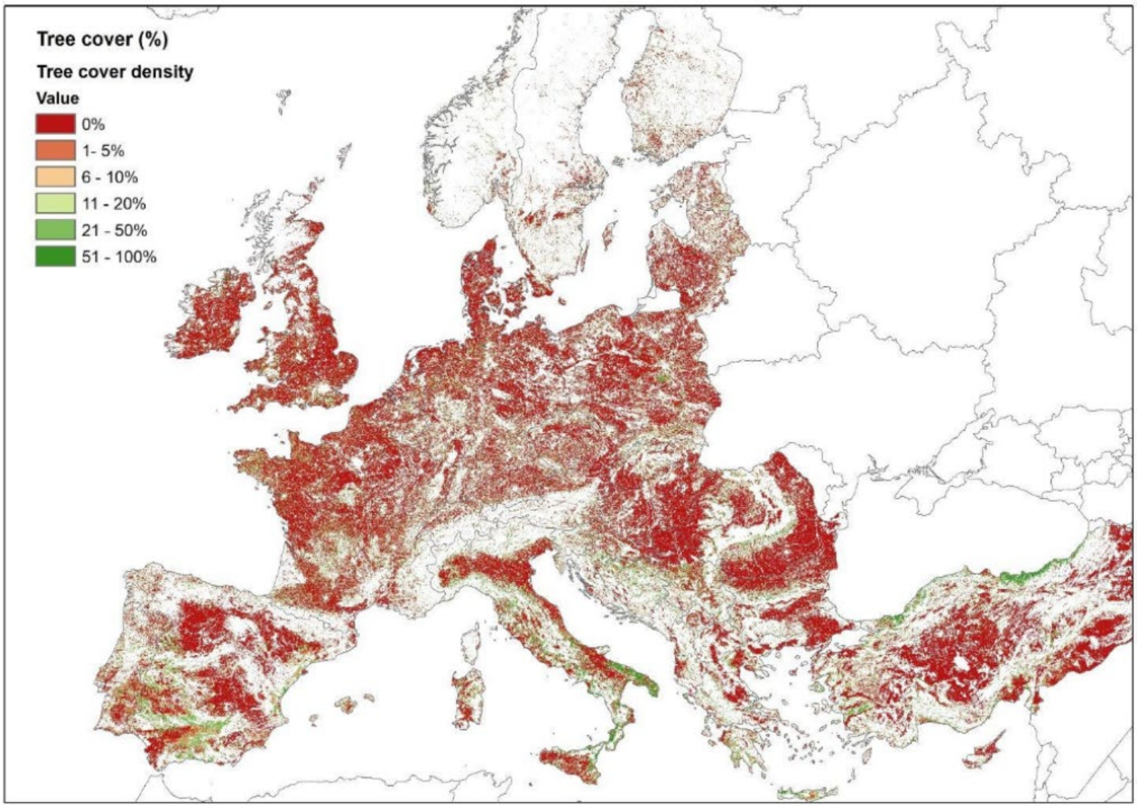


Figure 24: Tree-Cover-Density (TCD) on grassland/cropland land in the 39 EEA countries. Areas of white are non-agricultural land. Red areas are priority planting zones where TCD is particularly low. Source: Copernicus TCD-2018 superimposed on Corine agricultural land for 2018. Each pixel covers 1 ha (100 m x 100 m). The map was produced as part of the EU DigitAF project by Planet Inc and the European Forest Institute.

Work by the EU DigitAF Project [79] has mapped the distribution tree crown cover on grassland/cropland over the EU-27 (Figure 39), and also identified the NUTS-3 regions that have lowest tree cover on this type of agriculture (i.e. excluding permanent crops like olives). The next stage for DigitAF is to use country-specific data in national Land Parcel Identification Systems to identify the distribution of woody landscape features, and devise CAP results-based payment schemes for agroforestry, linked to CAP measures and to voluntary carbon certification.

IPCC Tier 3 modelling of emissions and removals using Approach 3 with LPIS data will allow national reporting of LULUCF to include the attempts being made by individual farmers to reduce emissions on their holdings.

Back to chapter 3.2.1 Common Agricultural Policy

[79] DIGItal Tools to boost AgroForestry, https://digitaf.eu/

Case study 2: High resolution maps for efficient incentives and norms in Denmark

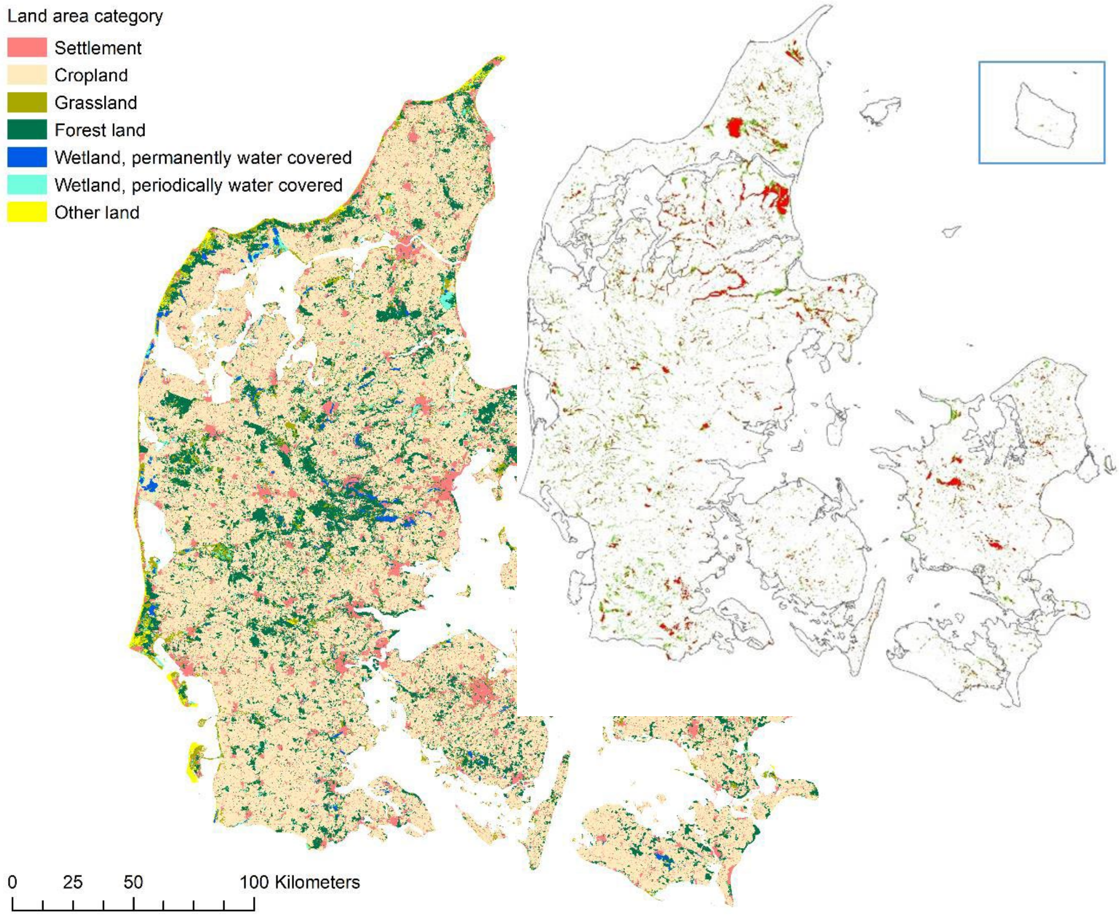
Environmental policies are often based on a benchmark: maximum level of pollution allowed threshold above which further action is subsidized, etc. Improving the local relevance of the benchmark increases the cost-efficiency of a policy. Denmark has already applied this rationale to two environmental policies: peatland rewetting and nitrogen limits.

High resolution maps of land use and organic soils (source: Danish National Inventory Report, 2023)

The Danish LULUCF inventory combines multiple high-resolution datasets to monitor land use change, organic soils, and to perform the carbon fluxes calculation. The following datasets are used:

- a complete wall-to-wall mapping of Denmark at 25*25 m pixel level;
- various geographically-explicit data sources, such as detailed map information on housing and road construction;
- digital maps for subsidy schemes on afforestation on Cropland and Grassland with the exact position of the afforested areas;
- National Forest Inventory (NFI) starting in 2002 based on 2*2 km grid squares;
- EU subsidy related annual digital registration of farmers' own crops at field level (EU Land Parcel Information System or LPIS), for dynamic modelling of carbon stock in agricultural soils;
- map of the organic soils, in a GIS overlay combined with the annual field position;
- Danish topographical maps (digital elevation model) for predicting hedges and other biotopes not qualified as forest;
- digital maps with exact position where wetland restoration is taking place;
- and others.

Figure 25: Land use in Denmark 2021 (on the left) and organic soil map (on the right) for Denmark 2010



Source: Levin & Gyldenkærne, 2022 and Greve et al., 2014.

Note: The left map is based on IPCC land use categories (Levin & Gyldenkærne, 2022) and the right map is the organic soil map for Denmark year 2010 (Greve et al., 2014). Green colour indicates soils with 6-12% of organic carbon and red colour indicates soils with more than 12% of organic carbon.

Since 2011, the availability of yearly spatially-explicit information allows for the assessment of annual changes in land-use at parcel level. This high spatial and temporal resolution increases the artefacts resulting from misclassification. To reduce these artefacts, improbable sequences of land-use changes (e.g. changes from Settlement to other land-uses) and too short durations in a given land use (e.g. fewer than 2 years as forest) invalidate some of the detected changes. In addition, land-use changes that add up to fewer than 8 cells (0.5ha) in a given region are ignored.

As every country, Denmark must deal with the differences of resolution between periods and products. From 1990 to 2011, the assessment is based on a baseline map of land categories for the year 2011 and subsequent backward mapping for the years 2005 and 1990. Since field parcel maps and topographic data are not available for the years 1990 and 2005, the assessment of land categories for these years are based on various other datasets and products, such as Landsat images, agricultural information, cadastre maps, Danish Building register, Danish Areal Information System (AIS).

Mapping organic soils has been a specific focus, with 10,000 points inventoried in 2009/10 and 1,000 points revisited in 2022. This large sample allowed to train a model with high resolution variables (altitude, land use, geology, climate and groundwater depth), resulting in a 10 m resolution map of organic soils (Greve, 2023).

Use of high-resolution maps in environmental policies

These high-resolution maps are then used to optimize the efficiency of environmental policies. The map of organic soils, for example, is the default basis to assess the eligibility of landowners to peatland rewetting subsidies: at least 60% of the rewetted area has to be a “carbon-rich soil” (organic content higher than 6%). Interestingly, ineligible landowners, land managers and public authorities are allowed to challenge the map on the basis of soil measurements in their parcels, potentially feeding back more measurements into the GHG inventory and its maps. The expected emissions reductions from rewetting are estimated through a calculator designed by Aarhus University, and funding is prioritized towards the most efficient projects (in euros per avoided tCO_2e). In 2023, 32 million euros were budgeted for this subsidy scheme, with 7 million euros prioritizing climate mitigation (rewetting of “carbon-rich soils”) and 25 million euros prioritizing “nitrogen wetland” creation (wetlands allowing the reduction nitrogen run-off by an average 90 kg N/ha) [80].

Another such example, although primarily aimed at water quality rather than climate mitigation, is nitrogen limits. All over Denmark, the amount of allowed nitrogen application is capped. But instead of setting a national maximum level, the cap is different for each crop on the 12 soil types 81, depending on production potential. In addition, voluntary schemes at catchment scale provide incentives to further limit nitrogen run-off through various measures including catch crops. There again, these subsidies are prioritized based on the efficiency nitrogen run-off mitigation, expressed in hectare of catch crop equivalent and a map with five classes for soil nitrogen retention capacity. In both cases, the policies are based on high resolution national soil maps and calculations.

Next steps and cautionary remarks

Research is being funded with these policies in mind, thereby trying to get high resolution information on as many environmentally relevant variables as possible. Denmark is also mulling over a tax on wetland drainage, possibly based on improvements in monitoring both wetland area and water table depth.

The synergy between GHG inventory improvements and effective policies comes however with nuance and cautionary remarks. Danish representatives point out that while improved GHGI can help designing more effective policies, they are not a cornerstone of mitigation policies and certainly should not fuel inaction along the lines that because an action is not captured in the GHGI, it is not worth funding or mandating.

Back to chapter 5.3.3 How to move to geographically-explicit monitoring?

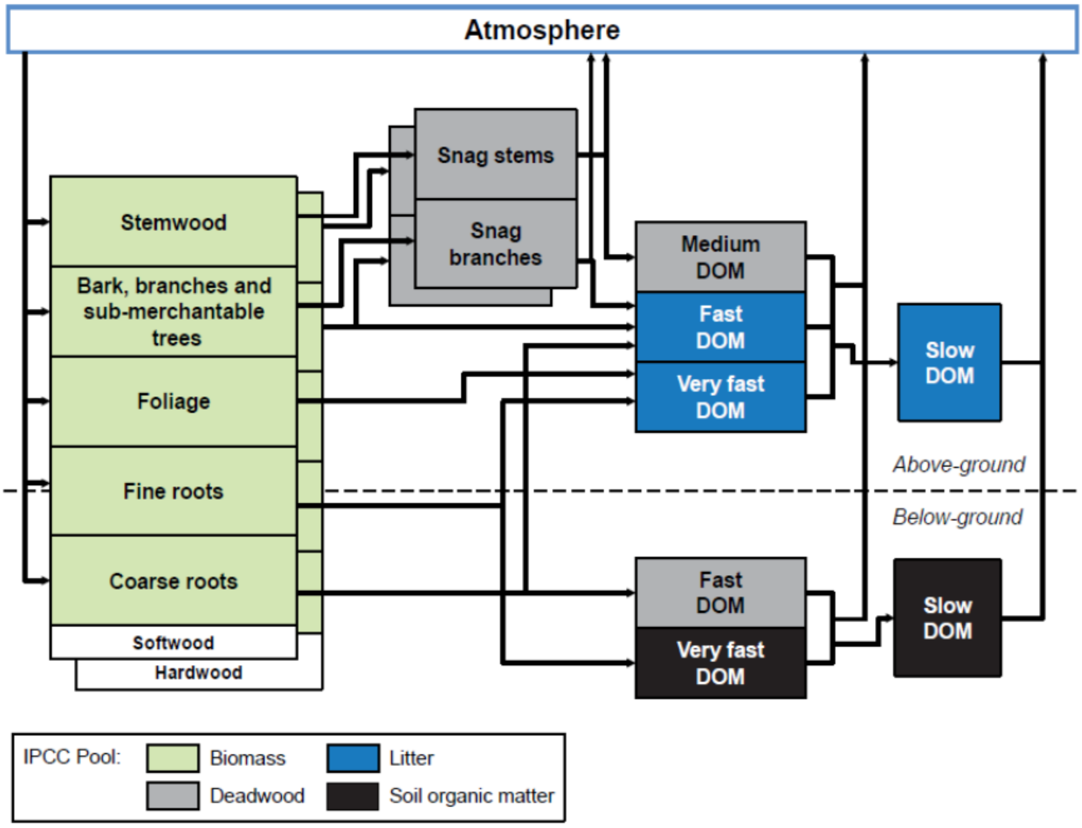
[80] https://mst.dk/erhverv/tilskud-miljoeviden-og-data/tilskudsordninger/tilskud-til-vand-og-klimaprojekter
[81] Other variables such as crop type, rainfall and previous crop type are also accounted for.

Case study 3: A verified and timely Tier 3 model serving multiple purposes beyond the inventory in Canada

Like many countries, Canada was confronted with the challenges of timely reporting and the combining of multiple datasets for estimating forest emissions and removals. To address these challenges, Canada developed the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). It is a complex Tier 3 model that can be used for other purposes and by other stakeholders (e.g. projections, harvest strategy, fire prevention).

CBM-CFS3 has been used for more than 10 years to report all emissions and removals related to forests. NFI data on living biomass, dead wood and soil carbon has been used to calibrate and verify the CBM-CFS3 model using Bayesian assimilation methods to optimize the fit between model and data. The model was explicitly designed to be used for the GHG inventory, thereby taking care to align pools and fluxes with IPCC language.

Figure 26: Carbon Pools and Transfers Simulated by CBM-CFS3



Source: Canadian NIR, 2023

Since it is a model, CBM-CFS3 can also be run pro-actively to make projections of forest-related emissions and removals (e.g. Smyth et al. 2014; Pilli et al. 2017), with the obvious benefit that these projections are intrinsically compatible with the GHG inventory, which is often a pitfall in projection studies. This is a useful 'built-in' potential for re-use which raises interest for the GHG inventory beyond inventory compilers and reviewers to a broader array of policymakers and stakeholders. Reliable estimations and projections of standing volumes and other variables are essential for harvest strategies, fire prevention, forest management policies, climate mitigation strategies (e.g. Smyth et al., 2017) and offset projects certification. A similar re-use of GHG inventory models for projections can be observed in other countries (e.g. Switzerland, Keel 2023). The Canadian Forest Service has also invested in the dissemination of CBM-CFS3 to both academics and forest managers, making the model freely downloadable as well as providing documentation and training for its use. This wide re-use potential builds a strong case for the Canadian Forest Service to keep investing in the maintenance and improvement of this part of the GHG inventory. A spatially-explicit version of the model which produces maps as well as tables has recently been made available [82].

Improvement is always needed. The improvement plan for CBM-CFS3 contains 31 items. The theme of forest inventory updates is prominent. Indeed, the model has been calibrated over NFI data from the 1990s and validated on NFI plots from the early 2000s. This was a very adequate approach as long as climate and management practices could reasonably be assumed to be similar to the 1990s, hence CBM-CFS3 has been a showcase for Tier 3. However, as we are

[82] https://natural-resources.canada.ca/climate-change/climate-change-impacts-forests/carbon-accounting/forest-carbon-accounting-tools/generic-carbon-budget-model/24366

moving further away from the conditions of the 1990s, CBM-CFS3 and its use in the inventory will need to be recalibrated on more recent NFI data or, even better, evolve towards a more integrated framework. For example, it could assimilate NFI data as it becomes available, so that the estimates remain consistent with actual measurements along the entire reported time-series.

Back to chapter 5.2.4 How to move to higher Tiers?

Case study 4: Combination of data and a simple model to increase time resolution in the French inventory

As many countries, France has an efficient forest inventory which provides accurate estimates of tree growth, harvest and mortality. The associated drawback is a coarse time resolution which hinders appropriation of the reported data by policy makers. To bridge this gap, a simple model combining 5-yearly forest inventory data with annual statistics was developed, allowing meaningful annual estimates which, among others, reflect dramatic events such as storms in the time series.

Thanks to the rolling monitoring of permanent plots, the French forest inventory provides accurate estimates of tree growth, harvest and mortality on a 5-yearly basis (it takes five years for all of the plots to be sampled once, after which sampling starts again). This coarse time resolution does not reflect annual variability, for example caused by natural disturbances, which led policy makers to question why they could not identify the effect of dramatic events in the time series of forest inventory data.

For this reason, the French GHG inventory developed a simple model to combine the 5-yearly forest inventory data with annual statistics on harvest, collected by the ministry in charge of the wood industry. This latter dataset is less accurate than the inventory but has a finer time resolution. Combining these two existing sets of information allows France to track the annual effects of natural disturbances and forestry practices while maintaining the best possible accuracy over the long term (Figure 26).

Frequently, different data can exist for the same type of parameter, and it is sometimes difficult to know which one to prioritise. It is also common to have data with high spatial resolution and data with high temporal resolution but none combining the two dimensions, although it would be useful.

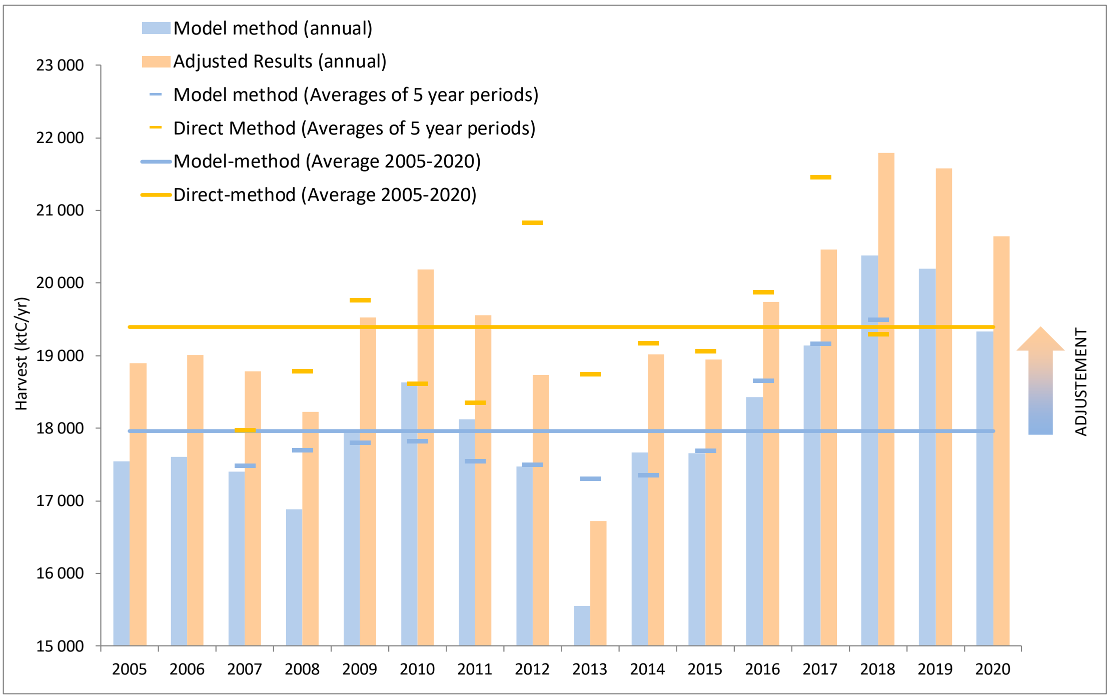
In France, two distinct methods are used to estimate forest harvests:

- A 'direct' method of wood removals by the national forest inventory. The estimate provides volumes harvested over rolling 5-year periods over big regions. This data is considered reliable for 5-year periods.
- A 'model' method by which the annual harvest level is estimated from various timber sales and wood energy consumption statistics, via a model that makes it possible to estimate the timber harvest and its destination.

The 'model' approach is calibrated on the 'direct' method so that the cumulated total of the model method corresponds to the 'direct' method over the long term. This calibration is not made on the basis of the 5-year periods which have high variability but on the entire period covered by the inventory (i.e. from 2005 to the previous year). The calibration modifies the result of the 'model' method by a few percents over the entire time series. This allows the reporting of annual variations while maintaining the best possible accuracy over the long term (Figure 26).

In addition, the model approach makes it possible to estimate harvest since 1990 and thereby allows reporting since 1990. The calibration procedure guarantees time-series consistency, as requested by the IPCC Guidelines.

Figure 27: Combination of two datasets to increase time resolution while maintaining the best possible accuracy level (harvest in forests in kt C/yr.)



Source: Own compilation based on 2023 National inventory of France.

Back to chapter 5.2.2 What are the benefits of reporting using higher Tiers?

Case study 5: Farm-level GHG assessments and their link with national monitoring and policies in France

Over the past few years in France, farmers have received incentives to define the GHG budget of their farm and identify climate mitigation levers through numerous channels. However, the synergies with the national GHG inventory and public policies are still underexploited.

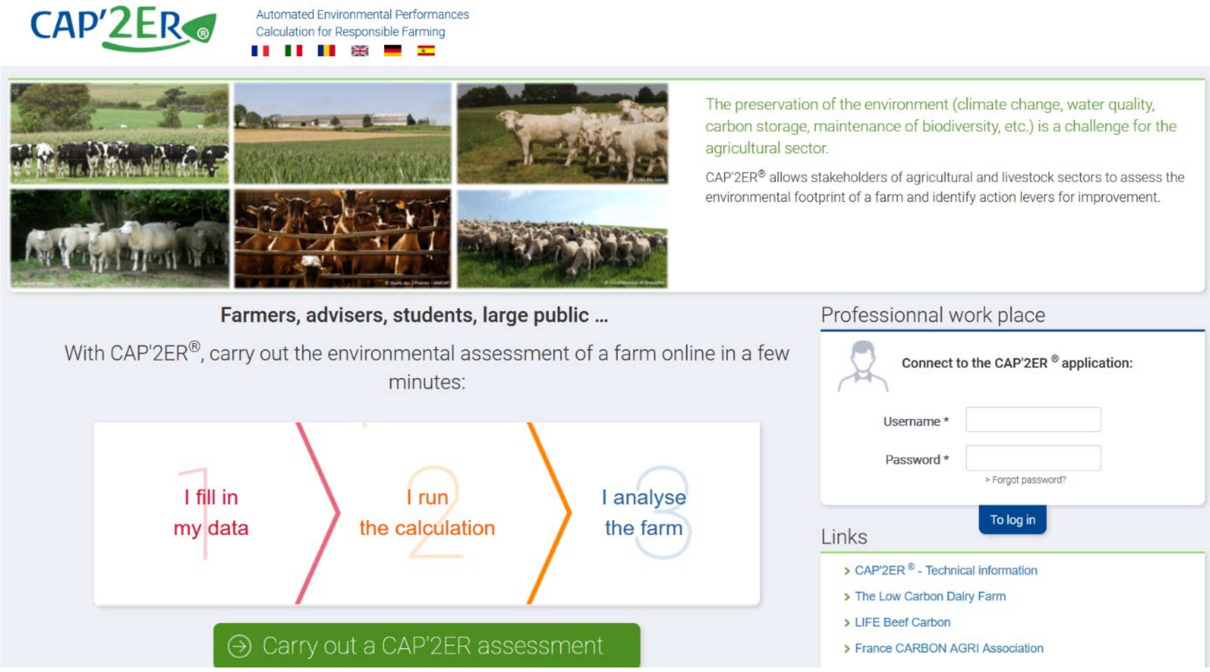
Four incentives to undertake a farm-level GHG budget

French farmers have been asked and subsidized to determine a GHG budget of their farms through four different channels: research projects, carbon offsetting, supply-chain premiums, and subsidized carbon diagnosis.

Research projects

Since the beginning of the 2010s, the technical institute for livestock (IDELE) has been developing farm-level GHG budgets as part of several LIFE and EIP research projects, for example Carbon Dairy, Beef Carbon, Green Sheep, Carbon Farming, Climate Farm Demo. Overall, IDELE has now developed more than 30,000 GHG budgets in livestock farms. These assessments were used both to advise farmers on how to improve their GHG budget and to refine the Institute's GHG assessment tool CAP'ER (Figure 24).

Figure 28. Webpage of CAP'2ER, one of the most frequently used farm-level GHG calculators in France



Certification of greenhouse gas reduction and carbon sequestration projects

In **2018, the French ministry for the Environment launched the "Label Bas Carbone", a domestic voluntary certification scheme for greenhouse gas reduction and carbon sequestration projects, delivering credits that can** be valued on voluntary markets. The launch was quickly followed by the validation of sub-sector specific methodologies to quantify emission reductions and storage increase at farm level. Each methodology is required to produce a calculator, which may be either a spreadsheet file or a program. It turns out that most of these calculators are comprehensive: they estimate the GHG budget of the entire farm as well as its mitigation levers.

Farmers can perform a quick self-assessment [83] when they start thinking about certifying their emission reductions, but they are also being approached by cooperatives and start-ups providing advisory services, ranging from a GHG budget to the sale of offset credits resulting from certified and verified improvements. As of February 2024, close to 2,000 farms were engaged in a Label Bas-Carbone project involving the whole farm, and therefore requiring at least two farm-level GHG assessments.

Supply chain premiums

In 2020, Saipol, a biodiesel manufacturer, started to offer a "GHG bonus" to farmers who could demonstrate a low carbon footprint for rapeseed. This move was triggered by the European Renewable Energy Directive (RED II) which mandates that the GHG budget of biofuels be at least 50% lower than its fossil counterpart. Interested farmers are invited to fill in a few variables online for both 2008 and the current year. On this basis, their cooperative may contact them to verify the numbers, advise them on how to reduce their GHG footprint and offer them a contract for their "low GHG rapeseed" [84]. This "low GHG rapeseed" is paid with a 0-50 € premium per ton

[83] https://cap2er.eu/
[84] https://www.oleomarket.fr/oleoze

of rapeseed, depending on the verified GHG budget, which is up to 10% of the 2023 rapeseed price. A document-based audit is conducted on all farms to corroborate areas, yield and nitrogen inputs based on CAP declarations, accounting books and fertilization books.

Since then, other supply chains have started offering premiums such as Nestle on popcorn maize, Danone and Sodiaal on milk or Cristal Union on beetroots.

Subsidized carbon diagnosis

From 2021 to 2023, as part of the Covid recovery plan, the Agriculture Ministry and the French environment agency (ADEME) subsidized 90% of the cost of farm-level GHG assessments ("Bon diagnostic carbone") [85]. 700 farm advisors were trained to perform GHG assessments, and 3,400 assessments were undertaken for a total initial budget of 10 million euros. 25% of the farms assessed were then willing to undertake a Label Bas Carbone project to obtain funding for reducing GHG emissions or increasing carbon storage. This positive experience encouraged the Agriculture Ministry to renew the scheme with a few changes in 2024, with a budget of 32 million euros. On top of this, some regional councils and private firms are also subsidizing farm-level carbon diagnosis, audit or advice.

Limited links with national monitoring and national policies

All in all, the various incentives for farm-level GHG assessments have now led to more than 30,000 farm-level assessment, together with the generation of an ecosystem of competent companies and advisors to perform them. The synergy with the national greenhouse gas inventory and national policies remains limited, although a few links exist.

Policy-wise, most French regions have started to offer a "Low Carbon" Agri-Environmental and Climatic Measure [86] based on farm-level GHG assessment. This Agri-Environmental and Climatic Measure offers a 18,000 euros payment to farms which manage to reduce emissions by at least 15% within five years. Both the target and the amount are based on feedback from Label Bas-Carbone projects and the calculators eligible to verify the reductions are also taken from Label Bas-Carbone methodologies. The Nouvelle-Aquitaine region which pioneered the scheme enrolled 18 farms in 2023, four of which had benefited from a subsidized carbon diagnosis.

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[85] https://librairie.ademe.fr/produire-autrement/6803-synthese-du-dispositif-bon-diagnostic-carbone-2021-2023.html

[86] Agri-Environmental and Climatic Measures are one type of payment for environmental services that can be implemented with Common Agricultural Policy budget.

Figure 29. "Paying a farmer for his low-carbon practices: how?", introductory slide used by an advisory firm at a farm fair in Dijon (source: Agrosolutions)

Regarding monitoring however, there is no link with the national greenhouse gas inventory, although CITEPA – the agency in charge of the national GHG inventory – has a statutory seat in the technical committee in charge of validating Label Bas Carbone methodologies. More promisingly, cooperatives and start-ups involved in farm-level GHG assessments are increasingly using data collected for Common Agricultural Policy payments to streamline the assessments and target farms with the most promising potential for GHG abatement.

There is however a bright side to this lack of link with the GHG inventory: no time is lost in wondering whether the abatement obtained at farm level will be 100% captured by the inventory. On this aspect, France may have been learning from past mistakes. During the first commitment period of the Kyoto Protocol (2008-2012), the Environment ministry spent a lot of energy checking that the locally monitored abatement of the domestic carbon offsetting scheme ("Projets domestiques CO_2") was captured by the national accounting system, and rejected all projects where this was not the case, thereby rejecting some worthy projects due to pitfalls in the national accounting system.

Back to chapter 5.3.2 What are the benefits of geographically data in monitoring?

Case study 6: Assessing time series of forest cover dynamics in Romania

A discrepancy of 500,000 ha in forest area in Romania was found when comparing national legal forest maps and National Forest Inventory information. This case study describes how Romania has set up a multi-data integration system to more accurately assess time series of forest cover dynamics.

An issue with forest area

The primary challenge arises from Romania's significant discrepancies in forest definitions.

The legal **forest boundary** is defined by forests included in the national management plan. Forests covered by the plans are subject to strict silvicultural norms and legislation. This information is based on' precise mapping and regular updates, with forest districts reporting forest conversions annually. The actual extent of forests in Romania according to this dataset is 6.5 Mha.

The National Forest Inventory (NFI) applies a different definition of forests, based on vegetation found at the sampling site. The first cycle in 2012 [87] identified a forest area of roughly 7 Mha - resulting in a difference of about 500,000 hectares.

The NFI approach can be considered a robust estimate of the existence of forest at a certain site. However, the NFI is a statistical measurement. It consists of two statistical sampling grids, one of 500x500 meters where for each point, forest vegetation is evaluated by photointerpretation on orthophoto maps, and a 4x4 km sampling grid where forestland category is evaluated on the ground. Thus, the final values of the forest consist of the initial forest vegetation evaluation, which is weighted by the field measurements. It also faces limitations in evaluating forest areas

[87] National Forest Inventory, Romania. https://roifn.ro/site/rezultate-ifn-2/

under conversion due to its sampling grid and due to its only two points in time sampling (i.e., 2012 and 2017).

Figure 30 Forestland category in and outside the management plans

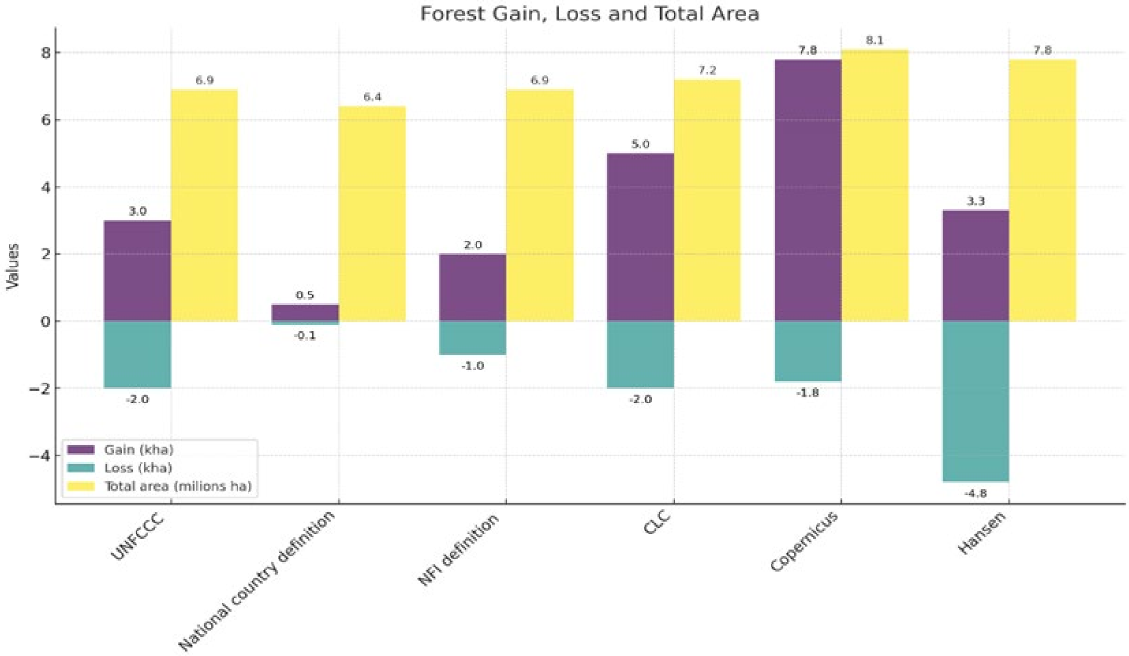
A paradigm shift: from statistical reporting to a geographical approach

To overcome these discrepancies, Romania's GHGI in the LULUCF sector needs substantial improvements. These include transitioning to a spatially explicit system and enhancing the annual reporting system. The new national arrangements by government decision with the 2020 inventory submission, delineate the reporting responsibilities among four research institutes, each focusing on distinct aspects like forest, other land use categories, soil, and remote sensing. The new legislation also specifies the data sources, mandating national agencies and data collectors to provide necessary data for LULUCF reporting.

The goals were to create uniform land use data across time series, increase the accuracy of annual changes in forest land use, and align with the IPCC Guidelines and LULUCF regulations.

The challenge was to integrate land use and land cover data available nationally, globally, and regionally and combine datasets with different forest definitions, coverage, precisions, and spatial projections.

Figure 31 Different systems and datasets represent the forest area (yellow) and land use conversion from and to the forest (blue and purple)



The new approach implied creating a 100x100-meter point sampling with national coverage. For each point, data were collected from:

- National Datasets: Historical datasets from topographic and military maps (1980, 2018), Forest Maps from forest districts (1990 onwards), the Land Parcel Identification System (LPIS)/Integrated Administration and Control System (IACS) (from 2007 onwards); LC maps from orthophoto maps (2006), and
- Global/Regional Products as Corine Land Cover (CLC) products (1990 onwards), Copernicus products (Forest Type 2015, 2018), Urban Atlas (2020),
- Global datasets, including high resolution global forest maps [88] for 2000-2020 period, Eastern Europe's forest cover dynamics [89] for 1985-2012, and forest disturbance regimes of Europe [90] for 1986-2016.

Further layers were used to improve the classification and identify misclassification errors such as Digital Terrain Model, distance to roads, urban areas and forest edge, and forest height [6]

Time series analysis of forest cover dynamics

The data was used to track changes in forest cover over time at the sampled points to identify stable forests, afforestation, and deforestation patterns. This analysis involved the following key steps:

1) Initial classification, based on evaluating the presence or absence of forest cover in the time series.

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[88] Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., ... & Townshend, J. R. (2013). High-resolution global maps of 21st-century forest cover change. science, 342(6160), 850-853

[89] Potapov, P. V., Turubanova, S. A., Tyukavina, A., Krylov, A. M., McCarty, J. L., Radeloff, V. C., & Hansen, M. C. (2015). Eastern Europe's forest cover dynamics from 1985 to 2012 quantified from the full Landsat archive. Remote Sensing of Environment, 159, 28-43.

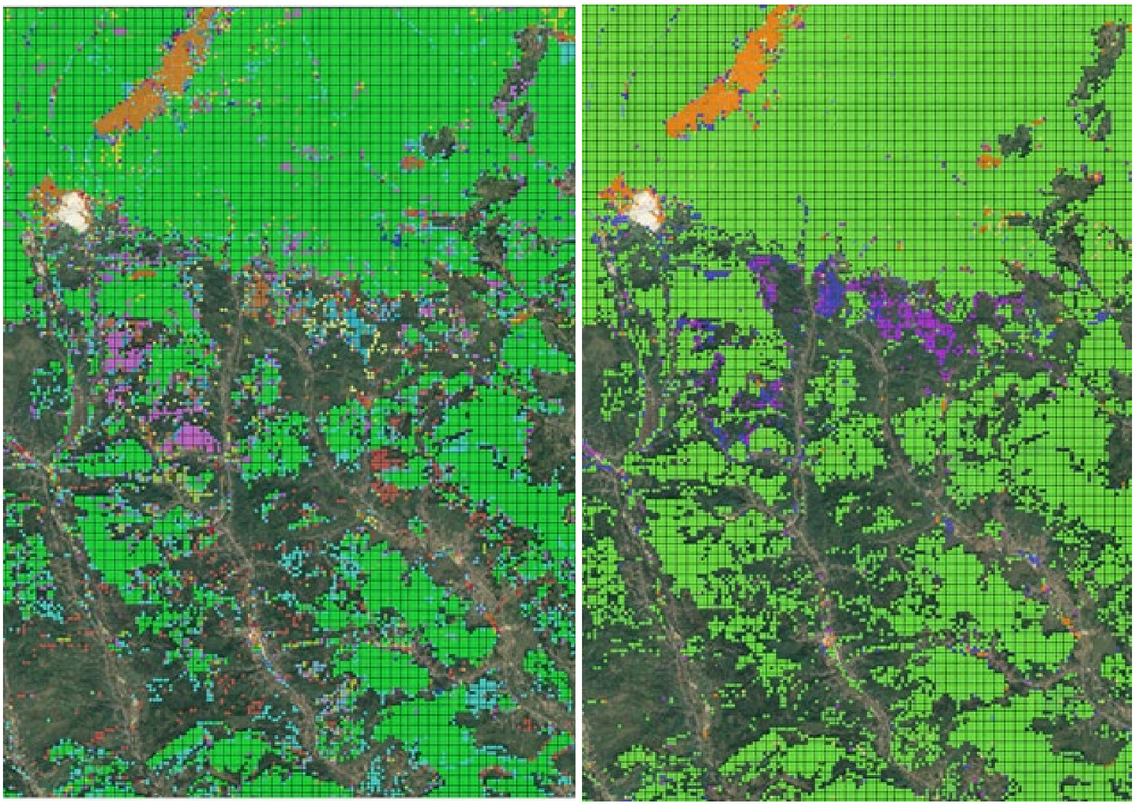
[90] Senf, C., & Seidl, R. (2021). Mapping the forest disturbance regimes of Europe. Nature Sustainability, 4(1), 63-70.

2) Reclassification and refinement to correct false positives and negatives by considering temporal continuity, spatial patterns, and the influence of neighbouring points to enhance the identification and correction of misclassifications.

3) Definition of a hierarchy to prioritize the dataset and asses the likelihood based on specific criteria of classification errors in isolated instances (e.g., distinguishing land conversion from georeferencing errors on forest margins) and also include contextual factors such as proximity to urban areas, roads, forest margins, to assess the classification.

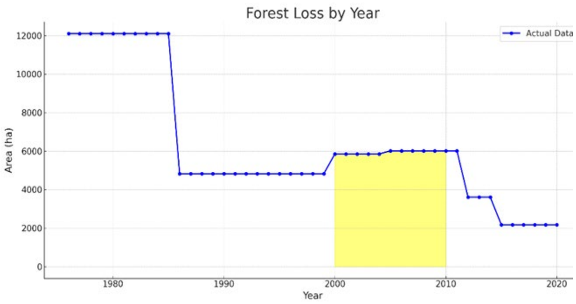
4) Validation of sampling points by manually classifying and correcting classification errors.

Figure 32 Representation of the sampling grid points after the initial classification (left) and reclassification (right).



The method produces forest classes for each period. Additionally, it provides information about potential forest degradation areas, where forest cover was lost following the restitution process, and regeneration is delayed due to improperly applied silvicultural practices. It can also help to spatially track large-scale phenomena of natural disturbances and offer information about land potentially available for afforestation.

Figure 33 Loss of forest cover over time (left), highlighting the period with the highest momentum of the restitution process (yellow) and natural disturbance map (right) showing areas with loss of forest cover larger than 20 ha in a selected year (2007- red and 2012 - blue), average elevation of 1300 meters and steep slope.



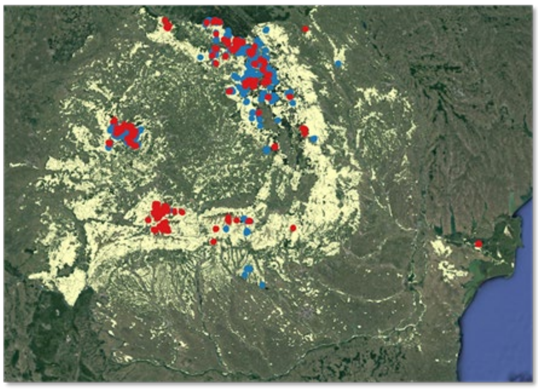
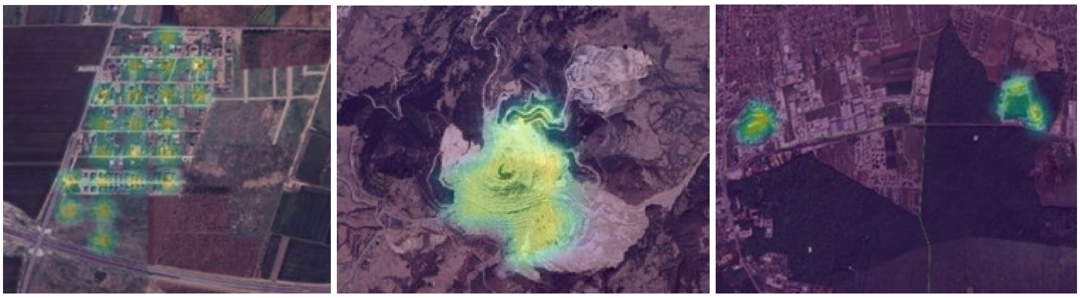


Figure 34 Example of conversion of forestland to other land categories.



The system limitations and future development needs

The temporal resolution of the approach is constrained by the spatial products used. Moreover, it relies on information taken at intervals of several years and requires interpolation to assess forest areas annually. The approach might therefore overlook critical dynamics, particularly rapid or short-term changes in land cover. Furthermore, the method for classifying and reclassifying forest cover is based on expert-driven criteria (hierarchy of datasets) and involves manual validation steps. This may cause errors and requires efforts for identifying and correcting misclassifications. The system's capacity to identify and measure forest conversion in recent years relies on the availability of accurate land use maps for validation, distinguishing between forest degradation, forest cover loss due to harvesting, and deforestation. The system tends to overestimate areas of forest conversion. This can be considered a conservative approach for reporting deforestation. However, it requires extra efforts for identifying afforestation areas.

Back to chapter 5.3.3 How to move to geographically-explicit monitoring?

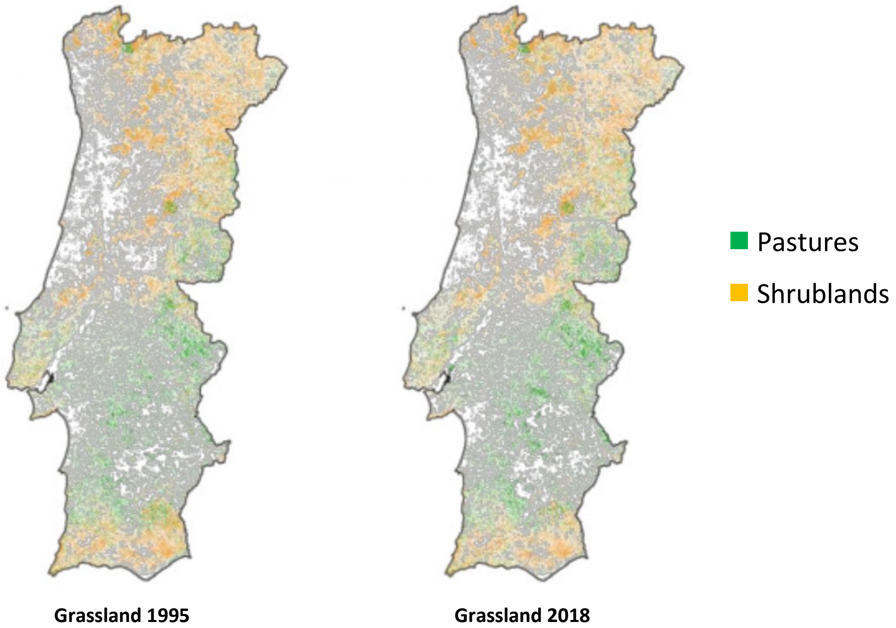
Case study 7: The vector maps of Portugal

Portugal has developed its own land use and land-use change map that is a good example of a geographically-explicit approach to monitoring areas for the LULUCF inventory with a temporal consistency. This case study also presents Portugal's method to cover past periods.

Overview

Portugal is one of the first Member States to use maps for monitoring land use changes in its national GHG inventory. Before 2014, Corine land cover maps were used but since the 2014 submission Portugal has been using data from the national Land-Use Cartography made available from the Direcção Geral do Território. The end of the first commitment period of the Kyoto Protocol coincided with this change and can be linked to the focus made at that time on the monitoring of afforestation and deforestation. Currently, Portugal uses its national product, called Cartografia de Ocupação de Solo, which was last updated in 2018 and now includes maps for the years 1995, 2007, 2010, 2015 and 2018, and uses a consistent nomenclature over time.

Figure 35: A consistent dataset for grassland mapping, with two editions allowing to detect land use changes.



Source: Portugal, National Inventory Report 2023 [91], LULUCF Chapter.

By using these maps, Portugal manages the monitoring of 21 accurate categories of land uses. This categorization fits well with both national profiles of land uses and commonly accepted land use categories. The period since 1995 is fully spatially-explicit while the precedent period is based on more basic data on land uses. Total land-use changes were compiled for the periods 1995-2007, 2007-2010, 2010-2015 and 2015-2018 by overlapping the respective land-use maps. The results were then annualized by dividing the area that changed by the number of years between maps (respectively 12, 3, 5 and 3 years). Comparisons with older cartographic products have been made to correct improbable land use changes. This shows that quality control is needed and should be implemented to ensure the quality of spatially explicit products.

Temporal coverage

To cover the times series between 1970 and 1995, Portugal has put in place a series of procedures allowing to complete the periods that are not covered by the cartographic products.

Different information sources are used:

- For forestlands, the main sources are the National Forest Inventories (1974, 1985, 1995).
- For croplands, the main sources are the General Census of Agriculture (1979, 1989, 1999).

Spatial coverage

For Portugal, there is also the challenge of covering the different parts of its territory as this includes the Azores and Madeira. For these territories, the main sources of information are:

- Corine Land-Cover CLC (1990, 2000, 2006, 2012, 2018) – full wall-to-wall map
- IFRAA (2007) – Regional Forest Inventory of the Autonomous Region of Azores

[91] https://unfccc.int/documents/627602

- IFRAM (2004, 2010) – Regional Forest Inventory of the Autonomous Region of Madeira
- RGA (1989, 1999, 2009) – General Census of Agriculture

The basis for the estimation of land use and land-use change in the Azores and Madeira was Corine Land Cover but the disaggregation into the 21 strata was made based on the other sources.

Thus, a large set of products was used to complete the exhaustive inventory for the entire period and the entire territory.

Back to chapter: 5.3.3 How to move to geographically-explicit monitoring?

Case study 8: The combination of multiple geographically-explicit data on a grid for France

This case study presents how France implemented a new geographically-explicit method to move from Approach 2 to Approach 3 for land representation. This method combines several national and European datasets within a high-resolution grid, using hierarchy rules and correspondence between nomenclatures.

France has recently migrated to a geographically-explicit monitoring of land uses in response to national expectations. Formerly the French inventory was based on an exhaustive national survey of land uses named ‘Teruti’, that was the single data source used for land use monitoring. The change from a survey system to a geographically-explicit system was done to overcome challenges with understanding land use changes. The geographically-explicit system was built to facilitate quality control of GHG inventories, understanding of land use changes and better management of lands.

Figure 36: An example of a grid-based approach in France

Source: Citepa, France's visualisation tool of land use of LULUCF inventory, 2023.

The following steps were followed to build the geographically-explicit system:

1. A grid was placed over France (see Figure 34) and intersected with several maps. so that heterogeneous datasets, even having different spatial resolutions, could be combined.
2. The spatial resolution of the grid was chosen to fit the minimal threshold for the national definition of Forest (0.5ha), and to fit the scale of usual land use change such as small-scale urbanization.
3. Maps at a specific time were chosen as a reference for each land use type. For instance, forest maps (around year 2015) were prioritized for forest while LPIS data from 2021 was chosen for agricultural lands.
4. Strict hierarchy rules between datasets have been defined so that the choice of the most relevant datasets is automatically made for each plot.
5. Products that focus on land-use and/or land-cover changes were prioritized for the monitoring of actual land use change.
6. Strict consistency rules have been defined so that the estimation of land use change reflects as much as possible actual change, and not map artefacts.
7. Years in which land use change occurred were derived from the time periods covered by the datasets (randomly on the period).
8. Land use changes were extrapolated for years not covered by maps. Estimations were made for years prior to the first available map, and for years after the last available map.
9. The system was designed so that an annual time series of land use for each cell of the grid is produced.
10. Corrections or post-adjustments were made, when needed, to ensure consistency with other reference datasets such as NFI areas or Agricultural census.
11. A GIS portal was established to visualize the results and allow for verification processes.

France's geographically-explicit inventory is recent and will be improved in the coming years by considering new products and developing additional controls on land use monitoring. It is already a significant improvement and opportunity to efficiently monitor policy action at national and local level.

Back to chapter 5.3.3 How to move to geographically-explicit monitoring?

Case study 9 National portal in Italy

To visualize priority areas for the LULUCF monitoring and mitigation actions, various environmental geospatial products are available from national, European or international products. In this case study, we present Italy's national portal that displays such maps.

Italy has developed a national portal that allows displaying a wide range of geospatial information. The public website 'Geoportale nazionale' [92] allows the user to visualize various environmental information in the same map.

The view can display around one hundred maps with environmental data, among them we can find:

- specific habitats zones in national parks,
- forest fires areas,
- land use,
- geology,
- protection sites for biodiversity,
- population density,
- vegetation maps,
- etc.

[92] http://www.pcn.minambiente.it/viewer/

Figure 37: Screenshot of Geoportale nazionale

Back to chapter 5.4.5 National portals for maps comparison

Case study 10: Using national data sources to improve knowledge on drained organic soil emissions in Austria

Agricultural use of organic soils contributes substantially to GHG emissions from organic soils. The Austrian Environment Agency addresses these questions in a project aiming to improve the estimates of drained organic soils in the Austrian National GHG Inventory.

The IPCC Wetland Supplement defines organic soils, which besides peat soils also include other soils with high SOC content. Reducing GHG emissions by adapting management of drained organic soils is one possibility for farmers to significantly contribute to climate change mitigation. In addition, drainage due to forestry is likely a high emission source. To report the GHG emissions, but also to address the mitigation potentials, it is important to know the location of organic soils, their drainage status and how farmers manage these soils.

The Austrian Environment Agency addresses these questions in a project aiming to improve the estimates of drained organic soils in the Austrian National GHG Inventory (duration January 2022 to May 2024 funded by the Federal Ministry of Climate Action). For this purpose, all available soil, land use and drainage data sources were analyzed in close cooperation with national soil experts and data providers of the respective sources. To estimate the areas of drained organic soils per land use category, three main steps were conducted:

1) The area of drained soils was gathered based on a compilation of national soil inventories: agricultural soil mapping (Landwirtschaftliche Bodenkartierung) and federal financial land valuation (Finanzbodenschätzung), the melioration registry (Meliorationskataster) and historic peat mapping information (historisches Moorkataster).

2) Information on the occurrence of organic soils is based on the same national soil inventories, historic peat mapping information and the Austrian peat protection map (Moorschutzkatalog).

3) The information on the current land-use is derived from a status layer which combines various data sources such as the Austrian Cadastral Map (DKM), forest map, national IACS/LPIS and

agriculture layers, water bodies layer, Austrian peat protection map (Moorschutzkatalog) and remote sensing data for detection of bare rocks/unvegetated areas.

Finally, the results of these three steps were combined, using a weighting factor according to the quality/reliability of the data sources, and put into a rasterized GIS product which depicts the likelihood of occurrence of drained organic soils for Austria in a geographically-explicit manner. Due to a lack of national data on emissions from drained organic soils, literature research was conducted to identify emission factors (e.g. from neighboring countries) which are suitable for the Austrian conditions in order to replace the IPCC default factors, where applicable. The result is the countrywide estimate of GHG emissions for managed organic soils.

Back to chapter 5.4.5 National portals for maps comparison

Case study 11: The role of coordinated science for improving GHG reporting in Ireland

Ireland has experienced a fast evolution of methodology of the reporting of GHGs from grassland and wetlands that was influenced by a close collaboration between the communities of GHG reporting and research. A basis for this is the involvement of GHG inventory staff members in research projects as discussed by this case study.

Bridging between research and reporting communities

According to its NIR, Ireland's LULUCF sector is a net source of emissions in all reporting years. The net balance is dominated by the impact of drainage of organic soils in grasslands and wetlands. Despite the large share of these land categories, Ireland has (up until 2024 inventory submission) applied Tier 1 methodologies due to a lack of country specific data. In 2023 two peer reviewed publications provided significant updates to the methodologies employed for grasslands on organic soils and wetlands. Close collaboration between the inventory agency (the Irish Environmental Protection Agency, EPA) and the research community in Ireland (e.g. Universities, and the Irish Agriculture and Food Development Authority (Teagasc)) is currently and will continue to lead to significant improvements in the LULUCF inventory going forward.

A basis for the close collaboration is the involvement of GHG inventory staff members in research project steering committees. This is enabled by the rather small communities involved in agriculture and land use research in Ireland. However, another important factor is that topics of GHG inventory improvement actively drive the agenda of scientific work at academic and other research organisations. Good knowledge and understanding of the IPCC reporting guidelines among researchers is another supporting element of successful collaboration in Ireland.

For identification and better coordination of research needs EPA and the Department of Agriculture, Food and the Marine have set up an inventory improvement group. The group meets on several occasions during the year to discuss issues around GHG inventory improvements for both the agriculture and the LULUCF sectors and involves additional experts where required depending on the topic to be discussed.

Improving reporting by setting national research priorities

Grassland is the dominant land-use category in Ireland, accounting for almost 60% of land area. To improve estimates of GHG emissions and removals from grasslands, the EPA has funded research into remote sensing technologies and analytical techniques for the quantification of non-forest woody biomass and carbon stocks in the landscape, especially hedgerows [93]. Hedgerows form traditional means of establishing field and ownership boundaries and protecting crops from livestock incursion. In recent years, environmental payment schemes have included incentives for hedgerow plantation, maintenance and protection. However, knowledge of past hedgerow extent and management is largely lacking and therefore the focus of current discussions and exploration of remote sensing techniques.

The nutrient and drainage status of grasslands on organic soils is another field of research that directly feeds into GHG reporting. How relevant such targeted research projects are for advancing GHG reporting was demonstrated by two scientific articles published in 2023 (Aitova et al. 2022; Tuohy et al. 2023) that led to significant recalculations in relation to emissions from organic soils (in both the grasslands and wetlands categories) in Ireland. The publications provided a review of recently unearthed historic information of the drainage status of grasslands on organic soils and meta-analysis of national research undertaken on peatlands. This helped establishing country specific emission factors based on nutrient and drainage status of organic soils. For grasslands, total emissions were reported to be on average 3.6 Mt CO_2eq (-53%) lower across the timeseries 1990-2021. This study has led to the development of further work in this area (DAFM Research funding 2023 [94]).

Wetlands is the second largest land-use category in Ireland, accounting for more than 17% of the land area. The EPA has recently established three research fellows that are investigating conditions for GHG emissions and removals from peatlands in Ireland for CO_2, CH_4 and N_2O under the EU-LIFE program [95].

Bord Na Mona, the Irish Peat Bord, a semi state commercial company, has since 2021 undertaken a large-scale peatland rewetting and restoration program on 33.000 ha of exploited peatland, which will be completed by mid-2026 [96]. Data on the extent of activities is being collated and will be incorporated along with relevant research studies to assess these actions as they occur in future inventory submissions.

The scientific understanding of emissions and removals from grassland on both mineral and organic soils will be enhanced even more in the future. Recently, the Irish Department of Agriculture, Food and the Marine has funded the National Agricultural Soil Carbon Observatory (NASCO). 28 eddy covariance flux towers will provide measurements of gas exchange between soil, vegetation and the atmosphere. The results collected by NASCO will be used to further constrain estimates of GHG emissions and removals and understand underlying processes. The

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[93] https://www.epa.ie/publications/research/climate-change/research-454-farm-carbon-hedgerows-and-non-forest-woodland-hedgerow-carbon-project.php

[94] https://www.google.ie/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiRifWA9rKFAxWyQkEAHfV2BmoQFnoECBIQAQ&url=https%3A%2F%2Fassets.gov.ie%2F278893%2F6f712254-7a63-4a60-8232-27e8309d2cf5.pdf&usg=AOvVaw2t3swsi_LbhMgD3PV_JAUP&opi=89978449

[95] https://peatlandsandpeople.ie/

[96] https://www.bnmpcas.ie/

use of such data sources requires also modelling tools and capacities for running them to integrate the information into GHG inventories.

On the importance of long-term research for improved GHG inventory information

Mutual understanding of the needs and constraints is important for successful collaboration between science and GHG reporting communities. For example, for reporting of GHG emissions and removals from soils with reasonable accuracy, research needs to produce multi-year and multi-site data covering a range of environmental conditions and treatments.

Also advancing GHG reporting by moving towards more use of spatially explicit data requires multi-year research efforts. The integration process towards a new system of land use mapping in Ireland for reporting under the LULUCF Regulation is a multi-year project that is currently underway and will take a number of years to complete with significant human and monetary resources involved.

An important aspect of research planning regarding the integration of spatially explicit information into GHG reporting is the consideration of opportunities for the reuse of data going forward. Multi-purpose maps require that during the process of map combination and intersecting as many attributes as possible are being included. While a low number of attributes in map integration decreases computation time and costs, a higher number makes map products relevant for more potential users and alternative applications. Such considerations are crucial for planning of GHG improvements as later inclusion of additional attributes is often challenging.

Back to chapter 6.1.1 Challenges for Member States

Case study 12: Iceland's improvement group: institutional arrangements for advancing GHG reporting

Iceland still lacks country specific data for applying higher tier methodologies and approaches, especially for grasslands, croplands and wetlands. A case study presents how the country established an "improvement group" for advancing GHG reporting.

Iceland still lacks country specific data for applying higher tier methodologies and approaches, especially for grasslands, croplands and wetlands. One concrete example is country specific stock change factors for organic soils. In the past, a strong focus has been placed on improving data availability for forestry and revegetation being mandatory and elected activities under the Kyoto protocol.

In 2021 the Ministry of Environment, Energy and Climate requested improvements and together with the Ministry of Food, Agriculture and Fisheries, gave the mandate to the two former institutions, the Soil Conservation Service of Iceland and the Icelandic Forest Service from 2024 merged together in Land and Forest Iceland, to carry out work for improving the national GHG inventory. Dedicated staff from the four institutions came together and formed "the improvement group". Key features of the group's working mode include:

- Work plans are established for three-year periods. Work plans are built around data needs and how these will be fulfilled. The source for identifying areas of improvements are the table of key categories and comments received by the technical expert review. The first work plan was concluded in 2023, the next will conclude in 2026.
- Work plans contain a limited number of specific projects, with clearly defined outputs and required resources. The projects may address data collection from existing sources or set up new processes for generating data. Each institution has its assigned projects.
- Progress on these projects is tracked and there is annual status reporting.
- The group meets regularly. Experience showed that four to eight times a year is an adequate meeting frequency.

- A key factor for successful implementation of the projects is the availability of dedicated technical staff and assignment of necessary resources.
- The group collaborates with universities in projects to carry out modelling and field measurements. It coordinates work and carries out quality control, ensuring that the work carried out and the results fit reporting requirements.

The improvement group has so far been successful because it brings together decision makers in the ministries and technical experts in the agencies. This allows not only identifying and prioritizing required improvements, but also discussing the implications of methodological changes. This increases mutual understanding of needs and constraints. For example, clear communication by inventory compilers of the anticipated impacts arising from changes in an applied methodology and the use of improved data, increases the acceptance of methodological improvements for policy makers. The group also facilitates a meaningful exchange about which improvements are possible and which not as well as about required resources for implementation. The involvement of all relevant stakeholders in the improvement process ensures that all are committed to implementing the agreed changes. Iceland's experience shows, the importance of having decision makers from the ministries involved in the process from early on.

Advancing GHG reporting and projections under the LULUCF Regulation is the primary driver for the improvement group. However, other data needs also play a role when implementing improvement projects in Iceland. For example, the new soil map, currently under development, will also be used for land use mapping, e.g. for determining suitability of areas for specific uses, creating a soil erosion map and identifying degraded areas. The latter will be used in the context of commitments under the Kunming-Montreal Global Biodiversity Framework, to identify priority areas for restoration. Needs related to biodiversity will also play a role in the next cycle of the national forest inventory, which will include biodiversity monitoring. Identifying opportunities for the multiple use of data, research results and innovation technics increases the number of potential users and thus can reduce costs, which is another benefit of institutional arrangements like the improvement group founded in Iceland.

Back to chapter 6.1.2 Opportunities for Member States initiatives

Case study 13: Life project MediNet

Moving to higher tiers often requires moving from default emissions factors and parameters, using more relevant values from national or regional studies. This case study presents how a regional project covering European Mediterranean countries developed information on carbon stocks and fluxes for living biomass in cropland and grasslands to improve the LULUCF monitoring in this region with specific ecological conditions.

The main objective of the MediNet[1] (Mediterranean Network for Reporting Emissions and Removals in the Mediterranean Region) project was to propose new default coefficients for the reporting of emissions and removals from living biomass in cropland (permanent crops) and grasslands (shrublands).

Only Portugal and Italy were formally partners to the consortium, but all Mediterranean Member States contributed. The main carbon pools in cropland and grassland are living biomass and soil carbon. The project focused on permanent crops and shrubby grasslands and for agri-forests systems or systems involving tree or shrub hedges. As there are no inventories of biomass for permanent crops and grasslands in these areas, the main objective of the project was to identify "equivalent" sources of information to improve the default factors for biomass pools in the Mediterranean area. The outputs of MediNet have been used in most inventories of the Mediterranean Member States. These new emission factors for permanent crops were also incorporated to the 2019 IPCC Refinements. Paradoxically, this international recognition of the project's outputs has – somewhat artificially – downgraded the inventories of these Member States from Tier 2 to Tier 1 as their "country-specific" emission factors became IPCC default values.

Figure 38: Area of intervention of the MediNet project

Source: Canaveira et al. 2018.

Back to chapter 6.2.2 Cooperation between Member States: are the opportunities worth the effort?

Case study 14: Building a national system to monitor land-use over time in Croatia: the LIFE CROLIS project

Croatia needed to develop a geographically-explicit approach for land monitoring. This case study presents a LIFE-funded project [97] that is aimed at creating such approach, using different earth observation products. The creation of a national land-use change timeseries has many policy implications for Croatia.

Initial situation

Croatia lacked a harmonised land use and land cover monitoring framework to generate robust data sources for the LULUCF inventory. Default data sources such as Corine Land Cover could not provide sufficient spatial, temporal and thematical resolution to track land-use changes and monitor land policies implementation. Moreover, Croatia needed to develop a geographically-explicit approach for land monitoring as required by the LULUCF regulation.

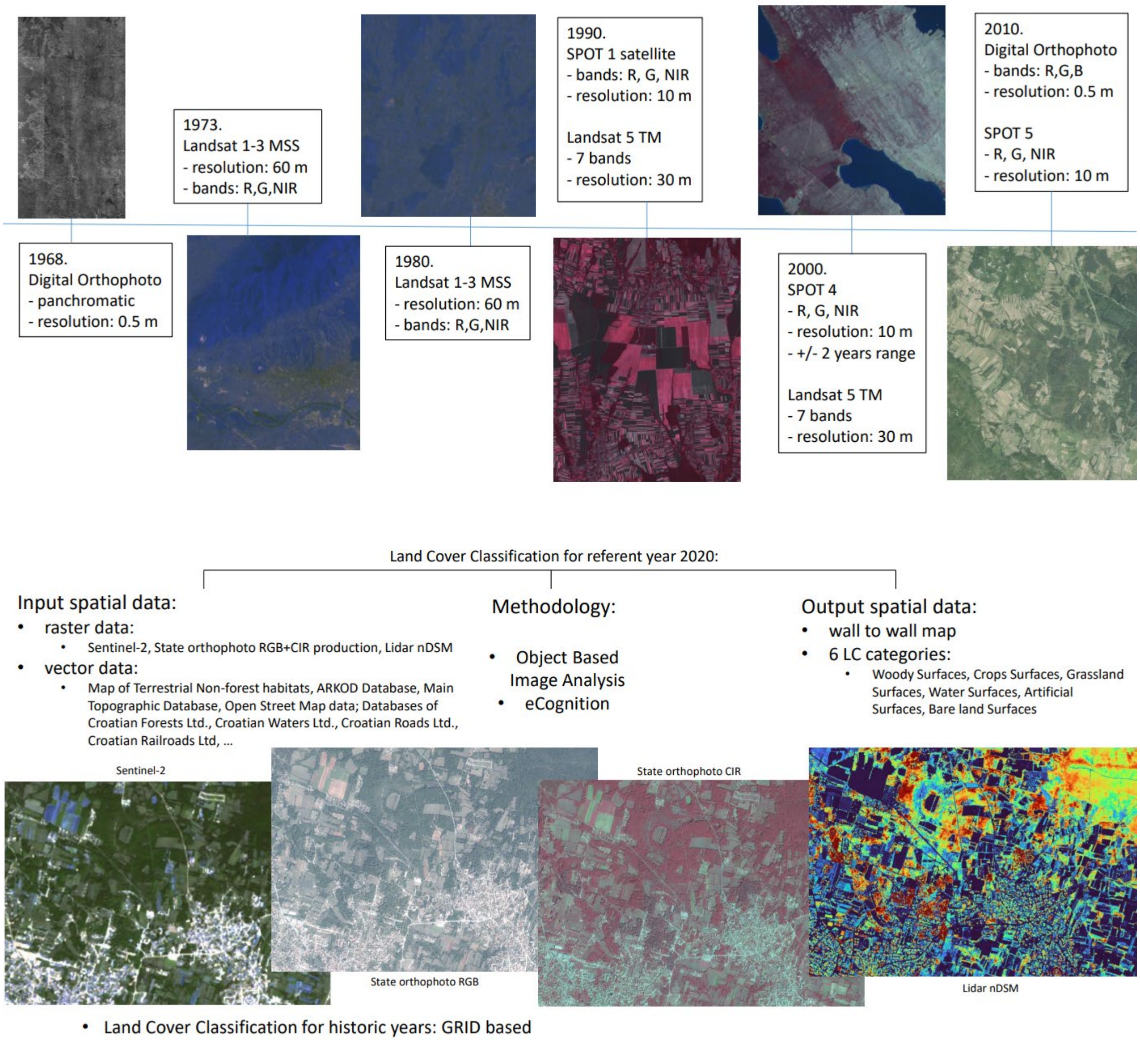
How it was resolved

The Croatian Land Information System (CROLIS) project started in 2020, through the EU LIFE programme financing support. The project ends in April 2024. The aim of the project was to develop and implement a harmonised land monitoring data model that enables the integration and processing of Land Cover (LC), Land Use (LU) and land management data from different data sources. Outputs of the project include the production of a consistent time series with land-use/land cover classes adapted to the needs of LULUCF inventory. One key element is that the time series go back to the 1970's, allowing the monitoring of 20-years matrixes in accordance

[97] https://www.lifecrolis.hr

with the inventory calculations needs. Several earth observation sources are combined to produce a multisource but harmonized dataset. In addition, the project takes advantages of more recent Sentinel products that provide high resolution maps for the recent years. Other spatial datasets such as "ARKOD", i.e. LPIS information on cropland areas, are also used in this approach. Therefore, the project created the methodological and technical framework to combine such heterogeneous datasets and produce a policy-relevant new hybrid information.

Figure 39: Some data source used in the LIFE CROLIS project to produce land-use and land-cover change time series for the historical period (picture above) and for the recent period (picture below).



Policy implications

The LULUCF inventory reporting requirement was not the only use expected of the outputs of the project. The idea was to create a multi-purpose land information monitoring system in Croatia, for the LULUCF inventory, for planning and implementing GHG mitigation actions and for other objectives such as rural development and conservation of natural habitats. This new hybrid system also creates flexibility in the use of data and helps avoiding duplication of data production or other issues regarding the monitoring of specific areas such as abandoned land. However, the capacity building, support and involvement of policy authorities and other stakeholders is crucial to enable a permanent implementation of this new system.

Back to chapter 6.3 Overcoming financial barriers

Annex 2: Linkages of land accounting categories in the LULUCF Regulation to inventory categories under the UNFCCC

Article 2 of the LULUCF Regulation defines land accounting categories that aggregate certain inventory categories or are based on LULUCF categories under the UNFCCC. A slightly different terminology is introduced for reporting under the LULUCF Regulation compared to terminology used under the UNFCCC (see Table A-1). The Convention inventory defines the aggregate categories as total forest land, total cropland, total grassland, total wetlands, total settlements, and total other land. Aggregated land accounting categories of afforested and deforested land, as under the LULUCF Regulation, do not exist in the Convention reporting. Due to this rearrangement of sub-categories into different aggregate categories, separate reporting tables and separate data submissions by Member States are required under the LULUCF Regulation in addition to the inventory submissions under the UNFCCC.

Table A-1: Land accounting categories in the LULUCF Regulation (1st period) and their linkages to inventory categories under the UNFCCC

Land accounting categories in LULUCF for the period 2021-25	UNFCCC land accounting categories
Afforested land	Cropland converted to forest land (4.A.2.1) Grassland converted to forest land (4.A.2.2) Wetlands converted to forest land (4.A.2.3) Settlements converted to forest lands (4.A.2.4) Other land converted to forest lands (4.A.2.5)
Deforested land	Forest land converted to cropland (4.B.2.1) Forest land converted to grassland (4.C.2.1) Forest land converted to wetlands (4.D.2.1) Forest land converted to settlements (4.E.2.1) Forest land converted to other land (4.F.2.1)
Managed cropland	Cropland remaining cropland (4.B.1) Grassland converted to cropland (4.B.2.2) Wetlands converted to cropland (4.B.2.3) Settlements converted to cropland (4.B.2.4) Other land converted to cropland (4.B.2.5) Cropland converted to wetlands (4.D.2.2.2 and 4.D.2.3.2) Cropland converted to settlements (4.E.2.2) Cropland converted to other land (4.F.2.2)
Managed grassland	Grassland remaining grassland (4.C.1) Cropland converted to grassland (4.C.2.2) Wetlands converted to grassland (4.C.2.3) Settlements converted to grassland (4.C.2.4) Other land converted to grassland (4.C.2.5) Grassland converted to wetlands (4.D.2.2.3 and 4.D.2.3.3) Grassland converted to settlements (4.E.2.3) Grassland converted to other land (4.F.2.3)
Managed forest land	Forest land remaining forest land (4.A.1)

Land accounting categories in LULUCF for the period 2021-25	UNFCCC land accounting categories
Managed wetland	Wetlands remaining wetlands (4.D.1) Settlements converted to wetlands (4.D.2.2.4 and 4.D.2.3.4) Other land converted to wetlands (4.D.2.2.5 and 4.D.2.3.5) Wetlands converted to settlements (4.E.2.4) Wetlands converted to other lands (4.F.2.4)

Source: Own compilation from LULUCF Regulation and UNFCCC inventory.

Table 5: Land accounting categories in the LULUCF Regulation (2nd period) and their linkages to inventory categories under the UNFCCC

Land Accounting Categories in LULUCF for the period 2026-30	UNFCCC land accounting categories
Forest land	Forest land remaining forest land (4.A.1) Cropland converted to forest land (4.A.2.1) Grassland converted to forest land (4.A.2.2) Wetlands converted to forest land (4.A.2.3) Settlements converted to forest lands (4.A.2.4) Other land converted to forest lands (4.A.2.5) 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (Forest) 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils 4(V) Biomass Burning
Cropland	Cropland remaining cropland (4.B.1) Forest land converted to cropland (4.B.2.1) Grassland converted to cropland (4.B.2.2) Wetlands converted to cropland (4.B.2.3) Settlements converted to cropland (4.B.2.4) Other land converted to cropland (4.B.2.5) 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (Cropland) 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils 4(V) Biomass Burning
Grassland	Grassland remaining grassland (4.C.1) Forest land converted to grassland (4.C.2.1) Cropland converted to grassland (4.C.2.2) Wetlands converted to grassland (4.C.2.3) Settlements converted to grassland (4.C.2.4) Other land converted to grassland (4.C.2.5) 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils

Land Accounting Categories in LULUCF for the period 2026-30	UNFCCC land accounting categories
	4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (Grassland) 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils 4(V) Biomass Burning
Wetlands	Wetlands remaining wetlands (4.D.1) Forest land converted to wetlands (4.D.2.1) Cropland converted to wetlands (4.D.2.2.2 and 4.D.2.3.2) Grassland converted to wetlands (4.D.2.2.3 and 4.D.2.3.3) Settlements converted to wetlands (4.D.2.2.4 and 4.D.2.3.4) Other land converted to wetlands (4.D.2.2.5 and 4.D.2.3.5) 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (Wetland) 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils 4(V) Biomass Burning
Settlements	Settlements remaining settlements (4.E.1) Forest land converted to settlements (4.E.2.1) Cropland converted to settlements (4.E.2.2) Grassland converted to settlements (4.E.2.3) Wetlands converted to settlements (4.E.2.4) Other land converted to settlements (4.E.2.5) 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (Settlement) 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils
Other land	Other land remaining other land (4.F.1) Forest land converted to other land (4.F.2.1) Cropland converted to other land (4.F.2.2) Grassland converted to other land (4.F.2.3) Wetlands converted to other land (4.F.2.4) Settlements converted to other land (4.F.2.5) 4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to managed soils 4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (Other land) 4(III) Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils 4(V) Biomass Burning
Harvested wood products	Harvested wood products (4G)

Land Accounting Categories in LULUCF for the period 2026-30	UNFCCC land accounting categories
Other	Other (4H)
Atmospheric deposition	4(IV) Indirect nitrous oxide (N_2O) emissions from managed soils
Nitrogen leaching and run-off	4(IV) Indirect nitrous oxide (N_2O) emissions from managed soils

Source: Own compilation from LULUCF Regulation and UNFCCC inventory.

Annex 3: Specific accounting rules

Difference between reporting and accounting

Assessing progress towards agreed targets requires a transparent, accurate, comparable, consistent monitoring system for greenhouse gas emissions and removals.

Reporting aims at documenting the level and development of GHG emissions and removals over time. It intends covering all anthropogenic emissions and removals (e.g. planting of trees and timber harvest) but also emissions and removals from biological processes on land areas directly or indirectly influenced by human activities (e.g. emissions from the drainage of peatlands). International guidelines for the reporting of emissions and removals in GHG inventories by countries have been developed and adopted under the UNFCCC and the same guidelines are used in the EU. If complete, reporting under the UNFCCC forms an important basis for assessing the impact of human activities on emissions and removals and thus its impact on climate change. In the second compliance period of the LULUCF Regulation (2026-2030), reported data forms the basis for assessing compliance with the national targets (see Section 4 and see below).

Accounting, in contrast to reporting, relates reported data to a reference value. Accounting can involve a variety of accounting elements, such as baseline or base year against which reported are compared. Such accounting elements are used for assessing compliance with the LULUCF Regulation in the period 2021-2025 (see below).

The rational of using accounted emission and removal values instead of just reported data is the following. In the LULUCF sector, directly and indirectly human-induced emissions and removals are occurring. An example of **directly human-induced** emissions is biomass harvest in forests, e.g. for bioenergy. It has to be noted though that emissions do not occur at the time of harvest but later when the biomass is burned. Also the removals occurring in growing forests that were planted can be considered directly human-induced. The planting activity, however, can have happened already decades ago. But trees are also regenerating naturally. Removals from such forests can also be interpreted as an **indirect human-induced** or even **natural effect**. Another example of indirect human-induced removals is the increased growth of trees due to increased CO_2 concentration in the atmosphere and nitrogen deposition from agriculture and transport. A differentiation between direct and indirect human induced effects is not always possible. However, a differentiation is useful for an effective planning of mitigation measures as direct effects can usually be addressed more easily by policies and measures. Differentiated accounting of emissions and removals can help reduce the influence of natural and indirect human-induced effects.

Accounting introduces a reference, baseline or base year against which reported GHG emissions and removals are compared. This reference is also referred to as ‘counterfactual’. It can be based on historic or projected data. Accounting against a reference level of emissions or removals in the LULUCF sector aims to factor out management effects. This is achieved by assuming that the reference includes indirect human-induced effects. The reported data also include indirect effects but also effects of a management change that occurred. Comparing the reference with reported data makes the effect of a management change visible.

Accounting rules for 2021-2025

The 'no-debit' target

The objective in the first period of 2021 to 2025 is to achieve an **EU-wide and national** '**no-debit' target**. This means, Member States need to ensure that within the LULUCF sector, **accounted emissions do not exceed accounted removals**, calculated as the sum of accounted emissions and removals in all the land accounting categories defined in the Regulation. For example, that if a Member State converts forests to other land uses, it has to make sure that emissions are compensated, e.g. by afforestation or by improving the sustainable management of existing forests, enhancing C stocks in soils on croplands, grasslands or wetlands, etc.

As described above, accounted emissions and removals differ from reported net emissions and removals (see also Annex 1 of the Handbook). When accounted, reported net emissions and removals are compared to a historic or projected level of net emissions and removals. Balancing **accounted** emissions and removals during the period 2021 to 2025 could thus correspond to a **reported** net sink of about -225 Mt CO_2 for the EU according to estimates of the European Commission based on data of the 2020 submission.

While the regulation requires that data is reported annually, accounting only takes place once at the end of the 5-year period of 2021-2025, thus in 2027 when reported data for accounting become available.

Emissions and removals **from all carbon pools** on the land accounting categories are reported and accounted. Member States may exclude changes in carbon stocks of carbon pools from their accounts provided that the carbon pool is not a source. However, the carbon pools of above-ground biomass, dead wood, and harvested wood products, in the land category of managed forest land should not be excluded.

Accounting for afforested land and deforested land

According to the LULUCF Regulation (Art. 2) '**afforested land'** refers to non-forested areas, i.e. cropland, grassland, wetlands, settlements or other land that are converted to forests. Inversely, '**deforested land' comprises** land areas reported as forest land converted to cropland, grassland, wetlands, settlements or other land.

Accounting for afforested land and deforested land is based on **gross-net accounting** (Art. 6, see Figure 40b). This means that **all net removals or emissions reported** during the compliance period 2021 to 2025 are taken into account.

For calculating emissions and removals from afforested and deforested land and also managed forest land, Annex II of the LULUCF Regulation indicates specific parameters of **forest definitions** for each Member State. The parameters are minimum values for forest area, tree crown cover and tree height for each Member State. Areas range from a minimum of 0.05 ha for the Czech Republic and Austria to a minimum of 1.0 ha for Spain and Malta. Minimum tree crown cover ranges from 10% to 30% and minimum tree height is specified as either 2, 3 or 5 m. The different values reflect different national circumstances and differences in forest types. The use of country-specific definitions allows for consistency with national forest definitions used for other forest related policies implemented at national level.

Accounting for managed cropland, managed grassland and managed wetland

Accounting for managed **cropland**, managed **grassland** and managed **wetland** is based on **net-net accounting** (Art. 7, see Figure 40a). This means that reported net emissions or removals in the periods from 2021 to 2025 are **compared** to the average annual emissions and removals in a **base period**. The difference of net emissions compared to net emissions in the reference period is accounted for. The base period defined in the LULUCF Regulation is the period from 2005 to 2009. By using a base period instead of a single year, fluctuations in emissions or removals between years and extreme values are expected to be levelled out. Accounting of emissions and removals from managed wetland will be mandatory only from 2026 onwards using the same approach. However, the category needs to be reported already.

Accounting for managed forest land and harvested wood products

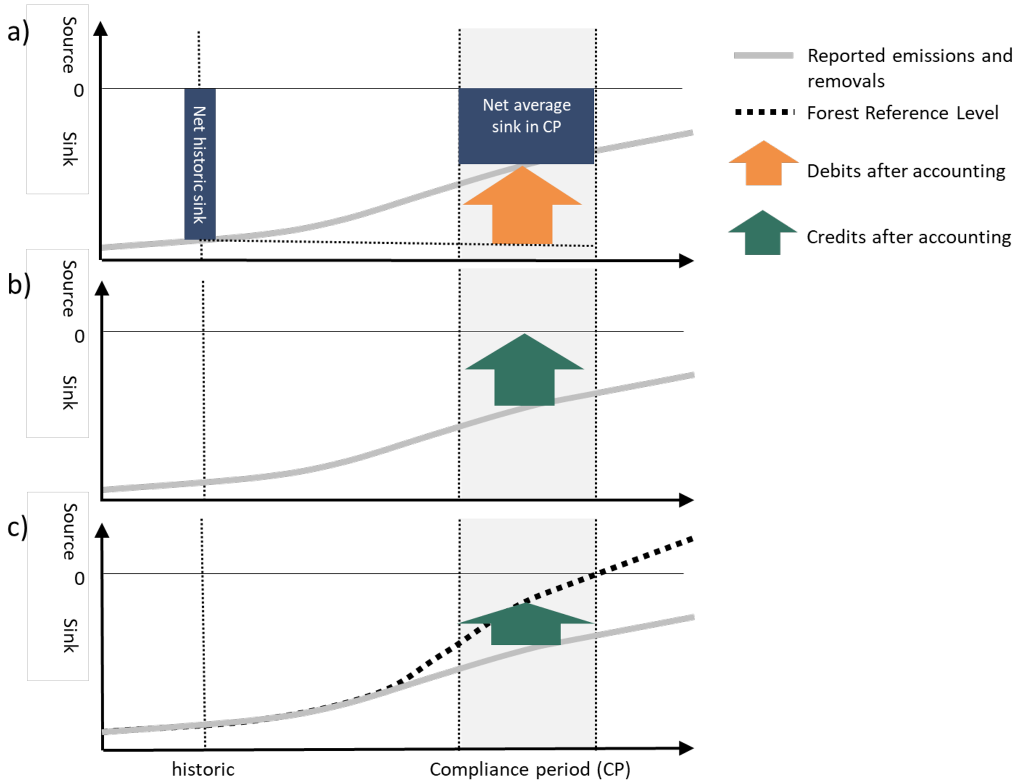
Accounting for managed forest land including harvested wood products is based on **accounting compared to a reference level** (Art. 8, see Figure 40c). As a reference, the so-called **Forest Reference Level** (FRL) is calculated. As described above, the main idea of the concept of accounting against a reference is to separate direct human-induced effects, e.g. caused by management changes, from natural and indirect human-induced effects in the forest (e.g. due to the age structure of forests). Management changes include also changes in the use of wood as raw material or for energy production. The FRL is the counterfactual value of emissions and removals that would occur in managed forest land in the future based on the continuation of 'sustainable forest management practices,' as documented in the period from 2000 to 2009 and assuming a constant ratio of raw material and energy use. Annex IV of the LULUCF Regulation defines criteria for the establishment of such FRL and estimated FRLs for each Member State.

Of the emissions and removals from managed forest land estimated and reported during the period, only the difference between the FRL and the reported net emissions and removals is accounted for. This means that **the accounted amount deviates considerably from the annually reported net emissions and removals** in the GHG inventory. A country with a reference level that assumes a large net sink will face debits if an intensification of management decreases the sink compared to the reference despite the fact that the forest is still a net sink of CO_2.

Art. 8, para. 2 of the LULUCF Regulation applies a **cap of 3.5% of total emissions of the base year** (often 1990) to the total accountable net removals from managed forests, excluding sub-categories HWP and dead wood. This means that the maximum accountable net removals from managed forest land in each accounting period are limited to five times of the emissions in the base year per Member State as specified in Annex III of the Regulation.

The FRL includes separate estimates for emissions and removals from managed forest land and **harvested wood products** (HWP). For reporting HWP, the so-called 'production approach' is to be applied that estimates the annual HWP carbon stock change originating from wood harvested in the reporting country only, and thus includes the exported wood products but excludes the imported wood products. The default approach applied by most Member State distinguishes three categories of products: paper, wood panels, and sawn wood. It is assumed that the harvested wood is sorted to these categories and the CO_2 embedded within the wood is emitted to the atmosphere after a certain period of use. The residence time of CO_2 in the product pools is estimated using a first order decay function for each product group and default half-life values specified in Annex V of the Regulation. Energy wood and wood in landfills is excluded and considered to cause emissions immediately.

Figure 40: Illustration of different accounting methods: a) net-net, b) gross-net, c) accounting against a reference level.



Source: Adapted from Böttcher and Graichen 2015. a) Net-net accounting: Applied to managed cropland, grassland and wetlands. The average annual net emissions and removals in the compliance period are be compared to the reference value. As a result, a country with decreasing net sink in the compliance period would receive debits under this approach (even when the category remains a net sink). The reference value for managed cropland, grassland and wetlands are historic net emissions and removals. b) Gross-net accounting: Applied to afforested and deforested land. Considers all emissions and removals that occur during the accounting period. No comparison with any historic or future reference is made (actually it is compared to zero). A country with a declining net sink receives credits if the sink still exists in the accounting period. Hence, all emissions or removals from the deforested and afforested land are accounted for. According to this logic, afforestation and deforestation are 100% attributable to human behaviour and are thus fully considered. c) Reference level accounting: Applied to managed forest land. The forest reference level (FRL) is the counterfactual value of emissions and removals that would occur without a management change. The aim is to factor out natural and indirect human-induced effect Accounting against a reference level means that in the category managed forest land – which makes up most of the LULUCF removals in the EU – the generation of accountable removals is much more limited than under a net-net or even a gross-net approach.

Annex 4: Monitoring tools and existing solutions

Tools for data collection

Basically, there are two options for data collection: 'traditional' ground-based surveys (e.g. National Forest Inventories) and remote sensing classification (i.e. LCLU information derived from aerial or satellite imagery). Please note that this Annex only deals in more detail with remote sensing approaches (more information on NFIs can be found in section 5.3).

Remote sensing-based data collection provides **the possibility of covering large and/or difficult to access areas at comparatively low costs even for repeated, frequent observations.**

the possibility of **reconstructing historical time-series** of land cover information due to the archives of remote sensing data that now span several decades back to as early as 1972.

However, remote sensing-based data collection poses certain challenges:

Information derived from remote sensing will mostly be **land cover** which needs to be used as proxy for land use.
Interpretation and classification of the data needs a certain **consistency** in order to produce reliable land cover maps, as changes in the methodology may lead to changes in the resulting map which merely correspond to technical changes but not to real land cover changes.
Data acquisition may be impaired by the presence of clouds, smoke and haze. This challenge, however, becomes less critical due to the increasing number of satellites and thus increased frequency of observations which reduces the likelihood of not having any cloud-free imagery available for a certain area.

Chapter 3A.2.4 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories describes the basics of remote sensing techniques in detail.

Overview of available geographically-explicit datasets

A range of data sources provide datasets that can be exploited. Three data sources are briefly presented below: a. Copernicus, b. national datasets such as LPIS or GSA, and c. global datasets. This list is not exhaustive; rather, it offers a brief overview and idea of potential usable geospatial dataset.

Copernicus

The Copernicus Land Monitoring Service (CLMS)[98] is one of the 6 operational Copernicus services, providing operational EO based products on various elements of Land Cover and Land Use (among others), free and open for all users. Although the main focus of the available data is on biophysical parameters and land cover products, some products contain also elements of land use. Among others, the following Copernicus products can contribute to improved geospatially-explicit mapping and monitoring of activity data (or proxies to activity data):

[98] https://land.copernicus.eu/

Corine Land Cover (CLC) [99]

This dataset provides land cover/land use information as well as changes for long time series: CLC is available for the reference years 1990, 2000, 2006, 2012 and 2018 with respective change products for 1990-2000, 2000-2006, 2006-2012 and 2012-2018. The next product will be for the reference year 2024, which will be produced throughout 2025 and become available thereafter.

Note that several informal feedbacks are consistent in judging that the accuracy of CLC maps not high enough to derive reliable land transition matrices. It also has a relatively coarse spatial resolution with a minimum mapping unit of 25ha (change product: 5ha).

A highly accurate pan-European land cover map (**CLC+ Backbone** [100]), available for 2018, with an update for 2021 available end of 2023, and then updates every 2 years.
The **High-Resolution Layers** (HRLs) provide maps of vegetation and vegetation change (tree cover and forest, grassland) [101] as well as non-vegetated areas (impervious areas, water) [102].

Note that the HRLs have a 3-yearly update cycle from 2012 up to 2018. The vegetation related products move to yearly updates from 2018 onwards and will be complemented by a new annual crop type layer (currently in production).

The 2018 editions of the HRLs are available at 10m spatial resolution while earlier versions have a resolution of 20m.

Hedges, agroforestry, trees outside forests are included in the special product called **Small Woody Features** [103], available for 2015 and 2018, at 5m spatial resolution.
On **burnt area** [104]: the global component of the CLMS has burnt areas in their portfolio and there is also a global fire monitoring element of the Copernicus Atmosphere Monitoring Service. [105]
As a part of the new generation CLC (**CLC+**) [106], the CLMS is **currently developing tailor made 100m grid** products **that try to approximate LULUCF activity data categories**, the so called 'LULUCF Instances'. These combine the aforementioned existing land cover and land use data produced in the frame of CLMS in a web-application/database (CLC+ Core). CLC+ Core is also available for countries to use, and additional training can be offered in 2024. First instances prototypes became available in Q2/2023.
Another component of the CLMS is the **Priority Area Monitoring**, which aims to provide tailored and more detailed LC LU information for specific areas of interest (so-called hot spots).

- **Urban Atlas** [107] provides land use information in the spatial resolution of 10 m for core urban areas in 870 cities across Europe. Urban Atlas data are available for the 2006, 2012 and 2018 reference years, including the two change products for 2006-2012 and 2012-2018. This data gives more spatial and thematical resolution for land use mapping in and around main cities than CLC.

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[99] https://land.copernicus.eu/en/products/corine-land-cover
[100] https://land.copernicus.eu/en/products/clc-backbone
[101] https://land.copernicus.eu/en/products/high-resolution-layer-forest-type, https://land.copernicus.eu/en/products/high-resolution-layer-tree-cover-density
https://land.copernicus.eu/en/products/high-resolution-layer-tree-cover-density,
https://land.copernicus.eu/en/products/high-resolution-layer-dominant-leaf-type, https://land.copernicus.eu/en/products/high-resolution-layer-grassland
[102] https://land.copernicus.eu/en/products/high-resolution-layer-imperviousness,
https://land.copernicus.eu/en/products/high-resolution-layer-water-and-wetness
[103] https://land.copernicus.eu/en/products/high-resolution-layer-small-woody-features
[104] https://land.copernicus.eu/global/products/ba
[105] https://atmosphere.copernicus.eu/global-fire-monitoring
[106] https://land.copernicus.eu/en/products/clc-a-new-generation-land-information-system-for-europe
[107] https://land.copernicus.eu/en/products/urban-atlas

- **N2K (Natura 2000)** [108] provides detailed land cover and land use information for 55 thematic classes in selected Natura2000 sites for 2006, 2012 and 2018 reference year. The dataset has a Minimum Mapping Unit (MMU) of 0.5 ha and a Minimum Mapping Width (MMW) of 10 m and is available as vector data. This data gives more spatial and thematical resolution for land use mapping in Natura 2000 zones than CLC.
- **Coastal Zones** [109] provides a detailed land cover and land use information for 71 thematic classes for areas along the European coastline for the 2018 and 2012 reference year. The dataset has a Minimum Mapping Unit (MMU) of 0.5 ha and a Minimum Mapping Width (MMW) of 10 m and is available as vector data. This data gives more spatial and thematical resolution for land use mapping along the European coastlines than CLC.
- **Riparian Zones** [110] provides detailed land cover and land use information for 55 thematic classes in a variable buffer zone of selected rivers across Europe for the 2018 and 2012 reference year. The dataset has a Minimum Mapping Unit (MMU) of 0.5 ha and a Minimum Mapping Width (MMW) of 10 m and is available as vector data. This data gives more spatial and thematical resolution for land use mapping in Riparian zones than CLC.
- Note: the datasets provide only LC/LU data for specific areas and are not available on a pan-European level or for complete countries.

Established by the European Commission (EC) in collaboration with the national fire administrations the **European Forest Fire Information System** (EFFIS) [111] consists of a modular web geographic information system that provides near real-time and historical information on forest fires and forest fire regimes in the Europe. Fire monitoring in EFFIS comprises the full fire cycle, providing information on the pre-fire conditions and assessing post-fire damages [112].

LUCAS [113] (Land Use/Cover Area frame statistical Survey) is a land-use and land-cover ground survey that also contains a soil survey. The soil component (**LUCAS Soil**) is an extensive and regular topsoil survey that is carried out across the European Union to derive policy-relevant statistics on the effect of land management on soil characteristics. Soil samples have been collected from different time periods.

High Value Datasets (HDV) [114] [115]

This application is providing an overview and the possibility to access (geospatial) high-value datasets and other core datasets which are falling under the scope of the Open Data Directive [116] in accordance with the related Implementing Act [117]. In regard to geospatial datasets the following spatial datasets are available for selected countries in the scope of the INSPIRE data themes: Agricultural parcels (GSAA and LPIS), Addresses, Administrative Units, Cadastral parcels, Geographical names and Buildings established by the INSPIRE directive [118]. High Valuable Datasets will be available from June 2024 at the INSPIRE geoportal [119].

[108] https://land.copernicus.eu/en/products/n2k
[109] https://land.copernicus.eu/en/products/coastal-zones
[110] https://land.copernicus.eu/en/products/riparian-zones
[111] https://effis.jrc.ec.europa.eu/
[112] https://www.copernicus.eu/en/european-forest-fire-information-system
[113] LUCAS - ESDAC - European Commission (europa.eu)
[114] https://data.europa.eu/en/publications/datastories/high-value-datasets-overview-through-visualisation
[115] https://inspire-geoportal.ec.europa.eu/srv/eng/catalog.search#/hvdshome
[116] https://eur-lex.europa.eu/eli/dir/2019/1024/oj
[117] https://eur-lex.europa.eu/eli/reg_impl/2023/138/oj
[118] https://knowledge-base.inspire.ec.europa.eu/index_en
[119] https://inspire-geoportal.ec.europa.eu/srv/eng/catalog.search#/hvdshome

National datasets

Examples for national datasets originate from **Integrated Administration and Control Systems** (IACS) and **Land Parcel Identification Systems** (LPIS).

An LPIS is an information system recording the land-use of all parcels for which a subsidy from the Common Agricultural Policy is requested. There is not a unique European portal to access these systems, but some Member States allow access to their LPIS through the internet, and the reporting agency should have internal access to them, at least for non-confidential attributes. LPIS will typically provide activity data on:

- Land use and management changes (at least between annual crops, perennial crops and grassland). This information is geographically-explicit and exhaustive, and therefore good material for an Approach 3 to land representation, at least for these land uses.
- Permanent versus temporary grassland (different impact on soil carbon). Note that the agricultural fields that do not receive CAP subsidies are not always included into LPIS systems, and their quantity can vary between Member States.

GSAA is related to the Common Agricultural Policy and is a subsystem of Integrated Administration and Control System (IACS). GSAA is an electronic application form based on a geographic information system that allows beneficiaries to spatially declare the agricultural parcels of the holding. GSAA data is referenced to the units identified in the LPIS. There again, the type of activity data which can be retrieved from GSAA varies between countries. In Denmark for example, afforestation subsidies recorded in IACS are used as activity data for the monitoring of land converted to Forest. Agro-Environmental and Climatic Measures (AECMs) recorded in IACS, as well as future Eco-Schemes, could provide activity data for some management practices, provided that these practices do not take place without CAP support.

Another national dataset is, for example, the **Farm Accountancy Data Network** (FADN). FADN is a European database originally focused on farm accounts (products, costs, profits, …) in Euros, although it is evolving towards data on physical amounts in tons or number of animals, with the objective of performing environmental assessments. It is updated annually and covers only a representative sample of farms.

The European FADN can already provide activity data on the extent of organic farming in hectares, although the relevance of this practice for soil carbon monitoring is debatable (see 3.2.6).

More interestingly, the national FADNs usually contain more data than what is sent to DG Agri for the European compilation. This data can sometimes be the source of activity data for a relevant practice regarding soil organic carbon. The Italian FADN for example contains data on the amounts of organic inputs to agricultural soils. Whether your national FADN contains useful information on activity data for soil organic carbon monitoring is to be assessed on a country-by-country basis.

Agricultural census: There is no aggregated agricultural census at the European level. However, most Member States conduct an exhaustive agricultural census or similar non-exhaustive surveys at variable frequencies (3-15 years). Similarly to national FADNs, whether your agricultural census contains useful information for deriving activity data is to be assessed on a country-by-country basis. One may hope to find activity data on food standards (e.g. organic, geographical indications), the number of hedges or agroforestry plots, the crops and the management practices applied, etc.

Farm practices surveys: There is no aggregated farm practices survey at the European level. However, most Member States conduct such surveys on a small sample of farms or fields at variable frequencies (5-15 years). Similarly to national FADNs, whether your farm practices survey contains useful activity data is to be assessed on a country-by-country basis. One may hope to find activity data on the amounts of organic inputs to soils, the number of hedges or agroforestry plots, the extent of cover crops, etc.

Generally speaking, if national datasets do not cover the whole national territory, it is at least a good practice to explore the possibility to extrapolate its information. National datasets can be used to validate information taken from other sources to increase the confidence in inventories.

Global datasets

There is fairly broad range of global datasets available that can be used if certain pre-conditions are considered. The list presented below is not exhaustive.

- **ESA Climate Change Initiative – Global Land Cover Products (CCI – LC)** [120]: This is a series of consistent global LC maps at 300 m spatial resolution on an annual basis from 1992 to 2020. 2021 and 2022 are expected to be published soon.
- **Global Forest Change Map** [121] by the University of Maryland: Results from time-series analysis of Landsat images characterizing global forest extent, forest cover loss and gain based on land cover information from 2000 to 2022 at 30m spatial resolution.
- **Copernicus Global Dynamic Land Cover** [122]: The Dynamic Land Cover product at 100 m resolution provides a primary land cover scheme at three classification levels with class definitions according to the Land Cover Classification System (LCCS) scheme e.g. forests, grasslands, croplands, lakes, wetlands for the 2019 base year. The data are updated annually and are available for the 2015-2019 years. Next to these discrete classes, the product also includes continuous field layers or ‘fraction maps’ for all basic land cover classes that provide proportional estimates for vegetation/ground cover for the land cover types.
- **Sentinel-2 10m land use/land cover time series of the world** (produced by Impact Observatory, Microsoft, and Esri): The layer displays a global map of land use/land cover (LULC) derived from ESA Sentinel-2 imagery at 10m resolution. Each year (2017-2022) is generated with Impact Observatory’s deep learning AI land classification model. The algorithm generates LULC predictions for nine classes [123].
- **ESA World cereal** [124] is a EO based system for timely global cropland monitoring at a field scale at 10m resolution. The system can generate a range of seasonal products (including maize, winter cereals, spring cereals, active cropland and active irrigation) by using open and free data from the Copernicus Sentinel satellites (Sentinel-1 and Sentinel-2) and data from the USGS’ Landsat satellites, combined with meteorological and in situ data. WorldCereal products are available for download and processing on the open EO cloud [125].

[120] http://maps.elie.ucl.ac.be/CCI/viewer/download.php
[121] https://glad.earthengine.app/view/global-forest-change
[122] https://land.copernicus.eu/en/products/global-dynamic-land-cover
[123] https://www.arcgis.com/home/item.html?id=cfcb7609de5f478eb7666240902d4d3d
[124] https://esa-worldcereal.org/en
[125] https://openeo.cloud/

When using such international datasets to compile or complement national land representations, several things have to be considered (cf. Chapter 3 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories):

The **classification scheme, i.e. class definitions of LCLU classes, may differ from the nationally used scheme. It may therefore be necessary to harmonize, filter and/or transfer between classes from one to the other nomenclature.**

The spatial resolution may be coarse. It is important to consider the envisaged or required minimum mapping unit (MMU) (i.e. the smallest size of a feature can have so that it will still be represented in the map). Pixel size and detectability by remote sensing data have to be considered to assess the MMU suitability. A commonly accepted criterion is that the pixel area should not exceed 1/4 MMU.

The accuracy of the classification as well as potential errors in geo-referencing should be investigated. As with national data, it might be necessary to explore possibilities of interpolation or extrapolation to develop estimates for the time periods to match the dates required for reporting.