Joint Research Centre

SCIENCE FOR POLICY BRIEF

Unlocking the Carbon Farming potential via a new generation of Monitoring, Reporting, Verification (MRV) systems

2026

HIGHLIGHTS

- The Carbon Removals and Carbon Farming (CRCF) regulation (EU-2024/3012) aims at developing a voluntary carbon (C) market for the EU, generating a new 'green business model'.
- 'Carbon farming activities', such as improved soil management, afforestation, and peatlands restoration have the potential to store additional C in biogenic pools (or reduce their emissions) in the order of hundreds Mt per year.
- In the EU, the biomass and soil pools contain a considerable amount of organic C but changes are difficult to be detected.
- The credibility and deployment of a voluntary C market is linked to the level of accuracy of reported C changes, which is directly correlated with the costs.
- A new generation of Monitoring, Reporting, and Verification (MRV) systems would allow lowering the certification costs and create, at the same time, high quality carbon removals credits.

- Soil and forest inventory data, remote sensing, AI and process-based models can be integrated under a holistic framework dealing with quantification, monitoring, risk assessment and scenario analysis.
- The JRC has been funded under a reserved Europe Horizon call (WP 2026-27 Food, Bio-economy, Natural Resources, Agriculture and Environment.) to develop a project called "Improving Monitoring, Reporting and Verification systems (iMRV)" tackling those challenges.

THE CRCF regulation

Mitigation potential

The European Union (EU)'s commitment to achieve climate neutrality by 2050, as outlined in the EU Climate Law (2021/1119), necessitates a significant reduction in greenhouse gas emissions across energy-consuming sectors and a substantial effort to maintain and further increase the land carbon (C) sink. To support this target, the European Commission has proposed the Carbon Removals and Carbon Farming (CRCF) regulation (2024/3012), which aims at deploying a voluntary carbon market using nature-based solutions, such as improved soil management, afforestation, and restoration of peatlands, the so called 'carbon farming activities'. This market will be sustained by private and public capitals of entities willing to inset or offset their emissions. Various studies provide a large range of **mitigation values**, depending on the activities and if their **technical** or **achievable potential** (i.e. constrained by social-economic and environmental barriers) is considered.

For instance, pan-European modelling estimations suggested a potential soil organic carbon sequestration of 400–1300 Mt CO_2 eq. by 2050, allocating 12 to 28% of the European arable land to different carbon farming activities [1]. Other studies suggest that technical sequestration potential for EU-27 including agroforestry might be much higher, reaching 1,566 Mt CO_2 eq. per year [2]. Indeed, a recent review of scientific literature and national information suggested an achievable agricultural soil carbon sequestration of 55 Mt CO_2 eq. per year in the EU [3].

Total forest biomass in the EU-27+UK is estimated at 9.8 Pg C [5] with 9.1 Pg C stored in forest mineral soils [4],[6]. The most recent annual GHG Inventory (EEA, 2025[1]) reports for the period 2020-2023 an average sink of 295.4 MtCO_2 eq. for forest land and harvested wood product, which is less than the average 2015-2019 that was 363.7 MtCO_2eq. The forest carbon sink in the EU has been declining over the last decade due to climate change, natural disturbances and increased forest harvesting [8]. Nevertheless, forests have a high potential to store carbon in biomass and soils [4]. According to recent reviews, afforestation has the potential to sequester from 2 to 35 Mg CO_2 per ha per year [7].

Peatland ecosystems store significant amount of organic carbon, currently decomposing fast to CO_2 because of drainage for peat extraction and cultivation. Some studies reported a mitigation potential of about 185 Mt CO_2 eq. per year in the 2020-2050 period, with achievable mitigation up to 60 Mt CO_2 per year by 2025, following binding Nature Restoration Regulation (NRR) targets [9]. Together, land-based activities may reach an achievable potential up to 190 Mt CO_2 eq. per year, summing up the mentioned mitigation estimates.

A new business model

While the range of the carbon farming achievable mitigation potential is wide and subject to many assumptions, a conservative estimate in the order of 100 Mt CO_2 eq. per year would already generate about 2-5 billion Euro per year (at CO_2 price of 20-50 Euro per ton expected by 2030[2]). This corresponds, for instance, to about 4-9% of the annual Common Agricultural Policy budget, but could be substantially higher if CRCF credits would have higher prices as perceived of high quality.

[1] https://www.eea.europa.eu/en/analysis/publications/annual-european-union-greenhouse-gas-inventory-2025

[2] https://decode6.org/articles/cabron-credits-priced-and-sold/

However, at the level of a single operator (farmer, land manager, etc.) the net revenue can be substantially affected by the certification costs, since removal rates are generally low and their accuracy inversely related to the quantification costs. Typical rate of carbon sequestration in mineral soils, for instance, are often below 1 Mg CO_2 per year. A large deployment of the carbon farming activities is then necessary to create an economy of scale for C credits, incentivising the enrolment in voluntary certification programs.

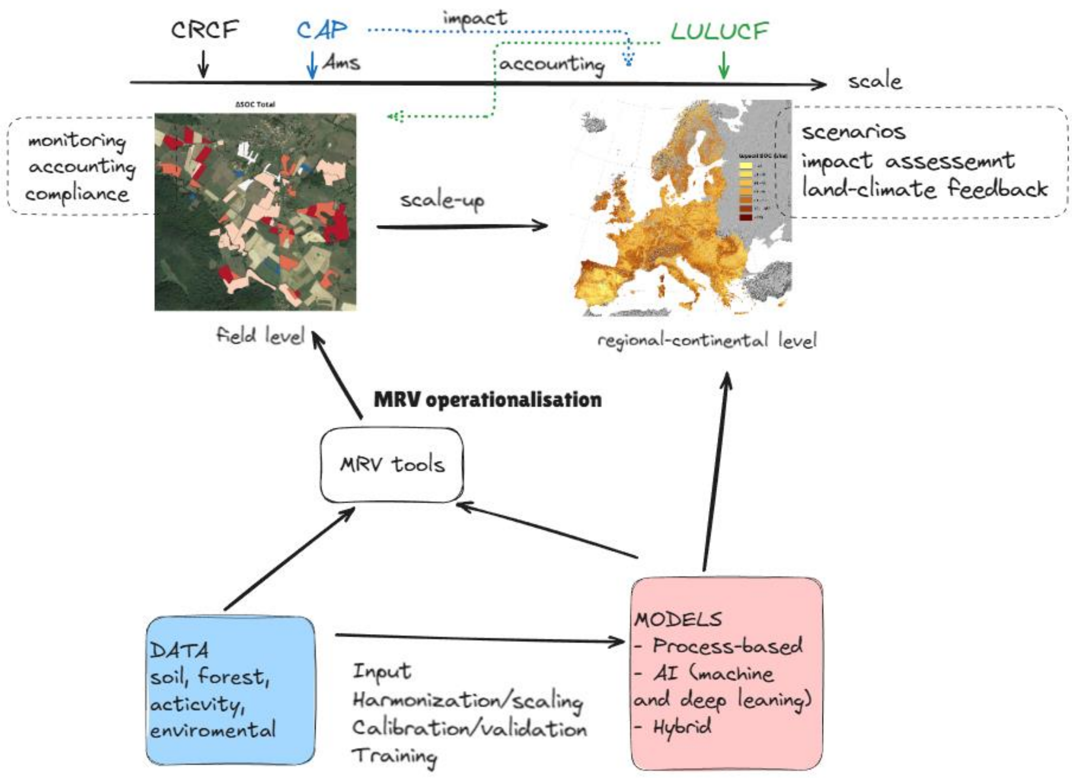
Under the CRFC, minimum sustainability criteria are also required for carbon farming activities implemented, as well mandatory co-benefits (art. 7 EU 2024/3012). Moving from a carbon centric toward a more holistic certification, improving the health and resilience of ecosystems, could add value of C credits beyond the mere CO_2.

MRV systems: a key component

A recent paper [10] strongly questioned the effectiveness of voluntary C credits in climate mitigation, due to the difficulty in assessing: i) additionality (i.e. the removal or reduced emissions that would not have been happened without the carbon farming activities), ii) C changes in pools and fluxes that are very uncertain and variable in time and space and iii) the permanence of removals due to natural disturbances. Moreover, low C prices may favour low-integrity offsets that undermine the incentive for polluters, who buy those credits, to cut their emissions. Developing high quality C credits is also directly linked to the cost for monitoring and quantifying carbon faming activities. This is where a Monitoring, Reporting and Verification (MRV) system can play a key role, lowering the cost of emissions/removals quantification while maintaining a good accuracy. An ideal MRV should embed these **4 pillars**:

- **Data**: fully exploiting existing data (remote sensing, soil and forest inventory data, statistical sources etc.);
- **Technology**: be technological advanced by incorporating AI, process-based models and hybrid approaches;
- **Scalability**: be scalable, in order to work at the local scale (with minimum input requirements) but also at the regional, national or continental scale;
- **Predictability**: be able to make predictions in time, ingesting land use and climate change scenarios, accounting for land-climate feedback and so the potential and risk related to the C farming activities.

Figure 1 – Data-modelling framework embedding the 4 pil-lars for an ideal MRV system.



Source: Joint Research Centre

Box 1: Definition of MRV

MRV, which stands for Monitoring, Reporting, and Verification, is a framework used to track, verify, and report on various activities, particularly those related to greenhouse gas (GHG) emissions and their reduction. MRV are characterized by three components:

Measurement/Monitoring of the emissions and removals.

Reporting of the data into format that facilitate their use.

Verification, a third party reviews that validates the reported data.

To develop robust MRV embedding these four pillars, a number of barriers and scientific developments are necessary. These developments are summarised in Table 1.

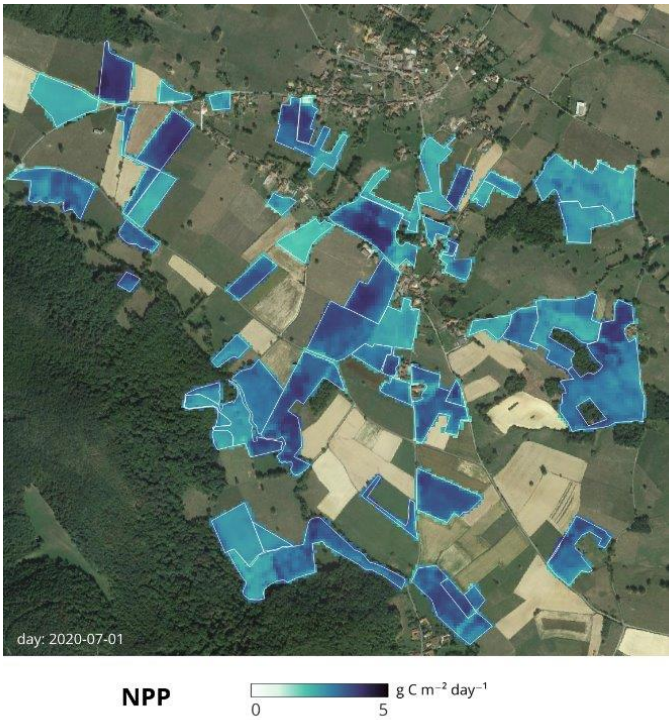
The iMRV project

The JRC is preparing a project proposal under a reserved Europe Horizon call (WP 2026-27 Food, Bioeconomy, Natural Resources, Agriculture and Environment.), called "**Improving Monitoring, Reporting and Verification systems (iMRV)**".

The project aims to tackle the aforementioned four pillars for MRV and provide a prototype to quantify baselines and monitor carbon emissions/removals in the forest-related and agricultural sectors as a result of carbon farming activities under the CRCF and other policies. The project aims at showing how different data streams can inform process-based, data-driven or mixed model (including AI), and how these models can be properly calibrated, trained and applied at different scales (from the field to the continental level).

The framework in Figure 1 illustrates these concepts. Data on environmental variables, activities and biogenic C pools and fluxes are necessary as: input for model initialization, calibration or model training and, validation. The different type of models can be run at regional and continental scale to assess large-scale feedback on the C cycle or making projection on climate change and policy driven scenarios. The same model can be also applied at parcel or local scale driven by high resolution input (such as remote sensing data) and activity data. In the latter application, this data-modelling framework can be operationalised to become a MRV and utilised for monitoring carbon farming activities and quantifying their emissions/removals under CRCF project. The overall framework is very scalable and allow to report, monitor and evaluate the performances of different policies operating at different scale (e.g. CAP, LULUCF).

Figure 2 – Calculation of the net primary productivity (NPP) using Sentinel-2 data at 10 m resolution in permanent grassland parcels.

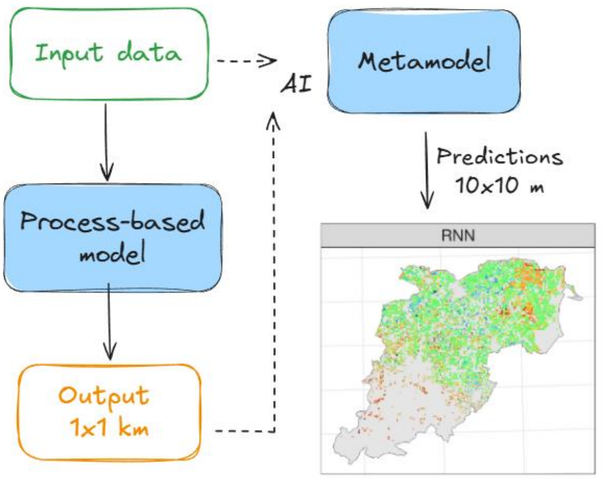


Source: Joint Research Centre

Figure 2 gives an example on how different data sources and technologies can be integrated to assess the C budget at parcel level. Spatial boundaries and the land use classification are gathered from the Land Parcel Identification System (LPIS), a spatial database used by EU member states to manage agricultural land and aid schemes under the CAP. For the permanent grassland parcels selected, the available time-series (2017-2024) of Sentinel-2 are extracted and interpolated in time. Then, the Sentinel signal is used to calculate the daily productivity (Net Primary Productivity - NPP) by a light-use efficiency model that considers daily radiation and other weather variables. The figure shows the grass productivity in a summer day, highlighting also the spatial variability within the parcels.

An example of MRV scalability is depicted in Figure 3. JRC is running complex process-based ecosystem models at European level but, due to the high computational requirements, the resolution is equal or lower than 1 km^2. Moreover, model running requires adequate IT infrastructures and high competence. However, it is today possible to build model emulators (or meta-models) feeding machine- and deep-learning algorithms with input and model output (creating a synthetic dataset). These methods are generally able to reproduce the process-based model results, once trained with these synthetic datasets, providing a meta-model that is easily scalable across the EU. Using high resolution input data (the same type of the meta-model training), the process-based model behaviour can be reproduced at higher spatial resolution that would be unfeasible by running it, offering also the advantage to incorporate local data.

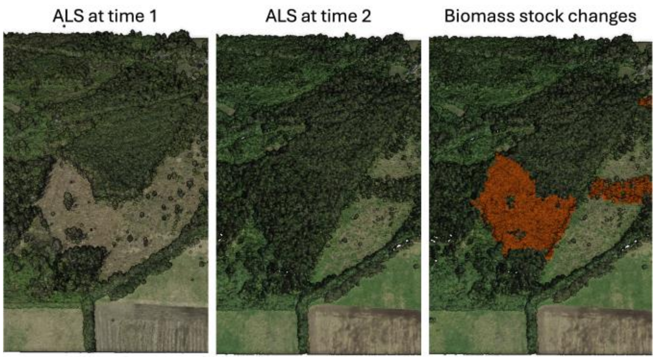
Figure 3 – Schematic representation of a model emulator (Meta-model) creation. Input and output data derived from complex process-based models are used to train AI algorithms that can provide predictions at much higher spatial resolution.



Source: Joint Research Centre

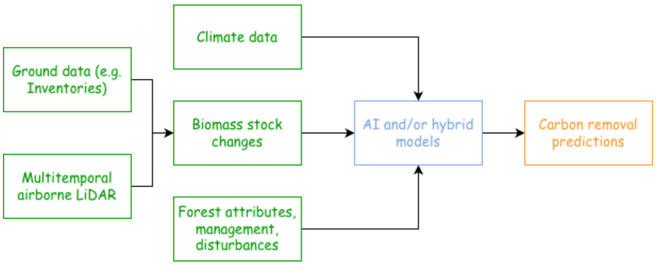
For MRV in forests, new developments in computing and AI, together with light detection and ranging (LiDAR) technology and/or satellite observations, are opening opportunities for high resolution mapping of forest attributes and biomass stock changes (Figure 4). Developing MRV for forests requires integrating advanced Earth observation data (e.g., satellite imagery, LiDAR, drones, and in situ networks like the National Forest Inventory) with AI to improve mapping and track critical forest parameters. For effective MRV it is key to narrow down the uncertainty in monitoring forest biomass and forest biomass stock changes, net annual increment, forest disturbances, forest management and forest biodiversity. Despite progress made in the field, it is still necessary a better algorithmic transparency, standardization and timeliness in data collection, including the release of high-resolution products to develop more robust and flexible hybrid models for the prediction of carbon removals in forests.

Figure 4 – Example of a reconstruction of forest area and height changes using multitemporal airborne LiDAR scan (ALS). The orange area in the right panel represents the area that experience a substantial change in tree height (for instance as consequence of afforestation). From multitemporal ALS is possible to estimate changes in forest cover, height and derive biomass stock at high resolution and with an accuracy in line with MRV requirements.



Source: Joint Research Centre, modified from [11]

Figure 5 – Schematic representation of a MRV workflow based on ground data (either from inventories or estimated from LiDAR) and modelling approach. Green boxes represent the training/predictor datasets, blue box the modelling approach; orange box is the expected output. The approach based on AI is preferable for monitoring stock changes. For scenarios, hybrid models (combination of AI and process models) shall be preferred for a better temporal extrapolation capacity.



Source: Joint Research Centre

Table 1 – Schemes of pillars and developments needed.

Pillars	Developments needed
Data	• High resolution Earth Observation data on vegetation properties • Harmonized and high resolution annual maps of past and present management and carbon farming activities • Water table depth at high resolution • Maps of natural disturbances • Farm activity data
Technology	• Empowering AI into process-based models for better prediction of disturbance and management on carbon removals • AI-based quantification tools that integrate earth observation and ground data • Incorporation of new mechanisms of soil organic carbon formation and stabilization into mechanistic models
Scalability	• Models flexibility across spatial scales; • Data harmonization/standardization of input and output • Scalable IT infrastructure
Predictability	• Improving scenarios for land use and climate change, and natural disturbances scenarios, for better carbon removals quantification tools • Accounting for land-climate feedback including extreme event and possible tipping points Better parameterization of disturbances in forest models

Conclusion

Large deployment of an EU voluntary C market requires trustable and highly quality credits. The CRCF is aiming for that, but a major challenge still lays on the inherently variability of the C cycle and, hence, the trade-off between monitoring, quantification accuracy and cost. The time is mature for a new generation of MRV systems. There is a huge amount of data not fully accessible or needed of being harmonised, which can be the basis for training AI algorithm or process-based model calibration. The latter can assimilate new observations (typically remote sensing) improving their predictions in time. While there are multiple EU policies operating on land, biogeochemical cycles are the same across policies. Definitely, this new MRV systems can facilitate the alignment of the policies in terms of monitoring, impact quantification and targets.

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