

EUSO annual report 2024

Providing data and knowledge to monitor, safeguard and restore soils

Broothaerts, N., Panagos, P., Arias Navarro, C., Ballabio, C., Belitrandi, D., Breure, T., De Medici, D., Fendrich, A., Havenga, C., Liakos, L., Martin Jimenez, J., Michailidis, V., Orgiazzi, A., Scarpa, S., Schillaci, C., Vieira, D., van Eynde, E., van Liedekerke, M., Wojda, P., Yunta, F., Jones, A.

2025



This document is a publication by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The contents of this publication do not necessarily reflect the position or opinion of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither European to other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Contact information

Name: Arwyn Jones Address: European Commission Joint Research Centre, Sustainable Resources, Via Fermi 2749, 21027 Ispra (VA), Italy Email: Arwyn.jones@ec.europa.eu Tel.: +39 0332 789162

EU Science Hub

https://joint-research-centre.ec.europa.eu

JRC141262

EUR 40246

PDF ISBN 978-92-68-25267-3 ISSN 1831-9424 doi:10.2760/9304175

KJ-01-25-153-EN-N

Luxembourg: Publications Office of the European Union, 2025

© European Union, 2025



The reuse policy of the European Commission documents is implemented by the Commission Decision 2011/833/EU of 12 December 2011 on the reuse of Commission documents (OJ L 330, 14.12.2011, p. 39). Unless otherwise noted, the reuse of this document is authorised under the Creative Commons Attribution 4.0 International (CC BY 4.0) licence (<u>https://creativecommons.org/licenses/by/4.0/</u>). This means that reuse is allowed provided appropriate credit is given and any changes are indicated.

For any use or reproduction of photos or other material that is not owned by the European Union permission must be sought directly from the copyright holders.

- Cover page illustration, © AdobeStock_360175483

How to cite this report: European Commission: Joint Research Centre, Broothaerts, N., Panagos, P., Arias Navarro, C., Ballabio, C., Belitrandi, D., Breure, T., De Medici, D., Fendrich, A., Havenga, C., Liakos, L., Martin Jimenez, J., Michailidis, V., Orgiazzi, A., Scarpa, S., Schillaci, C., Vieira, D., van Eynde, E., van Liedekerke, M., Wojda, P., Yunta, F. and Jones, A., *EUSO annual report 2024*, Publications Office of the European Union, Luxembourg, 2025, https://data.europa.eu/doi/10.2760/9304175, JRC141262.

Contents

Abstract		3	
Acknowledge	ements	4	
Executive su	immary	5	
1 Introduct	ion	8	
1.1 The	EU Soil Observatory and its policy context	8	
1.2 Obje	ectives of the EU Soil Observatory	9	
2 Activities	Activities and outcomes of the EU Soil Observatory in 2024		
2.1 Polic	2.1 Policy support		
2.1.1	Supporting the proposed Soil Monitoring and Resilience Directive		
2.1.2	Supporting the Carbon Removal Certification Framework		
2.1.3	Supporting the Mission Soil		
2.1.4	The state of soils in Europe report		
2.1.5	Other policy support		
2.2 EU-v	vide soil monitoring		
2.2.1	LUCAS Soil Module 2022		
2.2.2	Stratified sampling for soil monitoring	20	
2.2.3	Transfer functions	21	
2.2.4	Operational data flows for new data streams	21	
2.3 Mon	itoring soil health and soil policies	22	
2.3.1	The EUSO Soil Degradation Dashboard	22	
2.3.2	Monitoring EU soil policy actions	25	
2.4 Enha	ancing the functionality of the European Soil Data Centre	26	
2.4.1	New datasets	26	
2.4.2	ESDAC performance in 2024		
2.5 Supp	porting soil research and innovation		
2.5.1	Research at the EUSO		
2.5.2	Interaction with Mission Soil funded projects	40	
2.5.3	Interaction with Horizon 2020 projects	42	
2.6 Supp	porting stakeholder interactions and citizen engagement	43	

	2.6.1	EUSO Stakeholders Forum	43
	2.6.2	Young Soil Researchers forum	
	2.6.3	European Mission Soil Week	
	2.6.4	Other activities to support stakeholder interactions and citizen engagement	
3	Working	Group activities	
	3.1 WG	Soil erosion	
	3.2 WG	Data sharing and integration	
	3.3 WG	Soil pollution	
	3.4 WG	Soil monitoring	56
	3.5 WG	Soil biodiversity	57
	3.6 WG	Soil organic carbon monitoring, reporting and verification	57
	3.7 WG	Nutrients	58
4	Planned (developments for the EUSO in 2025	60
4.1 Policy support			
	4.2 EU-v	vide soil monitoring	61
	4.3 Mon	itoring soil health and policies	
	4.3.1	EUSO Soil Degradation Dashboard	
	4.3.2	EU Soil Health Portal	63
	4.3.3	EUSO Soil Policy Actions Tracker	
	4.3.4	African Soil Health Dashboard	
	4.4 Enha	ancing the functionality of the European Soil Data Centre	
	4.5 Supp	4.5 Supporting soil research and innovation	
	4.6 Supp	porting stakeholder interactions and citizen engagement	
5	Conclusio	ns	67
Re	eferences		
Li	List of abbreviations and definitions		
Li	List of boxes		
Li	st of figure	25	
Li	List of tables		

Abstract

Healthy soils are essential for providing healthy food and achieving climate neutrality. The publication of the EU Soil Strategy for 2030, the proposed Soil Monitoring and Resilience Directive and the Mission Soil marked major milestones for soil protection and restoration in the EU. Given this context, the EU Soil Observatory (EUSO) aims to be the principal provider of knowledge and data on soils at the EU-level and to underpin EU policies related to soils. This report highlights the main activities and outcomes of the EUSO in 2024. During this period, the EUSO provided policy support to a wide range of soil related areas, including the proposed Soil Monitoring and Resilience Directive, the Carbon Removal Certification Framework and the Mission Soil. A highlight was the launch of the science for policy report 'The state of soils in Europe', in collaboration with the European Environment Agency, providing an in-depth examination of the pressures affecting soils across Europe. Furthermore, the EUSO updated its Soil Degradation Dashboard and launched a novel EU Soil Strategy Actions Tracker. The latter shows that almost 70% of the policy actions listed in the EU Soil Strategy for 2030 are completed. Next, the European Soil Data Centre, the leading web platform for sharing data and knowledge about EU soils, has grown significantly with 15 new datasets and a 20% increase in requests for datasets. Additionally, the EUSO contributed directly to advanced scientific knowledge on soils with the publication of 47 scientific papers, 10 technical reports, and 3 science-for-policy reports. Finally, the EUSO organised and contributed to activities to support stakeholder interactions and citizen engagement regarding soils. Highlights include the fourth EUSO Stakeholders Forum, the second Young Soil Researchers Forum, the European Mission Soil Week and the activities of the EUSO Working Groups. During 2025, the EUSO will continue to be the principal provider of soil-related data and knowledge while supporting the implementation of EU policy objectives in relation to soils.

Acknowledgements

This work was jointly realised by the EUSO Project under the JRC's Institutional Work Programme 2024-2025 and the Administrative Arrangement JRC No 36283-2022 [AGRI-2022-0253, RTD LC-1158189]: Provision of scientific and technical support to DG AGRI and RTD in relation to the implementation of the soil monitoring tasks of Horizon Europe Mission "A Soil Deal for Europe".

The EUSO is thankful to all their stakeholders for the collaborations and interactions.

Authors

Broothaerts, N., Panagos, P., Arias Navarro, C., Ballabio, C., Belitrandi, D., Breure, T., De Medici, D., Fendrich, A., Havenga, C., Liakos, L., Martin Jimenez, J., Michailidis, V., Orgiazzi, A., Scarpa, S., Schillaci, C., Vieira, D., Van Eynde, E., Van Liedekerke, M., Wojda, P., Yunta, F., Jones, A.

Executive summary

This report highlights the main activities and outcomes of the **EU Soil Observatory (EUSO)** from 2024. It also presents planned activities and developments to be expected in 2025.

Policy context

Healthy soils are essential for achieving climate neutrality, providing healthy food and halting the loss of biodiversity. The publication of the **EU Soil Strategy for 2030** and the proposed **Soil Monitoring and Resilience Directive** (SMRD) marked major milestones for soil protection and restoration in the EU. In addition, the Mission 'A Soil Deal for Europe' (**Mission Soil**) supports the EU's ambition on soil health.

Given this context, the main objective of the EUSO is to provide the European Commission and other relevant stakeholders with the knowledge and data needed to monitor, safeguard and restore soils at the EU-level.

EUSO's activities and outcomes in 2024

Through its activities in 2024, the EUSO (1) supported a range of soil-related policies, (2) supported a EU-wide soil monitoring system, (3) contributed to the monitoring of soil health and policies, (4) contributed to sharing data and knowledge on EU soils, (5) supported soil research and innovation, and (6) supported stakeholder interactions and citizen engagement regarding soils (**Figure 1**):

- 1. The EUSO provided **policy support** to a wide range of soil related areas. This includes the proposed SMRD, the Carbon Removal Certification Framework, and the Mission Soil. Another highlight was the launch of the science for policy report 'The state of soils in Europe'.
- The EUSO coordinated the LUCAS Soil Module, the only **EU-wide** harmonised and regular soil survey currently available. In 2024, the EUSO published the call for tender for the laboratory analysis of the soil samples collected during the 2022 LUCAS Soil Survey. Complete results are expected in 2026. In addition, the EUSO proposed a stratified sampling method for soil sampling and developed new transfer functions.
- 3. The EUSO Soil Degradation Dashboard was updated in 2024. It is a unique tool to monitor and report on the state of soil degradation at the EU-level, showing that ca. 60% of the EU-soils are currently degraded. In addition, the EUSO published the EU Soil Strategy Actions Tracker, showing that almost 70% of the actions listed in the EU Soil Strategy for 2030 are completed.
- 4. The **European Soil Data Centre (ESDAC)**, a core part of the EUSO, has become the leading web platform for sharing data and knowledge about EU soils. ESDAC has grown significantly in 2024, with 15 new datasets and a 20% increase in requests for datasets.
- 5. In **support to soil research and innovation**, the EUSO contributed directly to advanced scientific knowledge on soils in the EU by publishing 47 scientific papers and 10 technical reports. Furthermore, the EUSO was actively involved in the soil monitoring elements in the Mission Soil and worked closely with numerous Mission Soil funded projects.
- 6. In 2024, the EUSO organised and contributed to activities to support stakeholder interactions and citizen engagement regarding soils. Highlights include the 4th EUSO Stakeholders Forum, the 2nd Young Soil Researchers Forum and the EU Mission Soil Week.

Working group activities in 2024

The **Working Groups** (WGs) are a key element of the EUSO. These WGs consists of relevant experts from academia, business and policy, and aim to advance the knowledge and data on a specific aspect of EU-soils. In 2024, seven working groups were active: (1) WG Soil erosion, (2) WG Data sharing and integration, (3) WG Soil pollution, (4) WG Soil monitoring, (5) WG Soil biodiversity, (6) WG Soil organic carbon monitoring reporting and verification, and (7) WG Nutrients. The latter WG was launched in 2024.

Activities included advancing scientific knowledge, stimulating technical advances and integration of data, and providing policy support. The main platform for interaction was the fourth **EUSO Stakeholders Forum**, bringing together WG members, soil scientists, policy makers, and interested citizens. The Stakeholders Forum of 2024 had almost 800 participants.

Planned developments for the EUSO in 2025

Also in 2025, the EUSO will continue to provide reference data and knowledge at EU-level for all matters related to soils to underpin EU policy development and implementation. Activities will also be aligned with the European Commission's priorities for 2024-2029, such as competitiveness and sustaining our quality of life. Highlights of the planned activities are listed below:

- 1. The EUSO will further support EU **soil-related policymaking**, including the implementation of the proposed SMRD, the Mission Soil, the EU declaration as being affected by desertification, the standardised baseline for carbon farming, and the Spatial Agricultural Information System interoperability platform.
- 2. Related to the **EU-wide soil monitoring**, the EUSO will adapt the current LUCAS Soil Module's approach to match the needs of the SMRD. In addition, the EUSO will process first results of the lab analysis of the LUCAS Soil Module 2022.
- 3. The EUSO will start the development of a new **EU Soil Health Portal**, as proposed by the SMRD. Discussions will also focus on a new soil pollution dashboard and watch list.
- 4. The EUSO will take further steps to enhance the capacity and functionality of the **ESDAC** and to consolidate its position as the one-stop-shop for soil related data in the EU and beyond. ESDAC 3.0 will be built, to integrate data from Member States, Mission Soil funded projects and novel data streams such as drones, precise agriculture and citizen science.
- 5. The EUSO will continue to support **soil research and innovation**, by in-house scientific research and collaboration with Mission Soil funded projects. The latter will be organised through bilateral meetings and the Mission Soil Cluster meetings.
- 6. Finally, the EUSO will continue to **engage with stakeholders** on soil-related topics and will bring together these stakeholders within the Working Groups and during the EUSO Stakeholders Forum and the EU Mission Soil Week in 2025.

EU Soil Observatory (EUSO) highlights 2024



Source: JRC analysis.

1 Introduction

1.1 The EU Soil Observatory and its policy context

Healthy soils are essential for our environment and society, as soils deliver crucial ecosystem services such as prevent droughts and floods, mitigate climate change and ensure food security. However, it is estimated that currently more than 60% of the soils in the EU are affected by one or more soil degradation processes and thus affecting the functioning of the soils (Panagos et al., 2024b). The European Green Deal has highlighted the crucial aspects of soils and soil protection and restoration and turned the spotlight on the vital role of soils in achieving several objectives of the Green Deal, including climate change, halting the loss of biodiversity or achieving zero pollution. Soil-related targets are found in many of the strategies published as part of the European Green Deal, such as the EU Biodiversity Strategy for 2030, the Farm to Fork Strategy, the Zero Pollution Action Plan, and the Fit for 55 Package.

Furthermore, the publication of the <u>EU Soil Strategy for 2030</u> in November 2021, and the proposal for a <u>Soil Monitoring and Resilience Directive (SMRD)</u> in July 2023 marked a major milestone for soil protection in the EU. In parallel, the Horizon Europe research programme (2021-2027), includes a mission on soils. Entitled '<u>EU Mission: A Soil Deal for Europe</u>' (Mission Soil), this mission is expected to significantly advance the state of knowledge and data available on soils in the EU and beyond. These soil related strategies are aligned with the <u>EU Strategic Agenda for 2024-2029</u> and the <u>Commission's priorities for 2024-2029</u>.

The EU Soil Observatory (EUSO) was launched in December 2020 as part of the European Green Deal. The EU Soil Observatory (EUSO) aims to be the principal provider of soil-related data and knowledge at the EU-level and to support EU policymaking related to soils. The EUSO is hosted within the Joint Research Centre (JRC) of the European Commission, Directorate D (Sustainable resources), Unit D.3 (Land Resources and Supply Chain Assessments). The EUSO is an inclusive and dynamic platform that supports EU soil-related policymaking that provides the relevant Commission Services and relevant stakeholders with the knowledge and data flows needed to monitor, safeguard and restore soils at the EU-level. Furthermore, the EUSO supports EU Research and Innovation on soils and aims to raise societal awareness of the value and importance of soils to the lives of citizens. Active for four years now, the EUSO plays a key role in supporting soil policy development, monitoring the state of soil health, supporting and interacting with research activities, supporting stakeholder interactions and raising citizens' awareness of the need for soil protection.

This report presents the activities of the EUSO that have taken place in 2024 and highlights the main messages drawn from these activities. The report also shortly discusses the planned developments and activities for the EUSO in 2025.

1.2 Objectives of the EU Soil Observatory

The vision of the EUSO is to be the principal provider of knowledge and data on soils to underpin EU policy development and implementation. To achieve this goal, the following objectives has been defined (**Figure 2**):

- 1. Supporting policymaking related to soils.
- 2. Supporting the development of an operational **EU-Wide Soil Monitoring System**.
- 3. **Monitoring** the state of soil health and the policies in place to enhance soil protection, through a **Soil Degradation Dashboard and Soil Policy Actions Tracker**.
- 4. Consolidating and enhancing the capacity and functionality of the **European Soil Data Centre (ESDAC**).
- 5. **Supporting soil research and innovation** through the implementation of Horizon Europe's Mission 'A Soil Deal for Europe'.
- 6. Providing an open and inclusive Forum that supports **stakeholder interactions and citizen engagement** and the drive towards a societal change in the perception of soil.



Figure 2. The main objectives of the EU Soil Observatory.

Source: JRC analysis.

2 Activities and outcomes of the EU Soil Observatory in 2024

2.1 Policy support

2.1.1 Supporting the proposed Soil Monitoring and Resilience Directive

One of main EUSO's tasks for the past year was the support to the legislative process of the proposed <u>Soil Monitoring and Resilience Directive (SMRD)</u>. In April 2024, the European Parliament adopted its first reading position while the Council adopted its position in June 2024. Subsequently, the trialogue process began under the Hungarian Presidency during the autumn months.

The EUSO intensively supported the Directorate-General for the Environment (DG ENV) in discussions with the European Parliament and the Belgian Presidency leading up to the Council General Agreement. A series of weekly meetings with experts from the Working Party on the Environment (WPE), were established to help Member States evaluate different options for the proposed sampling design for the SMRD. The LUCAS Soil approach was presented to a meeting organised by EJP Soil and the Permanent Representatives from Sweden and Finland for WPE while targeted interventions were made on possible soil biodiversity indicators and thresholds. Collectively, the EUSO, replied to numerous questions from Member States and DG ENV on technical aspects of the SMRD (e.g. data access and privacy issues, indicator selection and thresholds). This support continued under the Hungarian Presidency.

To support the implementation of the SMRD, the EUSO started working in December 2024 on a new Administrative Agreement to

- Upgrade the ESDAC to integrate the results of Member States soil monitoring programmes, as well as outcomes from other sources, into a common digital soil health data portal, to develop innovative soil-related EU level assessments. This task is done in coordination with the European Environmental Agency (EEA) who are designing and implementing the reporting data flows.
- Upgrade the LUCAS Soil Module to comply with the SMRD's requirements, including ensuring delivery of results in line with legal timetables,
- Build on the EUSO Soil Degradation Dashboard to reflect the requirements of the EU Digital Soil Health Data Portal,
- Provide support, in coordination with the EEA, to guide and help Member States implementing the SMRD including guidance documents to Member States.

Progress on these tasks will be reported in the 2025 Bulletin.

2.1.2 Supporting the Carbon Removal Certification Framework

The increase of atmospheric carbon removal in biogenic pools, such as soil, has been proposed to mitigate climate change and improve food security. In the EU, operative policy instruments to increase the land carbon sink are new atmospheric carbon dioxide (CO₂) removal targets in the land use, land use change and forestry (LULUCF) regulation as well as the recent <u>Carbon Removal</u> <u>Certification regulation</u> (including carbon farming targets). The Carbon Removal Certification Regulation foresees payment for the voluntary implementation of practices. Where improvement in

the land carbon sink as a result of alternative management practices is quantified against a standardised baseline.

In the case of agricultural mineral soils, the standardised baseline is represented by the change of soil organic carbon (SOC) stock. Herbaceous vegetation pools have a short-turnover and what is incorporated into the soils is already part of the SOC budget. The EUSO has supported the administrative agreement with Directorate-General for Climate Action (DG CLIMA) on developing a proposal for an EU standardised baseline. The standardised baseline represents average regional emissions/removal of CO₂ over a homogenous region (i.e. it should not be confounded with a project-specific baseline in the parcel/land applying for the certification). Some Member States (MS) may have high tier methodologies in place under their Greenhouse Gas Inventory (GHGI), with wall-to-wall estimates of SOC changes that can be directly used by operators for this purpose (if made available). However, given the disparity of conditions across MS, a standardised methodology should be developed that is consistent between GHGI accounting and carbon farming activities quantification. The methodology can also generate new data and methods that can be taken up by MS for increasing their tier approaches.

In this context, the JRC has worked on two separate approaches (**Figure 3**). The first consists of refining the statistical model to calculate SOC changes in agricultural soils (De Rosa et al., 2024) by: i) the use of a different statistical model and comparison with machine learning approaches, and ii) inclusion of other drivers that can better explain changes in SOC such as soil cover, secondary crop presence and tillage. The second approach consists of metamodel development based on simulations of the biogeochemical process-based model DayCent. These are large scale simulations that quantify carbon and nitrogen dynamics within the soil and the exchange between soil, atmosphere, and vegetation. The rationale behind the metamodel is to reproduce the output layers from DayCent simulations by training a statistical model on the same input variables that have been used for DayCent implementation. Formulating a metamodel serves as an approximation method for the computationally intensive DayCent simulations. Consequently, it is more flexible in case alternative data sources are available. For example, high resolution maps of SOC on MS level. The two approaches can be combined to create an ensemble estimate.

The JRC hosted a workshop on carbon farming in early October 2024 where the main idea was to bring the main actors involved in developing the standardised baseline methodology together: These included DG CLIMA and JRC, as well as the MARVIC and MRV4SOC projects funded under the Soil Mission. The JRC methodology was applied to six case-study areas that were selected to align with the work of the MARVIC and MRV4SOC projects, which are also developing methodologies for defining a standardized baseline on local and regional scales. The case-study sites were selected so that they covered the variety of agricultural and pedo-climatic conditions across the EU. The main aim of the exercise was to agree on a roadmap to improve the current proposal for an EU standardised baseline.

Figure 3. Framework for a standardised baseline development from repeated LUCAS soil samples that were used to train a regression model (upper panel) and a meta-model built upon DayCent pan-European simulations (lower panel), both extrapolated at a regional scale (EU-wide ensemble approach).



Source: JRC analysis.

2.1.3 Supporting the Mission Soil

The Mission 'A Soil Deal for Europe' (Mission Soil) supports the EU's ambition on soil health and sustainable land management. The Mission Soil aims to establish 100 Living Labs and Lighthouses to co-create, test and pioneer innovations for soil health, next to advancing the knowledge on healthy soils. Moreover, the Mission Soil is supporting the development of a harmonised framework for soil monitoring in Europe. In this context, the EUSO is providing scientific and technical support to the Directorate-General for Agriculture and Rural Development (DG AGRI) and the Directorate-General for Research and Innovation (DG RTD). This support mainly relates to the soil monitoring activities set out in the Mission Soil Implementation Plan.

Key outcomes and relevant activities of this scientific and technical support to the Mission Soil includes:

— A robust **indicator framework** for soil health in the EU, consisting of nineteen soil degradation indicators and their thresholds (Broothaerts et al., 2024). These indicators represent the main soil degradation processes in the EU and provide a perspective on the state of soil health at the EU-scale (Panagos et al., 2024b). The indicator framework is discussed in the report <u>a proposal for soil health indicators at EU-level</u> and in a <u>scientific publication</u>.

- The <u>EUSO Soil Degradation Dashboard</u> presents these soil degradation indicators and monitors the state of soil degradation in the EU. The dashboard shows that, based on the proposed indicators, thresholds, and the available datasets, more than 60% of EU soils are currently experiencing degradation processes (see also section 2.3.1).
- A review of existing tools for citizen science research on soil health identified a need for the development of standardised, user-friendly and cost-effective methodologies to generate soil data. The review also showed that engagement of citizens can be facilitated through protocols for providing feedback on their scientific contribution and supporting participants. This is published in the report <u>a review of existing tools for citizen science research on soil health</u>.
- The EUSO contributed to the drafting of the <u>Mission Soil Work Programme for 2024</u>. This included leading the preparation of calls for proposals on soil erosion, nitrogen fluxes, soil health in Africa, while contributing to the drafting of other calls, such as on carbon farming and peatland assessments. Proposals are asked to develop route towards open access, longevity, sustainability and interoperability of knowledge through close collaboration with EUSO.
- Co-organizing the European Mission Soil Week (EMSW), held on 12-13 November 2024 in Brussels. The EMSW is an annual event aimed at promoting the Mission Soil, raising awareness about soils, and driving action to protect and restore soils (see also section 2.6.3).
- Providing technical support to soil monitoring activities, through discussions and exchanges between Member States, the European Environmental Agency, EJP Soil and academia.
- Supporting the delivery of data from national monitoring programmes into the EUSO and the
 integration of data streams from LUCAS Soil, citizen science projects and Earth Observation.
 This includes operating the EUSO Working Group on Data Sharing, and collaborating with the
 SoilWise project to achieve the goal of EUSO functioning as the repository of Mission Soil
 outputs and outcomes.

2.1.4 The state of soils in Europe report

The science for policy report '<u>The state of soils in Europe</u>' (Arias-Navarro et al., 2024), published in 2024, is a major milestone in soil assessment, providing an in-depth examination of the state of soils across Europe (**Figure 4**). Coordinated by the JRC and the European Environment Agency (EEA), this report synthesises the latest scientific knowledge, soil monitoring data, and policy developments to present a comprehensive overview of soil condition in Europe. It covers the 32 EEA member countries and the six collaborating nations of the Western Balkans, together with Ukraine and the United Kingdom.

This assessment was made possible by the commitment and voluntary contributions of nearly 100 leading soil scientists from across Europe and beyond, representing key research institutions, universities, and policy advisory bodies. Stakeholders of the EUSO, including experts from the European Environment Information and Observation Network (EIONET), played a crucial role in shaping the report. Their collaborative efforts ensured a multidisciplinary approach that bridges science, policy, and land management practices.





Source: Arias-Navarro et al., 2024.

The report shows that Europe's soils serve as the foundation for a multitude of ecosystem services that are essential for human well-being and environmental sustainability. However, several degradation processes are threatening their capacity to provide these services. The report highlights key challenges, including:

- Nutrient imbalances and acidification, which affect soil fertility and agricultural productivity.
- Organic carbon loss, particularly in mineral soils and peatlands, reducing carbon sequestration potential.
- Peatland degradation, which contributes to greenhouse gas emissions and biodiversity loss.
- Soil erosion and compaction, affecting water regulation, soil structure, and plant growth.
- Pollution and salinization, which reduce soil quality and threaten food security.

Addressing these challenges requires a coordinated effort to understand the underlying drivers of soil degradation and implement effective management strategies. The report emphasises the need for integrated soil policies, improved monitoring frameworks, and the promotion of sustainable land-use practices to safeguard soil health for future generations.

By offering a data-driven, policy-relevant analysis of soil health, the state of soils in Europe report serves as a key reference for researchers, policymakers, and land managers working toward more sustainable soil governance in Europe and beyond.

To support the dissemination of the report's main outcomes, a series of thematic posters have been developed based on the report's key findings (**Figure 5**). The posters can be accessed at the following <u>link</u>.



Figure 5. Thematic posters developed based on the key findings of the state of soils in Europe report.

Source: JRC analysis. Image courtesies of (clockwise) Iban Amextoy, Juanita Degenaar, Tom Fisk off Pexels, Adobe Stock, and Adobe stock.

2.1.5 Other policy support

2.1.5.1 Zero pollution monitoring and outlook

The EUSO contributed to the <u>second edition of the Zero pollution monitoring and outlook</u> (ZPMO) report, which was prepared jointly by the EEA and the JRC.

Pollution across different sectors continues to pose a significant threat to ecosystems, the economy and public health. The European Green Deal, and particularly the zero pollution action plan, have modernised and expanded the EU's pollution-combatting regulatory framework. This second edition provides a comprehensive, up-to-date overview of pollution reduction efforts across different sectors.

Soil pollution in the EU is characterised by an extensive set of historic pollution (brownfields) as well as the impact of current polluting activities including waste, industry, mining, certain agricultural practices and others. Soils have the capacity to filter substances, thereby protecting crops, water quality and human health and provide the physical grounds for many human activities. However, contaminated soils affect food safety; 21% of EU agricultural soils, for example, have high cadmium levels as well as copper and zinc levels that exceed limits.

Finally, the two main topics were further developed in the ZPMO report, notably: heavy metals and pesticides in soils. Nevertheless, the soil pollution in the EU is poorly quantified compared to pollution in other media such as air and water. Consequently, the limited research linking soil contamination to human health relies on case studies from specific local populations, tackling merely a subset of contaminants – specifically, metals and pesticides – within the broader spectrum of soil pollutants found in the EU (Vieira et al., 2024).

In conclusion, with an increased investments from the EU in the Mission Soil and new perspectives offered by the legal proposal for the Soil Monitoring and Resilience Directive, more knowledge and data will be available in the upcoming years.

2.1.5.2 Supporting IACS data sharing

Continued policy support was provided by EUSO in the agricultural data governance realm, proposing methodologies and tools for big-data management through its Spatial Agricultural Information System (SAIS) prototype development. The SAIS project gathers Integrated Administration and Control System (IACS) data from Member States, integrates them with soil, environmental and climate information, allowing for more in-depth policy support and scientific developments.

The SAIS work performed in 2024 was presented at the 7th inter-service meeting on IACS data sharing on 21-22 January 2025 in Brussels, underscoring the competitiveness and data-driven innovation potential of the SAIS project. Key technical and scientific advancements were highlighted by the EUSO team and the JRC Big Data Analytics Platform/Dashboard Team, with in-depth discussions on big-data-management and soil-health-related use-cases. The strong interest expressed by attendees, including representatives from DG AGRI, ENV, CLIMA, EUROSTAT, CNECT, and the EEA, highlights the policy relevance and strategic importance of SAIS, while also setting the stage to explore synergies with the Interoperability project, further enhancing its impact and value proposition.

2.1.5.3 New proposal for a methodology to assess land degradation and desertification

In response to the European Court of Auditors special report n.33 (2018), the EUSO developed a proposal for a new methodology to assess land degradation and desertification that builds on the existing indicator framework for Sustainable Development Goal (SDG) Indicator <u>15.3.1</u> based on three indicators. It includes the analysis of relevant data on land degradation so that they can be regularly presented in a clear and user-friendly way for public use in the form of interactive maps. In this context, the proposed report outlines an updated scientific methodological approach while highlighting areas vulnerable to desertification in the EU. Data limitations restrict the current application of the method to continental EU. However, the method can be applied in all regions as data become available. In line with SDG 15.3.1, the methodology will allow progress towards land degradation neutrality to be tracked.

In summary, the proposed methodology consists of an improvement of the baseline assessment provided by the SDG 15.3.1 framework through a:

- better characterisation of land cover change, through a more relevant nomenclature, increased spatial resolution and a revised transition matrix that assess the impact of change based on biophysical changes in vegetation cover;
- an optimised characterisation of land productivity for the EU;
- replacement of the changes in soil organic carbon stock indicator with a more comprehensive and representative soil degradation indicator (Panagos et al., 2024b);
- application of an aridity threshold to define desertification; and
- identification of areas vulnerable to desertification based on future scenarios for the Aridity Index.

This methodology will be discussed with relevant stakeholders during 2025.

2.1.5.4 Soil fertility in the EU taxonomy for the construction of new buildings

When soils are used for construction, all their ecosystem services are irreversibly lost. The EU taxonomy and its delegated acts specify criteria to screen whether the building of new constructions can be considered environmentally sustainable. One of these criteria is that new constructions are not built on arable and crop land with a moderate to high level of soil fertility, and reference is made to the LUCAS Soil survey. Nevertheless, the data available in LUCAS soil currently do not provide a classification of soil fertility for the EU taxonomy regulation.

In a <u>technical report</u> (Van Eynde et al., 2024), the EUSO presented an overview of national legislations that classify agricultural land for spatial planning purposes, as well as EU and global methods and products (i.e. maps) to classify agricultural land. The advantages and disadvantages of these approaches as potential candidates for the EU taxonomy regulation criterion on soil fertility and new constructions are discussed. Considering recent developments in EU soil policies, the report proposes a new criterion for building new constructions on arable land that is better aligned with the European Commission's ambition of reaching no net land take by 2050.

2.1.5.5 Sustainable development in the European Union — Monitoring report on progress towards the SDGs in an EU context — 2024 edition

The EUSO developed and updated the Soil Erosion Indicators to assess the progress towards the implementation of the Sustainable Development Goals (SDG) 2 and 15. The analysis and the indicators have been made available to EUROSTAT and DG ENV who are compiling the Sustainable development in the <u>EU Flagship Report</u>. The JRC and EUSO provide the updates on this indicator that fits both in SDG2 and SDG15. The work of the EUSO shows that efforts to address and mitigate soil erosion by water helped to reduce the estimated EU land area at risk of severe soil erosion (soil loss of more than 10 tonnes ha⁻¹ yr⁻¹) by water from 198 607 km² in 2010 to 196 853 km² in 2016, equalling an average annual decrease of 0.1%. The improvements due to the implementation of agro-environmental standards required under the Common Agricultural Policy (CAP) may have helped to reduce the mean rate of soil loss by water erosion. The 2024 edition refers to all erosion processes, including water, tillage, wind and crop harvesting.

2.1.5.6 The global distribution of human-induced land degradation and areas at risk

The report "<u>The global distribution of human-induced land degradation and areas at risk</u>" provides new information on the status of land, soil and water resources, and evidence of the changing and alarming trends in resource use. The EUSO contributed to the chapter 2.4 "Trends" and 4 "Spatial relation between land degradation and areas at risk, and land cover". In the acknowledgements, JRC is mentioned with the contributing staff for providing data, knowledge and useful revisions for the development of the report.

2.1.5.7 Soil Organic Carbon Indicator to support the performance monitoring and evaluation framework of the Common Agricultural Policy (CAP 2023-27)

The EUSO provided the relevant soil indicators in the context of Regulation (EU) 2021/2115 of the European Parliament and of the Council establishing rules on support for CAP Strategic Plans. This regulation establishes the performance monitoring and evaluation framework (PMEF), which applies for the CAP from 2023 until 2027. The PMEF supports the shift in policy focus from compliance with rules to performance and results. This new performance-based delivery model uses a set of common performance indicators, which will be used to assess the overall policy performance against CAP objectives. In the new PMEF, the indicators relevant to soil are C.40 "Soil organic carbon in agricultural land" (ex C.41) and C.41 "Soil erosion by water" (ex C.42) are compiled by the EUSO. Supporting evidence available <u>here</u>.

2.1.5.8 Support to the soil-related elements of the Nature Restoration Regulation

In July 2024, the Nature Restoration Regulation was adopted, where the contribution of the EUSO was linked to the restoration of peatlands as well as to organic carbon levels in the soils of croplands and forests. The proposal has clear links with the EU Soil Strategy for 2030 and with the proposed SMRD because terrestrial ecosystems depend on, and interact with, the underlying soils. Specifically, the EUSO will support the implementation of the NRR with work on guidelines on the concept of satisfactory levels and condition of ecosystems.

2.1.5.9 Supporting the Science for Global Gateway and neighbourhood policy, including enlargement

Global Gateway is a flagship EU strategy, driven by the ambition and policy priorities for strengthening the EU's global leadership role, championing international standards and a multilateral, interdisciplinary approach to climate and energy, digital infrastructure, health, transport, education and research. The EUSO contributed to the science for policy report '<u>Status of Environment and Climate in the Western Balkans</u>'. This report provides an up-to-date overview of environment and climate in the Western Balkans. EUSO's contributions highlighted that soils in the Western Balkans are under significant pressures leading to widespread degradation across the region, and that unsustainable land use and management practices have resulted in major threats such as soil erosion, pollution, sealing, and nutrient mismanagement.

The work on the Western Balkans has been supplemented by the publication of three key reports that provide valuable insights into soil pollution, soil monitoring, and data integration in the region. The report on <u>Soil Pollution in the Western Balkans</u> highlights the main sources and impacts of soil contamination, emphasising the need for targeted mitigation strategies. The <u>LUCAS Soil 2015 in the Western Balkans</u>: <u>Overview and analysis of ancillary data</u> report presents an in-depth analysis of ancillary soil data (e.g. climate, topography, land cover and biogeographical zones), contributing to a

better understanding of soil properties and land use in the region and provides a background to the publication of an updated soil database for the Western Balkan Region based on LUCAS Soil Module (planned for 2025). Finally, the report on the <u>Implementation of the Integrated Administration and</u> <u>Control System (IACS) and LUCAS Data Integration Feasibility</u> presents a comprehensive review of IACS and LPIS, focusing on the potential for integrating these systems with soil quality data, exploring how such integration can support the implementation of environmental legislation in the Western Balkans, enhancing agricultural policy and sustainability.

These publications contribute toward strengthening soil governance and sustainable land management in the Western Balkans. The work is part of the JRC project on Environment and Climate in Enlargement and contributes to the Western Balkans Agenda on Innovation, Research, Education, Culture, Youth, and Sports.

2.2 EU-wide soil monitoring

2.2.1 LUCAS Soil Module 2022

The effectiveness of different policies and management practices on soil health can only be assessed by monitoring changes in indicators that capture the condition of soils to supply ecosystem services or the broad range of pressures that disrupt soil functions. The LUCAS Soil Module (**Figure 6**) is currently the only EU-wide mechanism for collecting harmonised data on soil characterisctics. It covers the entire continental territory of the EU, addressing all major land cover types simultaneously, in a single sampling period. Results of the LUCAS Soils survey are available for 2009, 2015 and 2018.

In 2022, the EUSO successfully rolled out the LUCAS Soil Module 2022, which contains a number of new developments, including (i) an increase of the sample size to 41,000 locations, (ii) an updated sampling framework based on predicted soil organic carbon levels, (iii) an increased focus on the Alpine region through the collection of samples above 1,500 m, and (iv) an increased collaboration with soil institutions in Member States, for example, building on the activities of EJP-Soil and LUCASA.

In 2024, a <u>call for tender</u> for the laboratory analysis of the soil samples collected during the 2022 LUCAS Soil Survey was published. The laboratory analyses were organised in three lots: (1) analysing basic soil physical and chemical parameters including the concentrations of metals/trace elements, (2) carry out metabarcoding DNA analysis, and (3) screen soil samples for the residues of active ingredients of plant protection products and to measure their concentrations.

While interim data will become available during 2025, complete results will be published in 2026 as a database and a report. The report will present an overview of the various laboratory analysis and will describe the spatial variability of soil properties by land cover class and a comparative analysis of the soil properties.



Figure 6. Overview of the LUCAS Soil Module.

Source: JRC analysis.

2.2.2 Stratified sampling for soil monitoring

The recently proposed Soil Monitoring and Resilience Directive (SMRD) sees monitoring as core action for ensuring soil protection. An effective strategy for tracking soil characteristics and their temporal variations at the EU level would be required. Such a monitoring programme should be able to assess soil parameters under different land use/land cover scenarios and in response to climate change, with a focus on spatial and temporal aspects. Moreover, the sampling strategy must gather comprehensive data, not just on the physico-chemical properties but also the biological component. To reach this goal, the EUSO proposed a stratified sampling method to meet these requirements, while minimising the cost of sampling. The minimum sampling size is calculated by implementing the Bethel algorithm (Bethel, 1989) with subgroups divided following the methodology of Ballin and Barcaroli (2013). The efficiency of stratification is measured by the extent to which it minimises the cost of sampling sufficient accuracy in estimating the target variables. In this context, it is important to select the independent variables that are most strongly correlated with the target variables, such as soil carbon content, pH, and nitrogen content (Ballin and Barcaroli, 2013). The EUSO's approach was discussed with EU Member States (MS) to verify its applicability and integration with national monitoring schemes.

Considering the proposed SMRD, the EUSO will deepen its interaction with MS to facilitate the exchange of harmonised information about the state of soils and their assimilation at EU level. The goal of the EUSO is to support the establishment of a European harmonised data infrastructure to

integrate pan-European national/regional soil monitoring data as well as legislative reporting obligations. The proposal from the EUSO for an EU wide soil monitoring framework included:

- Unbiased estimation of soil parameters upon which indicators are established
- Optimal coverage of different land cover types driving soil degradation processes
- Optimal coverage of the topographic, climatic, geological and biological variability of factors influencing soil features
- Economical sampling

In this regards the EUSO developed a code for stratified sampling for each Member State, which was then tested by national experts. The code and the procedure were explained in the 4th EUSO Stakeholder Forum. In addition, during the Forum, Belgium, France and Finland presented their national experiences in monitoring programs. <u>Recordings and presentations</u> can be found on the EUSO website.

2.2.3 Transfer functions

A key aspect of harmonisation of soil data, and consequent comparability at EU level and the possibility for integrating national and LUCAS datasets, is the development of "transfer functions" between different soil depths, measurement protocols and sampling methods. Transfer functions are needed to facilitate a smooth transition to a harmonized soil health assessment in the EU. While some knowledge on transfer functions exists, it is limited and not representative of the EU's soil variability. In 2024, the EUSO worked on developing new transfer functions. These transfer functions contribute to a consolidated and harmonized soil monitoring system, benefiting regional, national, and EU policymakers in promoting sustainable land use and soil protection.

2.2.4 Operational data flows for new data streams

The EUSO has launched in 2024 a <u>questionnaire</u> to collect information on the use of airborne-, drone-, or proximal sensors for soil surveys.

Proximal sensing of soils uses sensors placed close to or in direct contact with the soil to measure its properties. This method allows for in situ determination of physical, chemical, and biological properties. Such sensors may use optical, geophysical, electrochemical, and mechanical techniques to measure properties such as soil moisture, nutrient levels, pH, and soil texture. These technologies are widely used in precision agriculture to optimize crop management, monitor soil health, and improve land management practices, soil contamination assessment and archaeological studies. Proximal sensing provides high-resolution data, enabling detailed soil mapping and real-time monitoring.

Drones have become valuable tools in agriculture, particularly for measuring and monitoring plant health. However, there is increasing realisation of their potential to provide detailed and contemporary assessments of soil health. Drones equipped with multispectral scanners can help assess soil properties such as moisture content, organic matter, nutrient levels, soil texture, structure, and composition. These data can help farmers understand soil variability and manage their fields more effectively and aid the roll out of sustainable soil management practices. By integrating drone data with other technologies such as precision agriculture, farmers can more precisely adapt inputs such as water, fertilisers, and pesticides. This will aid soil health while reducing pollution and costs. Drones can also identify areas of soil erosion and compaction, helping farmers take corrective actions to prevent further soil degradation.

Despite increased applications of sensors, there is still a lot of unexplored potential to use sensorderived data for a more complete and cost-efficient monitoring of soil health. For example, the possible integration of data coming from sensors with other data streams (soil sampling surveys, etc.) is still unexplored. Within a policy context, sensor data can be relevant for: i.) monitoring the soil descriptors proposed in the SMRD, and ii.) the soil indicators in the EU Mission Soil Implementation Plan. Collecting information on studies using sensor data, and performing a metaanalysis of these studies, can help to advance soil data integration derived from sensor surveys.

The questionnaire has three objectives. In a first step, to make a database of research studies that have used sensors to collect soil data. In a next step, perform a meta-analysis of these studies to explore the potential of these data flows. Then in a final step, investigate the potential of sensors in monitoring the soil descriptors proposed in the SMRD and the soil health indicators in the EU Mission Soil Implementation Plan. The conclusions will be presented in a publication in 2025.

2.3 Monitoring soil health and soil policies

2.3.1 The EUSO Soil Degradation Dashboard

The aim of the <u>EUSO Soil Degradation Dashboard</u> is to monitor and report the state of soil degradation at the EU-level. The dashboard spatially combines different datasets to highlight the intensity and location of relevant soil degradation processes. As such, the dashboard provides a spatial assessment of where unhealthy soils may be located in the EU and which degradation processes affect them. The resulting map shows, for the first time, where current scientific evidence converges to indicate areas that are likely to be affected by soil degradation (**Figure 7**). The Dashboard consists of four key features. Firstly, a convergence of evidence map indicating the number of soil degradation processes likely to be present (**Figure 7**). Secondly, a gauge indicating the proportion of land likely to be affected by one or more soil degradation processes and soil sealing in the EU (**Figure 7**). Thirdly, a dependency wheel indicating the extent of the overlapping area between pairs of soil degradation processes. And fourthly, statistics and maps of each of the individual soil degradation process.

The EUSO Soil Degradation Dashboard was updated in June 2024. Four new soil degradation processes were added, namely Cadmium excess (Ballabio et al., 2024), Arsenic excess (Fendrich et al., 2024b), Zinc excess (Van Eynde et al., 2023) and post-fire recovery (Vieira et al., 2023a). In addition, the indicator 'Packing density' (Panagos et al., 2024c) replaced the "Susceptibility to soil compaction" indicator. Currently, nineteen indicators, representing the main soil degradation processes, are included (**Table 1**) (Broothaerts et al., 2024) representing the latest state-of-the-art of soil degradation indicators, for which published EU-wide geo-spatial data are available. Due to these changes, the proportion of land likely affected by one or more soil degradation process in the EU is now estimated at 62%, compared to 61% in the first version of the dashboard (version of February 2023, 15 indicators) (Panagos et al., 2024b). The resulting change map (**Figure 8**) shows the location of the new areas in the EU that are now indicated as degraded, due to the addition of the above-mentioned indicators. The change map also shows some area now free from degradation, due to the change in the used indicator for soil compaction (**Figure 8**).

Figure 7. EUSO Soil Degradation Dashboard and its convergence of evidence map (indicating the number of soil degradation processes likely to be present) and speedometer (indicating the proportion of land likely to be affected by one or more soil degradation processes or by soil sealing in the EU).



Source: Panagos et al., 2024a.

With the update in June 2024, new functionalities were added to the EUSO Soil Degradation Dashboard:

- A bar chart showing the percentages of degraded soils per land cover class, both for the convergence of evidence map (Figure 7) and the individual indicators.
- Adjustable thresholds for the soil erosion indicators. Users can change the thresholds to 1 t ha⁻¹ yr⁻¹ (precautionary principle), 2 t ha⁻¹ yr⁻¹ (sustainable baseline, default), 5 t ha⁻¹ yr⁻¹ (high erosion rates), and 11 t ha⁻¹ yr⁻¹ (severe erosion rates).
- The option to display a subset of indicators in the convergence of evidence map. Users can choose to display (i) all soil degradation indicators (19 indicators), (ii) the soil erosion indicators (5 indicators: water erosion, wind erosion, tillage erosion, harvest erosion, post-fire recovery), or (iii) the soil pollution indicators (5 indicators: excess of arsenic, copper, mercury, zinc, and cadmium).

Temporal changes are shown for those indicators for which temporal datasets are available. For the moment, this is the case for the indicator 'water erosion', for which the situation in 2000, 2010 and 2015 is shown. Results show that long-term average erosion rate decreased by 9% between 2000 and 2010, and by 0.4% between 2010 and 2015. This decrease of soil loss is mainly attributed to a limited increase of applied soil conservation practices and land cover change at the EU level (Panagos et al., 2020).

Results from the EUSO Soil Degradation Dashboard show that more than 60% of the EU soils are unhealthy (**Figure 7**). The dashboard also clearly shows that most unhealthy soils are subject to more than one type of soil degradation. The most prevalent types of soil degradation are the loss of soil biodiversity (33% of the EU), soil erosion by water (19% of the EU), and the loss of soil organic carbon (14% of the EU).

Table 1. Soil degradation indicators included in the EUSO Soil Degradation Das	hboard, and their respective
thresholds and data sources.	

Groups of soil	Indicator	Threshold	Reference
degradation			
processes			
Soil erosion	Water erosion	Erosion rate > 2 t ha ⁻¹ yr ⁻¹	Panagos et al., 2020
	Wind erosion	Erosion rate > 2 t ha ⁻¹ yr ⁻¹	Borrelli et al., 2017
	Tillage erosion	Erosion rate > 2 t ha ⁻¹ yr ⁻¹	Borrelli et al., 2023
	Harvest erosion	Erosion rate > 2 t ha ⁻¹ yr ⁻¹	Panagos et al., 2019
	Post fire recovery	Recovery rate < 1	Vieira et al., 2023
Soil pollution	Copper excess	Cu concentration > 100 mg kg ⁻¹	Ballabio et al., 2018
	Mercury excess	Hg concentration > 0.5 mg kg ⁻¹	Ballabio et al., 2021
	Zinc excess	Zn concentration > 100 mg kg ⁻¹	Van Eynde et al., 2023
	Cadmium excess	Cd concentration > 1 mg kg ⁻¹	Ballabio et al., 2024
	Arsenic excess	P(X > 45 mg kg ⁻¹) > 5%	Fendrich et al:, 2024
Soil nutrients	Nitrogen surplus	Agricultural areas where N	Grizzetti et al., 2022;
		surplus > 50 kg ha ⁻¹ yr ⁻¹	Lugato et al., 2018
	Phosphorus deficiency	P deficiency < 20 mg kg ⁻¹	Ballabio et al., 2019;
	Phosphorus excess	P excess > 50 mg kg ⁻¹	Ballabio et al., 2019;
Loss of soil organic carbon	Distance to max SOC level	Distance to max SOC level > 60%	De Rosa et al., 2024
Loss of soil biodiversity	Potential threat to biological functions	≥ Moderately High level of risk	Orgiazzi et al., 2016
Soil compaction	Packing density	Packing density ≥ 1.75 g cm ⁻³	Panagos et al., 2024
Salinization	Secondary salinization risk	Areas in Mediterranean region where >30% is equipped for irrigation	Siebert et al., 2013
Loss of organic soils	Peatland degradation risk	Peatlands under hotspots of cropland	UNEP, 2022
Soil sealing	Built-up areas	No threshold applied (all built-up areas)	Copernicus, 2018

Source: Broothaerts et al., 2024.

Figure 8. Map indicating changes between two versions of the dashboard, i.e. version of February 2023 (including 15 indicators) and version of June 2024 (including 19 indicators).



Source: JRC analysis.

2.3.2 Monitoring EU soil policy actions

The EUSO developed in 2024 a new tool to track the progress of policy actions in the EU Soil Strategy for 2030: the **EU Soil Strategy Action Tracker**. The <u>EU Soil Strategy for 2030</u> sets out a framework and concrete measures to protect and restore soils and ensure that soils are used sustainably. It aims to achieve healthy soils by 2050 with concrete actions by 2030. The EU Soil Strategy Actions Tracker provides an overview on the status of the actions, information on the due date, recent updates, links to related EU policies, links to relevant sources, and the main actors responsible for implementation. As such, it is a starting point to dig deeper in the status and progress of EU soil policy actions.

The <u>Tracker</u> is set up in three levels. At the first level, the EU Soil Strategy Actions Tracker provides a general overview on the status of the actions grouped by each section in the EU Soil Strategy for 2030. At the second level, the Tracker provides an overview of the status of the individual actions within one section of the EU Soil Strategy for 2030. At the third level, the Tracker provides an overview of the individual action, including the status, action details, due date, recent updates, links to related EU policies, links to relevant sources, and main actors. The actions can be filtered by action status. By doing so, only the actions that correspond to the selected status are displayed.

The EU Soil Strategy Action Tracker shows that, currently, 62 out of 90 actions (69%) are marked as completed, 24 actions (27%) as in progress, and 4 actions (4%) as withdrawn (**Figure 9**). The

Tracker provides a clear overview of the progress made by the European Commission under the EU Soil Strategy. With almost 70% of complete actions, the tracker shows that the Commission is well on track to complete most of the actions included in the EU Soil Strategy. Together with the EUSO Soil Degradation Dashboard (see section 2.3.1), it provides an informative overview on EU soil health status and ongoing actions to preserve and restore the state of soils in the EU. The EU Soil Strategy Actions Tracker is the first step towards an EUSO Soil Policy Actions Tracker to monitor all EU policy actions relevant to soils. An update is foreseen for 2025.

Details on the methodology used to develop the Tracker are provided in a technical report.

Figure 9. Summary of the status of the actions included in the EU Soil Strategy for 2030.





2.4 Enhancing the functionality of the European Soil Data Centre

The European Soil Data Centre (ESDAC) is the leading web platform for gathering and disseminating soil related datasets, maps and knowledge in the EU (Panagos et al., 2022). ESDAC is at the core of the EUSO by providing soil data and knowledge, thus supporting policy making and awareness raising related to soils in the EU. EUSO aims to continuously enhance the capacity and functionality of ESDAC.

The <u>ESDAC platform</u> currently hosts 126 datasets, over 6 000 maps, over 500 scientific documents, 7 atlases, and a wide range of soil related material. The ESDAC has grown significantly in 2024, both in terms of content hosted (see 2.4.1) and number of users (see 2.4.2).

2.4.1 New datasets

ESDAC has added 15 new datasets in 2024 (see **Figure 10**). All datasets were accompanied with a scientific publication. These newly added datasets are listed below. These datasets were downloaded already extensively; with some achieving more than 200 downloads in the first year of release (**Figure 11**).

Soil organic carbon losses with lateral transfer to the oceans

A spatially distributed model coupling erosion, transport, and deposition to the carbon cycle was developed and published in Fendrich et al. (2024a). The model was used to simulate the impact of cover crops on both erosion and carbon to show that cover crops can simultaneously increase organic carbon storage and reduce particulate organic carbon export to the oceans. The results

showed that in Europe 1.95 TgC/year of POC were exported to the oceans in the last decade and that the adoption of cover crops can reduce the annual export while increasing SOC storage. In a scenario of widespread adoption, cover crops alone are insufficient to achieve the 4‰ target. Data are available <u>here</u>.

Soil bulk density in Europe

In the LUCAS 2018 soil survey, bulk density was analysed at depths of 0–10 cm and 10–20 cm for around 6 000 points. By applying a Cubist model, a high-resolution map (100 m) of bulk density for the 0–20 cm depth was developed together with individual maps for the 0–10 cm and 10–20 cm layers. The modelling results, as described in Panagos et al. (2024c), show a very good prediction of bulk density for the 0–20 cm depth, which improves previous assessments. The bulk density maps were then used to estimate packing density which is a proxy to estimate soil compaction; to this end, clay content was also used. The full dataset includes these layers in addition to the individual point data measurements of bulk density. Data are available <u>here</u>.

Pesticides residues in European agricultural soils

This dataset contains the results of a study targeting the measurements of residues of the active ingredients of pesticides used as crop protection products in soil samples collected from the 2018 LUCAS survey. This dataset, described by Vieira et al. (2023b), provides the concentrations of 118 substances from 3473 sites. Data are reported at a regional level due to data protection requirements under the EU General Data Protection Regulation. Data are available <u>here</u>.

Land suitability in temperate Europe

Land suitability assessment is an approach to spatially model diverse aspects of soil functions, with the aim to facilitate a sustainable increase in agricultural production, reduce land degradation, or aid climate change adaptation. Compared to the existing datasets, the study of Dornik et al. (2024) provides a higher resolution geospatial assessment of the agricultural land suitability for several crops and land uses in the temperate continental climate across Europe. This dataset includes land suitability maps for several crops and land uses (14 crops, 7 fruit trees, 3 land-use types) in the temperate continental climate of Europe (2.7 million km²). To model the land suitability, geospatial data depicting seventeen eco-pedological indicators (e.g. soil texture, pH, porosity, temperature, precipitation, slope) were used. Data are available <u>here</u>.

Database on Soil health related citizen-science projects

Soil-related citizen science projects have gained significant interest, driven by the increasing prominence of soil within public policy agendas. The EUSO in collaboration with the ECHO Mission Soil project made a review of previous citizen science projects, initiatives and activities with a focus on soil. In this work, over 60 citizen science projects that considered soil health were reviewed. Citizen science projects were collected based on literature search, expert interviews, project partner contributions and through the mailing lists of the European Network for Soil Awareness (ENSA) and the European Soil Data Center (ESDAC). Data are available <u>here</u>.

Arsenic in topsoils

EUSO has developed a new method to model arsenic (As) contamination in EU soils using LUCAS 2009 soil samples. We introduced the GAMLSS-RF model, a novel approach that couples Random Forests with Generalized Additive Models for Location, Scale, and Shape. After fitting and validating a spatial model, we produced EU-wide As concentration maps at a 250 m spatial resolution and evaluated the patterns against reference values. By overcoming limitations in existing databases

and methodologies, the present approach provides an alternative way to handle highly censored data. The methodological approach is published in Fendrich et al. (2024b). The model also consists of a valuable probabilistic tool for assessing As contamination risks in soils, contributing to informed policymaking for environmental and health protection. Data are available <u>here</u>.

Sediments removal costs

As part of the EUSO Working Group on soil erosion, we provide a comprehensive assessment of the existing costs of sediment removal from EU catchments due to water erosion. These quantifications combine continental average and regionally explicit sediment accumulation rates with published remediation costs, integrating numerous figures reported in the grey literature. The study concluded that the cost of removing an estimated 135 million m³ of accumulated sediments due to water erosion only is likely to exceed 2.3 billion euro annually in the EU and UK, with large regional differences between countries. Considering the sediment delivered through all soil loss processes (gullies, landslides, quarrying, among others) through extrapolating measured reservoir capacity losses, the sediment accumulation in the circa 5 000 EU large reservoirs exceed 1 billion m³ with a potential cost of removal ranging between 5 and 8 billion euro annually. Details about both methods can be found in Panagos et al. (2024d). Data are available <u>here</u>.

European Soil Database v2 Raster Library 1kmx1km

This database (2024) is a new set of raster data (GeoTIFF) that have been derived from the <u>European soil database v2</u>, for 71 attributes. The values for the attributes are categorized (non-continuous). These rasters are an interpretation of the data that are contained in the ESDB v2.0. The resolution is 1km. For each GeoTIFF, we also provide the corresponding legend file. Data are available <u>here</u>.

Soil degradation indicators in the EU

We make available the pan-EU assessment of soil degradation based on the 19 latest state-of-theart indicators as demonstrated in the <u>EUSO Soil Degradation Dashboard</u>. Users can now develop maps based on the 19 soil degradation indicators (maps) as provided in the dashboard. The 'convergence of evidence' map in the dashboard shows where scientific evidence converges to indicate areas that are likely to be affected by soil degradation processes. The available dataset contains 20 bands (one per soil degradation indicator plus the combination of all indicators). Before use, it is recommended that users read carefully the documentation associated with the data and the related publication of Panagos et al. (2024b). Data are available <u>here</u>.

Land degradation in Europe

Land degradation is a complex socio-environmental threat, which generally occurs as multiple concurrent pathways that remain largely unexplored in Europe. Here we present an unprecedented analysis of land multi-degradation in 40 countries, using 12 dataset-based processes that were modelled as land degradation convergence and combination pathways in Europe's agricultural environments. The 12 indicators include: water erosion, wind erosion, soil organic carbon loss, l salinization, soil acidification, compaction,soil nutrient imbalances, soil pollution by pesticides and metals, vegetation degradation, groundwater decline and aridity. This dataset includes the Land Multi-degradation Index for arable and agricultural lands and is documented by Prăvălie et al. (2024). Data are available <u>here</u>.

Assessment of the UN land degradation indicator at EU scale

This dataset includes nine maps linked to the assessment of the land degradation indicator at EU scale in the context of the UN Sustainable Development Goal (SDG 15.3.1), and corresponding to the output reported in Schillaci et al. (2023). The main map is the one that expresses land degradation based on the UNCCD approach augmented by soil organic carbon and soil erosion values. Data are available <u>here</u>.

European Hydropedological Data Inventory

The database stems from an initiative from the European Commission Joint Research Centre. In November 2011, leading European soil hydrologists were invited to discuss the possibilities to assemble a comprehensive European Hydropedological Data Inventory (EU-HYDI). The EU-HYDI database contains soil properties with a special focus on hydrological properties. It also includes various other measured soil characteristics associated to the same samples. It can hence serve scientific research and modelling at different scales. The dataset consists of 10 interlinked csv-files. Data are available <u>here</u>.

DNA metagenomes - Antimicrobial resistance

The antibiotic resistance crisis dictates the need for resistance monitoring and the search for new antibiotics. Through an in-depth analysis of the metagenomes of 658 topsoil samples spanning the EU, we explored the distribution of 241 prokaryotic and fungal genes responsible for producing metabolites with antibiotic properties and 485 antibiotic resistance genes. The resulting dataset includes raw DNA sequences for 630 soil samples collected as part of the biodiversity module in the LUCAS 2018 Soil survey. The dataset includes DNA reads annotated as antibiotic resistance and biosynthesis genes revealed in the metagenomes from the 630 soil samples collected during the LUCAS 2018 Soil survey. More information in Dulya et al. (2024). Data are available <u>here</u>.

Clay mineral inventory in soils of Europe

Clay minerals are a key factor in mineral soils as they controll several physical, chemical and biological soil properties. X-ray diffraction analysis has been widely used to identify and quantify minerals in earth science. The aim of the research documented in a recent JRC technical report describes the clay minerals in a subset of 388 soil samples from the LUCAS 2015 Soil survey. The clay fraction (<2 μ m) was separated by sedimentation in distilled water. The data are documented in Yunta Mezquita et al. (2024). Data are available <u>here</u>.

GloRESatE - Global Rainfall Erosivity from Reanalysis and Satellite Estimates

Rainfall erosivity measures the impact of rainfall kinetic energy and intensity or its potential to cause soil erosion. The sparsely available gauge rainfall dataset limits reliable rainfall erosivity assessment globally. Global Rainfall Erosivity from Reanalysis and Satellite Estimates (GloRESatE) is a state-of-the-art dataset with a high spatial resolution of $0.1^{\circ} \times 0.1^{\circ}$. It integrates satellite data, reanalysis data, and observations from 6 170 gauge stations worldwide. Full documentation is provided in Das et al. (2024). It serves as a vital resource for hydrological research, aiding studies in soil erosion, water resource management, and climate change impact assessments on a global scale. Data are available <u>here</u>.



Figure 10. Datasets added to ESDAC in 2024.

Source: JRC analysis and ECHO Mission Soil project.



Figure 11. Number of downloads of the datasets added to ESDAC in 2024.

Source: JRC analysis.

2.4.2 ESDAC performance in 2024

ESDAC responded to 13 980 dataset requests during 2024, which is 20% higher than for 2023 (**Figure 12**). Compared to 2018, the number of ESDAC distributed datasets increased by 150%, whilecompared to 2011 the increase is an order of magnitude. This reflects the continuous increase in interest in soil-related datasets and the role of ESDAC in distributing these datasets.

Around 60% of these datasets were downloaded in an EU Member State. Most data requests came from Italy, China, Germany, Spain, France, United Kingdom and Netherlands, with more than 600 requests each in 2024 (**Figure 13**). Regarding the institutional type of the users, 57% of the distributed datasets were downloaded for use in academia, 16% for use in research organisations, 16% in private companies and 5% in public administration (**Figure 14**). These shares are comparable with the shares in 2023.

The most distributed ESDAC datasets in 2024 were the LUCAS topsoil data of 2018, 2015 and 2009, the European Soil Database v2, and the Global rainfall erosivity database (**Figure 15** and **Figure 16**).

The ESDAC website (<u>https://esdac.jrc.ec.europa.eu/</u>) had over 160 000 visitors and 560 000 page views in 2024. These numbers are comparable to those of 2023 and a doubling of the numbers of 2022. Around 10% of visitors are entering the ESDAC website from other websites, such as LinkedIn. Around 90% of the visitors are desktop users, with an increasing amount of smartphone users.



Figure 12. Trend in ESDAC distributed datasets.

Source: JRC analysis.

Figure 13. Number of ESDAC distributed datasets per country in 2024 (county codes can be found in the list of abbreviations).



Source: JRC analysis.



Figure 14. Number of ESDAC distributed datasets in 2023 according to institutional type.

Source: JRC analysis.





Source: JRC analysis.



Figure 16. Most downloaded ESDAC datasets in 2024.

Source: JRC analysis.

2.5 Supporting soil research and innovation

2.5.1 Research at the EUSO

A key objective of the EUSO is to support research and innovation, and to intensify targeted research, data and monitoring on soils. The EUSO contributes directly to advances in scientific knowledge on soils through its in-house research activities. In 2024, the EUSO team published 47 papers in Scopus-indexed journals (**Box 1**). This includes a paper reviewing <u>how the EUSO is</u> providing solid science to support healthy soils in the EU. The number of papers published in 2024 is comparable to the number in 2023 (i.e. 45), and larger than in 2022 (i.e. 38). In addition, the EUSO team has published 10 JRC technical reports in 2024 (**Box 2**) and 3 science-for-policy reports (**Box 3**).

Box 1. Scopus-indexed journal papers published by the EUSO in 2024. EUSO team members are underlined.

Prăvălie, R., Borrelli, P., <u>Panagos, P., Ballabio, C.</u>, Lugato, E., Chappell, A., Miguez-Macho, G., Maggi, F., Peng, J., Niculiță, M. and Roșca, B., 2024. A unifying modelling of multiple land degradation pathways in Europe. Nature Communications, 15(1): 3862. <u>link</u>

Panagos, P., Broothaerts, N., Ballabio, C., Orgiazzi, A., De Rosa, D., Borrelli, P., Liakos, L., Vieira, D., Van Eynde, E., Arias-Navarro, C. Breure, T., Fendrich, A., Köninger, K., Labouyrie, M., Matthews, F., Muntwyler, A., Martin Jimenez, J., Wojda, P., Yunta, F., Marechal, A., Sala, S., Jones, A., 2024. How the EU Soil Observatory is providing solid science for healthy soils. European Journal of Soil Science, 75(3): 13507. Link
Romero, F., <u>Labouyrie, M.</u>, <u>Orgiazzi, A., Ballabio, C., Panagos, P., Jones, A.</u>, Tedersoo, L., Bahram, M., Guerra, C.A., Eisenhauer, N. and Tao, D., 2024. Soil health is associated with higher primary productivity across Europe. Nature ecology & evolution, 8(10): 1847-1855. <u>link</u>

<u>Ballabio, C., Jones, A. and Panagos, P.,</u> 2024. Cadmium in topsoils of the European Union-an analysis based on LUCAS topsoil database. Science of the Total Environment, 912: 168710. <u>link</u>

McGuire, Luke A., Ebel, B.A., Rengers, F.K., <u>Vieira, D.C.S.</u>, Nyman, P., 2024. Fire effects on geomorphic processes. Nat. Rev. Earth Environ. 5, 486–503. <u>link</u>

Labouyrie, M., Ballabio, C., Romero, F., Panagos, P., Jones, A., Tedersoo, L., van der Heijden, M.G. and <u>Orgiazzi</u>, <u>A.</u>, 2024. Interaction effects of pH and land cover on soil microbial diversity are climate-dependent. Environmental Microbiology, 26(2): 16572. <u>link</u>

Das, S., Jain, M.K., Gupta, V., McGehee, R.P., Yin, S., de Mello, C.R., Azari, M., Borrelli, P. and <u>Panagos, P.</u>, 2024. GloRESatE: A dataset for global rainfall erosivity derived from multi-source data. Scientific Data, 11(1): 926. <u>link</u>

Gholami, H., Mohammadifar, A., Song, Y., Li, Y., Rahmani, P., Kaskaoutis, D.G., <u>Panagos, P.</u> and Borrelli, P., 2024. An assessment of global land susceptibility to wind erosion based on deep-active learning modelling and interpretation techniques. Scientific Reports, 14(1), p.18951. <u>link</u>

Fenta, A.A., Tsunekawa, A., Haregeweyn, N., Yasuda, H., Tsubo, M., Borrelli, P., Kawai, T., Belay, A.S., Ebabu, K., Berihun, M.L. Sultan, D., <u>Panagos, P.</u> 2024. An integrated modeling approach for estimating monthly global rainfall erosivity. Scientific Reports, 14(1), p.8167. <u>link</u>

Dornik, A., Chețan, M.A., Crișan, T.E., Heciko, R., Gora, A., Drăguț, L. and <u>Panagos, P.,</u> 2024. Geospatial evaluation of the agricultural suitability and land use compatibility in Europe's temperate continental climate region. International Soil and Water Conservation Research, 12(4): 908-919. <u>link</u>

Feeney, C.J., Bentley, L., De Rosa, D., <u>Panagos, P.</u>, Emmett, B.A., Thomas, A. and Robinson, D.A., 2024. Benchmarking soil organic carbon (SOC) concentration provides more robust soil health assessment than the SOC/clay ratio at European scale. Science of the Total Environment, 951: 175642. <u>link</u>

<u>Vieira, D.C.S., Yunta, F.,</u> Baragaño, D., Evrard, O., Reiff, T., Silva, V., de la Torre, A., Zhang, C., <u>Panagos, P.,</u> <u>Jones, A. and Wojda, P.,</u> 2024. Soil pollution in the European Union–An outlook. Environmental Science & Policy, 161: 103876. <u>link</u>

<u>Yunta, F., Schillaci, C., Panagos, P., Van Eynde, E., Wojda, P. and Jones, A.,</u> 2024. Ecological risk assessment of heavy metals from application of sewage sludge on agricultural soils in Europe. European Journal of Soil Science, 75(5): 13562. <u>link</u>

Dulya, O., Mikryukov, V., Shchepkin, D.V., Pent, M., Tamm, H., Guazzini, M., <u>Panagos, P., Jones, A., Orgiazzi</u>, A., Marroni, F. and Bahram, M., 2024. A trait-based ecological perspective on the soil microbial antibioticrelated genetic machinery. Environment International, 190: 108917. <u>link</u>

Aslani, F., Bahram, M., Geisen, S., Pent, M., Otsing, E., Tamm, H., <u>Jones, A., Panagos, P.,</u> Köninger, J., <u>Orgiazzi,</u> <u>A.</u> and Tedersoo, L., 2024. Land use intensification homogenizes soil protist communities and alters their diversity across Europe. Soil Biology and Biochemistry, 195: 109459. <u>link</u>

Girona-García, A., <u>Vieira, D.</u>, Doerr, S., <u>Panagos, P</u>. and Santín, C., 2024. Into the unknown: The role of postfire soil erosion in the carbon cycle. Global Change Biology, 30(6): 17354. <u>link</u>

Stamou, G.P., <u>Panagos, P.</u> and Papatheodorou, E.M., 2024. Connections between soil microbes, land use and European climate: Insights for management practices. Journal of Environmental Management, 360:121180. <u>link</u>

<u>Panagos, P., Vieira, D.,</u> Eekhout, J.P., Biddoccu, M., Cerdà, A., Evans, D.L., Tavoularis, N., Bezak, N., Negrel, P., Katsoyiannis, A. and Borrelli, P., 2024. How the EU Soil Observatory contributes to a stronger soil erosion community. Environmental Research, 248: 118319. <u>Link</u>

Sartori, M., Ferrari, E., M'Barek, R., Philippidis, G., Boysen-Urban, K., Borrelli, P., Montanarella, L. and <u>Panagos.</u> <u>P.</u> 2024. Remaining loyal to our soil: a prospective integrated assessment of soil erosion on global food security. Ecological Economics, 219: 108103. <u>link</u>

<u>Panagos, P.,</u> De Rosa, D., <u>Liakos, L., Labouyrie, M.</u>, Borrelli, P. and <u>Ballabio, C.</u>, 2024. Soil bulk density assessment in Europe. Agriculture, Ecosystems & Environment, 364: 108907. <u>link</u>

<u>Fendrich, A.N.</u>, Ciais, P., <u>Panagos, P.</u>, Martin, P., Carozzi, M., Guenet, B. and Lugato, E., 2024. Including land management in a European carbon model with lateral transfer to the oceans. Environmental Research, 245: 118014. <u>link</u>

<u>Fendrich, A.N., Van Eynde, E.,</u> Stasinopoulos, D.M., Rigby, R.A., <u>Yunta, F.</u> and <u>Panagos, P.</u> 2024. Modeling arsenic in European topsoils with a coupled semiparametric (GAMLSS-RF) model for censored data. Environment International, 185: 108544. <u>link</u>

Terribile, F., Acutis, M., Agrillo, A., Anzalone, E., Azam-Ali, S., Bancheri, M., Baumann, P., Birli, B., Bonfante, A., Botta, M. and Cavaliere, F., <u>Schillaci, C. , Montanarella, L., Panagos, P.</u> Basile, A., 2024. The LANDSUPPORT geospatial decision support system (S-DSS) vision: Operational tools to implement sustainability policies in land planning and management. Land Degradation & Development, 35(2): 813-834. <u>link</u>

Gupta, S., Borrelli, P., <u>Panagos, P.</u> and Alewell, C., 2024. An advanced global soil erodibility (K) assessment including the effects of saturated hydraulic conductivity. Science of the Total Environment, 908: 168249. <u>link</u>

<u>Yunta, F., Schillaci, C., Panagos, P., Van Eynde, E., Wojda, P. and Jones, A.,</u> 2024. Quantitative analysis of the compliance of EU Sewage Sludge Directive by using the heavy metal concentrations from LUCAS topsoil database. Environmental Science and Pollution Research, 1-16. <u>link</u>

<u>Panagos, P.,</u> Borrelli, P., <u>Jones, A.</u> and Robinson, D.A., 2024. A 1 billion euro mission: A Soil Deal for Europe. European Journal of Soil Science, 75(1): 13466. <u>link</u>

Song, X., Alewell, C., Borrelli, P., <u>Panagos, P.</u>, Huang, Y., Wang, Y., Wu, H., Yang, F., Yang, S., Sui, Y. and Wang, L., 2024. Pervasive soil phosphorus losses in terrestrial ecosystems in China. Global Change Biology, 30(1): 17108. <u>link</u>

<u>Panagos, P., Matthews, F.</u> Patault, E., De Michele, C., Quaranta, E., Bezak, N., Kaffas, K., Patro, E.R., Auel, C., Schleiss, A.J. <u>Fendrich, A., Liakos, L., Van Eynde, E., Vieira, D.</u>, Borrelli, P., 2024. Understanding the cost of soil erosion: An assessment of the sediment removal costs from the reservoirs of the European Union. Journal of Cleaner Production, 434, p.140183. <u>link</u>

De Rosa, D., <u>Ballabio, C.</u>, Lugato, E., Fasiolo, M., <u>Jones, A. and Panagos, P.</u>, 2024. Soil organic carbon stocks in European croplands and grasslands: How much have we lost in the past decade?. Global Change Biology, 30(1): 16992. <u>link</u>

Bezak, N., Borrelli, P., Mikoš, M., Auflič, M.J. and <u>Panagos, P.,</u> 2024. Towards multi-model soil erosion modelling: An evaluation of the erosion potential method (EPM) for global soil erosion assessments. Catena, 234: 107596. <u>link</u>

<u>Muntwyler, A., Panagos, P.,</u> Pfister, S. and Lugato, E., 2024. Assessing the phosphorus cycle in European agricultural soils: Looking beyond current national phosphorus budgets. STOTEN, 906: 167143. <u>link</u>

Batjes, N. H., Ceschia, E., Heuvelink, G. B. M., Demenois, J., le Maire, G., Cardinael, R., <u>Arias-Navarro, C.</u> and van Egmond, F. 2024. Towards a modular, multi-ecosystem Monitoring, Reporting and Verification (MRV) framework for soil organic Carbon stock change assessment. Carbon Management, 15(1). <u>link</u> Cristóbal, J., Foster, G., Caro, D., <u>Yunta, F.</u>, Manfredi, S., & Tonini, D. (2024). Management of excavated soil and dredging spoil waste from construction and demolition within the EU: Practices, impacts and perspectives. *Science of The Total Environment*, 173859. <u>link</u>

Binner, H., <u>Wojda, P., Yunta, F., Breure, T.,</u> Schievano, A., Massaro, E., ... & <u>Schillaci, C.</u> (2024). A systematic review and characterization of the major and most studied urban soil threats in the European Union. *Water, Air, & Soil Pollution, 235*(8), 494. <u>link</u>

Prieto-Castrillo, F., Rodríguez-Rastrero, M., <u>Yunta, F.</u> et al. Disentangling Jenny's equation by machine learning. Sci Rep 13, 20916 (2023). <u>link</u>

Basso, M., Baartman, J., Martins, M., Keizer, J., <u>Vieira, D.</u>, 2024. Predicting post-fire hydrological and erosive catchment response during rainfall events. A comparison of OpenLISEM and MOHID Land models. J. Hydrol. 636, 131258. <u>link</u>

Franco, A., <u>Vieira, D.</u>, Clerbaux, L.-A., <u>Orgiazzi, A.</u>, Labouyrie, M., Köninger, J., Silva, V., van Dam, R., Carnesecchi, E., Dorne, J.L.C.M., Vuaille, J., Lobo Vicente, J., <u>Jones, A.</u>, 2024. Evaluation of the ecological risk of pesticide residues from the European LUCAS Soil monitoring 2018 survey. Integr. Environ. Assess. Manag. 20, 1639–1653. <u>link</u>

Lopes, A., Gouveia, S., Serpa, D., Keizer, J., <u>Vieira, D.,</u> 2024. Exploring the inclusion of soil management practices in erosion models towards the improvement of post-fire predictions. Geomorphology 466, 109452. <u>link</u>

Mataix-Solera, J., Jiménez-Morillo, N.T., Úbeda, X., <u>Vieira, D.,</u> 2024. Editorial: Fire and Soils in a Changing World. Span. J. Soil Sci. 14, 13811. <u>link</u>

Lo Papa G.; <u>Schillaci C.</u>; Fantappiè M.; Langella G. - Editorial of the Special Issue Digital Soil Mapping, Decision Support Tools and Soil Monitoring Systems in the Mediterranean 2024, Land, 10.3390/land13060815. <u>link</u>

Diatta A.; Kanfany G.; Camara B.; Bassène C.; Manga A.; Seleiman M.; Mbow C.; <u>Schillaci C.</u>, 2024. Compost as an Alternative to Inorganic Fertilizers in Cowpea [Vigna unguiculata (L.) Walp.] Production, Legume Science, 10.1002/leg3.247. <u>link</u>

Fiorentini M.; <u>Schillaci C.</u>; Denora M.; Zenobi S.; Deligios P.A.; Santilocchi R.; Perniola M.; Ledda L.; Orsini R. 2024. Fertilization and soil management machine learning based sustainable agronomic prescriptions for durum wheat in Italy, Precision Agriculture 10.1007/s11119-024-10153-w. <u>link</u>

Zhao J.; Lipani A.; <u>Schillaci C.-</u> 2024. Fallen apple detection as an auxiliary task: Boosting robotic apple detection performance through multi-task learning, Smart Agricultural Technology <u>link</u>

Bulgari R.; Demiraj E.; <u>Schillaci C.</u>; Tlili A.; Xia Y. 2024. Urban Agriculture & Regional Food Systems Special Section: Improving Livability in Urban Areas: Examining Urban and Peri-Urban Soil and Plant Management, Urban Agriculture and Regional Food Systems 10.1002/uar2.20062, <u>link</u>

Stankovics P.; <u>Schillaci C.</u>; Pump J.; Birli B.; Ferraro G.; Munafò M.; Di Leginio M.; Hermann T.; Montanarella L.; Tóth G. 2024. A framework for co-designing decision-support systems for policy implementation: The LANDSUPPORT experience, Land Degradation and Development, 10.1002/ldr.5030. <u>link</u>

Chen S.; Chen Z.; Zhang X.; Luo Z.; <u>Schillaci C.</u>; Arrouays D.; Richer-De-Forges A.C.; Shi Z., 2024. European topsoil bulk density and organic carbon stock database (0-20 cm) using machine-learning-based pedotransfer functions, Earth System Science Data, 10.5194/essd-16-2367-2024. <u>link</u>

Acs, S., Costa Leite, J., Sanyé-Mengual, E., Caivano, A., Catarino, R., Druon, J.N., Di Marcantonio, F., De Jong, B., Guerrero, I., Gurría, P. and M'barek, R., Panagos, P. , Wollgast, J., Toth, K. 2024. Towards sustainable food systems: developing a monitoring framework for the EU. Frontiers in Sustainable Food Systems, 8, p.1502081. <u>link</u>

Box 2. JRC technical reports published by the EUSO team in 2024. EUSO team members are underlined.

Peiro, A., Mimmo, T., Sanz, F., <u>Panagos, P., Jones, A.</u>, <u>Breure, T.</u>, 2024. A review of existing tools for citizen science research on soil health. Publications Office of the European Union, Luxembourg. <u>link</u>

<u>Broothaerts, N., Panagos, P., Jones, A.</u>, 2024. A proposal for soil health indicators at EU-level: report on indicator framework available through the EU Soil Observatory. Publications Office of the European Union, Luxembourg. <u>link</u>

<u>Arias-Navarro, C.</u>, Vidojević, D., Zdruli, P., <u>Yunta Mezquita, F.</u>, <u>Jones, A.</u>, <u>Wojda, P.</u>, 2024. Soil pollution in the Western Balkans. Publications Office of the European Union, Luxembourg. <u>link</u>

<u>Arias-Navarro, C.</u>, Vidojević, D., Zdruli, P., <u>Yunta Mezquita, F.</u>, <u>Jones, A.</u>, <u>Wojda, P.</u>, 2024. LUCAS Soil 2015 in the Western Balkans: overview and analysis of ancillary data. Publications Office of the European Union, Luxembourg. <u>link</u>

<u>Arias-Navarro, C.</u>, Vidojević, D., Zdruli, P., <u>Yunta Mezquita, F.</u>, <u>Jones, A.</u>, <u>Wojda, P.</u>, 2024. Integrated Administration and Control System (IACS) implementation and LUCAS data integration feasibility in the Western Balkans. Publications Office of the European Union, Luxembourg. <u>link</u>

<u>Van Eynde, E., Yunta Mezquita, F.</u>, <u>Panagos, P.</u>, <u>Jones, A.</u>, 2024. Soil fertility in the EU taxonomy for the construction of new buildings. Publications Office of the European Union, Luxembourg. <u>link</u>

Broothaerts, N., Panagos, P., Arias-Navarro, C., Ballabio, C., Belitrandi, D., Breure, T., De Medici, D., De Rosa, D., Fendrich, A., Havenga, C., Koeninger, J., Kreiselmeier, J., Labouyrie, M., Liakos, L., Maréchal, A., Martin Jimenez, J., Matthews, F., Michailidis, V., Montanarella, L., Muntwyler, A., Orgiazzi, A., Scarpa, S., Schillaci, C., Simoes Vieira, D., Van Eynde, E., Van Liedekerke, M., Wojda, P., Yunta Mezquita, F., Jones, A., 2024. EUSO annual bulletin 2023. Publications Office of the European Union, Luxembourg. <u>link</u>

<u>Yunta Mezquita, F., Van Liedekerke, M.</u>, Fernández Ugalde, O., Németh, T., Balázs, R., Keresztes, M., Weiszburg, T., Rábl, E., Királyné Tóth, J., Gazsi, Z., Kovács, I., Ruíz García, A., Cuevas, J<u>., Van Eynde, E., Wojda,</u> <u>P., Panagos, P., Jones, A.</u>, 2024. Clay mineral inventory in soils of Europe based on LUCAS survey soil samples. Publications Office of the European Union, Luxembourg. <u>link</u>

<u>Vieira, D.</u>, Franco, A., <u>De Medici, D., Martin Jimenez, J., Wojda, P., Jones, A.</u>, 2023. Pesticides residues in European agricultural soils: results from LUCAS 2018 soil module. Publications Office of the European Union, Luxembourg. <u>link</u>

Lugato, E. and Migliavacca, M., Borio, D., <u>Breure, T.</u>, De Rosa, D., Capobianco, S., Caporaso, L., Cescatti, A., Fahl, F., Meroni, M., Oton, G., <u>Panagos, P.</u>, Piccardo, M., Sedano, F., Viskari, T. 2024. Technical development of the baseline for carbon farming: methodologies and case studies, European Commission, Ispra, JRC139820.

Box 3. Science for policy reports, published by and contributed to the EUSO team in 2024. EUSO team members are underlined.

<u>Arias-Navarro, C.</u>, Baritz, R. and <u>Jones, A</u>., 2024. The state of soils in Europe – Fully evidenced, spatially organised assessment of the pressures driving soil degradation, Arias-Navarro, C.(editor), Baritz, R.(editor) and Jones, A.(editor), Publications Office of the European Union, Luxembourg. <u>link</u>

Belis, C., Djatkov, D., Dobricic, S., De Meij, A., Kolarević, S., <u>Arias Navarro, C., Wojda, P., Jones, A.</u>, Lamy, M., Porcel Rodriguez, E., Marinov, D., Lettieri, T., 2024. Status of environment and climate in the Western Balkans, Publications Office of the European Union, Luxembourg. <u>link</u>

Maes, O., Rembold, F., Callenius, C. and <u>Van Eynde, E.</u>, Knowledge Review - Increasing agricultural production in sub-Saharan Africa: the role of fertilisers and soil health, European Commission, 2024, JRC135925. <u>link</u>

In 2024, the EUSO team made significant contributions to, or took the lead in, specific **research projects**. These research activities are listed below:

- SOLACE project: Soil pollution is a significant environmental and health concern in Europe, with potential links to cancer incidence. The JRC Exploratory Research project "Understanding the links between SOil pollution and CancEr (SOLACE)" investigated the complex relationships between soil properties, pollution, land use and human health, providing a foundation for further research and policy development, as part of the JRC's strategic scientific development. The scoping review of the existing studies linking soil pollution and cancer identified knowledge gaps in the fields. We also performed an ecological study across 26 EU countries, which revealed associations between the regional rates of lung cancer mortality and soil pollution with arsenic and cadmium. The SOLACE project underscores the importance of comprehensive soil monitoring to safeguard environmental and human health and emphasizes the need for continued investment in research, monitoring, and policy development to address the complex issues surrounding soil pollution and its impact on human health. The SOLACE project achievements contribute to policy initiatives such as the Soil Monitoring and Resilience Directive and the Zero Pollution Action Plan.
- The African Soil Health Project (AFSOH): The EU and African Union have both identified the need to boost safe and sustainable agri-food systems, where healthy soils are key for achieving this ambition. This JRC Exploratory Research project focuses on the quantification of soil health in Africa, and the identification of soil threats and possible solutions, taking into consideration the specific environmental and socio-economic context on the African continent. Appropriate and available soil measurements are being selected from existing data repositories, and translated into individual soil health indicators with the help of models and remote sensing. A holistic soil health score for soils in Africa will be developed in 2025.
- Collaborative Doctoral Partnership (CDP): The CDP is an initiative of the JRC to establish strategic collaborations with higher education institutions that grant doctoral degrees. In 2024, EUSO hosted and mentored the following doctoral candidates in the context of the CDP:
 - Francis Matthews successfully finished the collaborative doctoral training programme and obtained the doctoral degree in 2024 at KU Leuven, Belgium. The PhD thesis was entitled 'Dynamic modelling of soil erosion and sediment delivery in Europe'.
 - Anna Muntwyler successfully finished the collaborative doctoral training programme and obtained the doctoral degree in 2024 at ETH Zurich, Switzerland. The PhD thesis was entitled 'Modelling the nutrient cycle in EU agricultural soils and assessing trade-offs of agricultural management practices'.
 - Maeva Labouyrie successfully finished the collaborative doctoral training programme and obtained the doctoral degree in September 2024 at Zurich University, Switzerland. The PhD thesis was entitled 'Soil Biodiversity Assessment across Europe'.
 - Vasilis Michailidis currently works on a PhD project entitles 'Quantify soil carbon and nitrogen dynamics in relation to agricultural land management practices and climate change scenarios', a collaboration between the JRC and Aarhus University, Denmark. Delivery is expected in Q3 2025.

2.5.2 Interaction with Mission Soil funded projects

The EU Mission 'A Soil Deal for Europe' (Mission Soil) is one of the five missions funded under the EU Research and Innovation Programme Horizon Europe. The Mission Soil supports the EU's ambition on soil health and sustainable land management. The Mission Soil aims to establish 100 Living Labs and Lighthouses to co-create, test and pioneer innovations for soil health, next to advancing the knowledge on healthy soils. Moreover, the Mission Soil is supporting the development of a harmonised framework for soil monitoring in Europe and aims to raise public awareness on the vital importance of soils. The projects funded under the Mission Soil are available at this link.

The EUSO is actively involved in and responsible for the soil monitoring elements of the Mission Soil and contributes to the mission annual work programme. The EUSO is also beneficiary of the research activities in the Mission Soil funded projects and works in close collaboration with some of these projects.

Collaboration between Mission Soil funded projects is structured within Mission Soil Clusters. Two of these clusters are co-led by the EUSO:

- Mission Soil Cluster on Indicators and Monitoring. This Cluster focusses on indicator frameworks and soil monitoring at different scales. The Cluster aims to (i) improve indicators of the Mission Implementation Plan and further develop descriptors in the SMRD, (ii) provide orientation to other projects regarding indicators and monitoring, and (iii) elaborate a roadmap for the development of indicators and soil monitoring. In 2024, two online cluster meeting took place, as well as an in-presence meeting during the EU Mission Soil Week Cluster Event (see also section 2.6.3).
- Mission Soil Cluster on Data and Knowledge Management. This Cluster aims to achieve a better management of research data and knowledge related to soil. More precisely, it aims to deliver more structured research data management and templates for metadata for outcomes of Mission Soil funded projects. In 2024, two online cluster meetings took place, as well as an in-presence meeting during the EU Mission Soil Week Cluster Event (see also section 2.6.3).

Next to the interaction within the Mission Soil Clusters, the EUSO has worked in 2024 in close collaboration with some of the Mission Soil funded project on more specific topics. Some of these collaborations and the resulted outcomes are highlighted below, this list is however not exhaustive.

Al4SoilHealth and the EUSO have developed the observed/typical soil organic carbon (O/T SOC) index. This is an advancement compared to the classical SOC to clay ration (SOC/clay). "Typical" SOC is the average concentration in different pedo-climate zones. Compared with SOC/clay, O/T SOC is less sensitive to clay content, land cover, and climate, less geographically skewed, and better reflecting differences in soil porosity and SOC stock. This works supports two objectives of the Mission Soil (i.e. consolidating SOC stocks and improving soil structure for crops and biota). The resulting maps (available in ESDAC) illustrate the O/T SOC classes and the 12 pedoclimate zones, derived from LUCAS 2009-2018 observations, to stratify the landscape into areas suitable for benchmarking SOC concentrations for pan-European soil health assessment. The work has been documented in this <u>publication</u> (Feeney et al., 2024).

- Al4SoilHealth, the EUSO and scientists from the University of Bucharest, supported by the EU's NextGeneration instrument through the National Recovery and Resilience Plan of Romania have worked together for the development of the Land Degradation Assessment. This collaboration took place in the context of a <u>Nature Communications publication</u> (Prăvălie et al., 2024). The 12 indicators included in this land degradation assessment are: Water erosion, Wind erosion, Soil organic carbon loss, Soil salinization, Soil acidification, Soil compaction, Soil nutrient imbalances, Soil pollution via pesticides, Soil pollution via heavy metals, Vegetation degradation, Groundwater decline and Aridity.
- Al4SoilHealth, Soil O-LIVE and the EUSO have worked together to develop a Roadmap towards assessing soil health in the EU by 2030 achieving the Green Deal objectives. The body of knowledge will soon be enriched thanks to the investment of 1 billion euros towards the Mission Soil, which has the ambition to promote the development of new harmonized bottom-up and top-down soil health indicators. New data and knowledge are also anticipated through the national soil monitoring schemes to support the implementation of the SMRD. This is drafted in this <u>publication</u> (Panagos et al., 2024a).
- Al4SoilHealth and the EUSO have developed the Global soil erodibility assessment including the effects of saturated hydraulic conductivity. This resulted in the <u>dataset</u> (available in ESDAC) and a <u>publication</u> (Gupta et al., 2024) that encompasses global soil erodibility factor maps. In addition, measured values of saturated hydraulic conductivity (Ksat) have been incorporated into the original method to formulate the Ksat-based soil erodibility map.
- AI4SoilHealth and the EUSO have worked together for the development of the <u>EU Bulk density</u> map. This collaboration took place in the context of a <u>publication</u> (Panagos et al., 2024c) that applied a methodological framework using an advanced Cubist rule-based regression model to optimize the spatial prediction of bulk density in Europe. Measurements from around 6000 LUCAS samples were used developed the high-resolution map (100 m) of bulk density for the 0–20 cm depth and the maps at 0–10 and 10–20 cm depth.
- Al4SoilHealth. In June 2024, the EUSO hosted a delegation to develop a roadmap and enhance collaboration in utilizing soil health information through AI technology, in relation to the project's deliverables and in support of the Mission Soil and the EUSO. Discussions foccussed on indicators for soil degradation, erosion, soil biodiversity, soil organic carbon, water retention, porosity, salinity, and spectroscopy.
- BENCHMARKS. In April 2024, the EUSO hosted a delegation to discuss the common pathway in relation to the project's deliverables relating to harmonised and cost-effective indicators proposed for measuring soil health and the integrated soil health tool demonstrating the links between indicators, soil functions and ecosystem services.
- ECHO and the EUSO have published the report: <u>A review of existing tools for citizen science</u> research on soil health. This work reviewed over 60 citizen science projects that considered soil health. The data were collected based on a literature search, expert interviews, suggestions from project partners and through the mailing lists of the European Network for Soil Awareness and the EUSO/ESDAC. Projects were screened for the following characteristics: geographic coverage, duration, scientific factors, technological factors and their citizen engagement. Two-thirds of the reviewed studies were based in Europe and mostly conducted at regional or national scales. Recommendations include aligning the citizen science methodology with the desired level of participation, and developing standardised, user-friendly and cost-effective methodologies to generate soil data.

 In addition, bilaterial meetings where had with ARAGORN and ISLANDR (pollution), PREPSOIL and SOILL (support to Living Labs), and MONALISA (Desertification).

For the Mission Soil funded projects that started in 2024, the EUSO provided keynote presentations during their kick-off meetings. An overview is provided below, including an indication of the date of the kick-off meeting:

- <u>IcoSHELL</u> (September 2024)
- <u>LivingSoiLL</u> (June 2024)
- MONALISA (October 2024)
- <u>Path4Med</u> (September 2024)
- <u>SoilCRATES</u> (October 2024)
- <u>GOV4LL</u> (June 2024)
- <u>SUS-SOIL</u> (October 2024)
- <u>DEEPHORIZON</u> (October 2024)

2.5.3 Interaction with Horizon 2020 projects

2.5.3.1 European Joint Program on agricultural soil management (EJP Soil)

The EUSO had a close collaboration with the EJP Soil on many fronts during 2024. These included:

- The comparison of national and LUCAS Soil datasets in 12 Member States. The work assessed how spatial distributions of sampling sites lead to over/under sampling of some soil types or land covers leading to significant differences of statistical distribution of soil properties depending on the network considered.
- A double sampling exercise within LUCAS Soil 2022 to check the impact of sampling protocols and analytical methods and support the development of transfer functions. More than 600 locations were sampled, in some cases according to both LUCAS and national protocols. The results of the subsequent laboratory analysis will be presented in 2025.
- The EJP SOIL Science Days, which took place in Lithuania in June 2024. The EUSO contributed through an overview of its main activities with focus on how to better integrate the national monitoring programmes and other initiatives as the EJP SOIL. Participants of this event stressed the need for such a harmonised pan-European soil-monitoring scheme that will valorise legacy data and will pave the way for the application of the proposed SMRD. However, there is a clear need to inform regional and national policy makers about the future steps of the SMRD implementation and discuss with them the technical support provided by the European Commission.
- The EJP SOIL Final Policy Forum, which took place in Brussels on 18 November, as part of an extended panel question and answer session on how the relevance of the work of EJP Soil to the JRC.

2.5.3.2 SHARInG-MeD project

On 29 February-1 March 2024, the EUSO hosted a two-day training course for more than 20 soil surveyors of the <u>SHARInG-MeD</u> "Soil Health and Agriculture Resilience through an Integrated Geographical information systems of Mediterranean Drylands" project. The SHARING-MED project aims to develop an improved and harmonised set of soil and land degradation indicators that reflect the specificities of the Mediterranean region, where limited rainfall and low green ground cover result in a high risk of soil degradation, salinisation and desertification. The project is Coordinated by the University of Pisa under the <u>Partnership for Research and Innovation in the Mediterranean Area</u> programme. The project builds on the LUCAS Soil Module and will contribute to the JRC's Soil Atlas of the Mediterranean Region.

2.5.3.3 SOILS4AFRICA

The EUSO is a full partner of the SOILS4AFRICA Project, which aims to provide an open-access soil information system with a set of key indicators and underpinning data, accompanied with a methodology for repeated soil monitoring across the African continent. The soil information system will become part of the knowledge and information system of the EU-Africa Research and Innovation Partnership on Food and Nutrition Security and Sustainable Agriculture (FNSSA).

In this context, the EUSO participated in a two-day workshop (26-27 March 2024) in Nairobi, Kenya, with the aim of establishing a partnership for supporting national soil information system development in Africa. There was specific interest in the JRC's activities that support the development of a Soil Health Dashboard for Africa, which builds on recent support for the Soil Monitoring and Resilience Directive. The workshop was an initiative of the Bill and Melinda Gates Foundation.

2.6 Supporting stakeholder interactions and citizen engagement

2.6.1 EUSO Stakeholders Forum

The EUSO Stakeholders Forum is an annual event bringing together soil scientists, policy makers, regional and national representatives, land managers and interested citizens. It also aims to support citizen engagement and the drive towards a societal change in the perception of soils. The EUSO Stakeholders Forum of 2024 took place in two parts: the second Young Soil Researchers Forum on 14-15 October 2024 (see section 2.6.2) and the fourth edition of the EUSO Stakeholders Forum on 21-23 October 2024 (**Figure 17**).

The first day of the EUSO Stakeholders Forum discussed the status, prospects and implementation of the proposed SMRD. On the second day, the much-anticipated report '<u>The state of soils in Europe</u>' was launched, which was followed by session investigations diverse global perspectives on soil health. During the third day, the EUSO Working Group on Nutrients was launched, followed by a session dedicated to soil sciences and arts. With almost 800 participants, the fourth edition of the EUSO Stakeholders Forum was considered as a success. <u>Recordings and presentations</u> are available on the EUSO website.

Figure 17. Fourth EUSO Stakeholders Forum.



Source: JRC analysis.

2.6.2 Young Soil Researchers forum

The second edition of the Young Soil Researchers Forum (YSRF) (**Figure 18**) was a successful networking and knowledge exchange event. Early career scientists were given the opportunity to present their work and to get in contact with senior soil scientists, policy makers, and other relevant stakeholders. The YSRF included more than 60 presentations in six sessions addressing soil erosion, data sharing, soil biodiversity, soil organic carbon, soil pollution and nutrients. The YSRF also included a highly appreciated session dedicated to employment and funding opportunities, including keynote presentations from EU Human Resources Administration to describe job opportunities within the JRC and other services of the European Commission. The YSRF was attended by more than 300 participants. All presentations and recordings are available on the EUSO website.

Within the context of the YSRF, the EUSO also launched a <u>Call for Papers for a Special Issue in the</u> <u>European Journal of Soil Sciences</u>. The special issue is open to all early career soil scientists. Topics for this call for papers include, but are not restricted to, soil erosion, data sharing, soil biodiversity, soil organic carbon, soil pollution and nutrients. Submission deadline is 29 June 2025.



Source: JRC analysis.

2.6.3 European Mission Soil Week

The European Mission Soil Week is an annual event aimed at promoting the Horizon Europe Mission 'A Soil Deal for Europe' (Mission Soil), raising awareness about soils, and driving action to protect and restore soils. The second edition of the European Mission Soil Week was held on 12 and 13 November 2024 in Brussels. This edition was organised by the European Commission, Directorate-General for Agriculture and Rural Development (DG AGRI) together with the EUSO and with the support of the Directorate-General for Research and Innovation (DG RTD) and the European Research Executive Agency (REA). The European Mission Soil Week brought together researchers, policymakers, practitioners, farmers and other key stakeholders to build momentum for ongoing efforts to improve soil health. It provided a platform to display the latest achievements of the Mission Soil, including the launch of the first 25 Mission Soil living labs, and to present the results of Mission-funded projects. Over 250 people attended the event on site in Brussels and almost 270 attended online (**Figure 19**). <u>Presentations and recordings</u> are available.

The European Mission Soil Week was followed by a cluster event on 14 November 2024, bringing together Mission-funded projects working on data and knowledge management, communication and stakeholder engagement, and soil indicators and monitoring.



Figure 19. Graphical summary of the European Mission Soil Week 2024.

Source: European Mission Soil Week 2024 (graphics: Blanche Illustrates).

2.6.4 Other activities to support stakeholder interactions and citizen engagement

2.6.4.1 EUSO/ESDAC monthly newsletter

The ESDAC publishes since 2009 a monthly newsletter with the main highlights, such as new datasets, calls for data, activities involving the EUSO, important publications, events and vacancies. The newsletter is sent to more than 13 000 subscribers, including stakeholders from academia, business and policy, as well as interested citizens. In 2024, the newsletter moved to new format, reflecting the JRC corporate style (**Figure 20**). This new formatted newsletter includes, beside the new datasets, call for data, etc., also highlights of the main EUSO components and activities. Archive of newsletters and subscription form are available through the respective links.

Figure 20. New formatted EUSO/ESDAC newsletters.



Source: JRC analysis.

2.6.4.2 European Carbon Farming Summit

The EUSO participated in the first edition of the European Carbon Farming Summit (5-7 March 2024, Valencia), with a keynote presentation on modelling and monitoring soil organic carbon in the EU. The summit supported high-level conversations to shape up robust carbon farming markets and policies. It represented a space for sharing knowledge and experiences, upscaling solutions and enabling the multiplication of climate actions across the EU. The summit provided a space for the sector to agree on best mechanics to scale robust climate actions. The summit brought together over 500 stakeholders. Recordings are available <u>here</u>.

Furthermore, DG CLIMA presented updates on the Carbon Removal Certification Framework, crucial for Europe's net-zero roadmap. Carbon removals are especially crucial as it is expected that certain emissions will remain unabated by 2050. The Framework includes soil emission reduction units alongside sequestration units and acknowledges the impermanence of biogenic carbon (Carbon Farming). The JRC presented the framework for improved modelling and monitoring of SOC. Proper monitoring is essential to ensure the validity of carbon credits.

Participants of the Summit stressed the need for a harmonised approach across Europe to foster trust in carbon credits, given the disparate certification methods hindering a robust market. In addition, carbon farming extends beyond mere carbon sequestration; it is about driving the transition of agriculture towards resilience amidst climate change and biodiversity loss.

2.6.4.3 EUSO at RemTech Europe

On 16 September 2024, the EUSO organised and chaired the opening session of <u>RemTech Europe</u> - the International Conference and Exhibition on Land and Water Remediation Markets and Technologies. This session served as a collaborative platform uniting experts from academia, policymaking, and industry to focus on <u>Soil Pollution: Policies and Data</u>. Following the formal opening of the conference by JRC.D Director Alessandra Zampieri and Remtech colleagues, the session included presentations by a range of European Commission services on the proposed SMRD, the visionary and integrative role of the EUSO in implementing the SMRD, and the role of life-cycle assessment and safe and sustainable by design in soil pollution. Mission Soil funded projects and results of the EUSO-led workshop on Soil Pollution and Remediation Data Harmonisation were also discussed.

The EUSO team also took an active role in the hybrid days of the RemTech Europe event (18-20 September 2024), chairing numerous scientific sessions, contributing to the scientific committee, and presenting four scientific abstracts on soil pollution topics. These topics included a European perspective, advances in sewage sludge application, and issues related to pesticides.

The participation of the EUSO and the JRC at the RemTech Europe Conference is of strategic importance, building upon a five-year legacy. It provides an essential link between research and innovation, and it takes advantage of tangible experiences of field practitioners from around the world. It is also crucial for enhancing the European competitiveness in different domains in the global arena, especially in the critical areas of soil health and sustainability and water reuse.

2.6.4.4 EUSO at the 75th anniversary of European Journal of Soil Science

On 7 February 2024, the EUSO co-led a 'Zoom into Soil' webinar organised by the British Society of Soil Science in the occasion of the 75th anniversary of the European Journal of Soil Science. The presentation introduced the audience to the article <u>Forty years of soil research funded by the</u> <u>European Commission: Trends and future</u>, and emphasised the key role of the EUSO and the Mission Soil. With over 200 attendants, the event showed a significant level of interest and engagement around EUSO's activities and opened new avenues for upcoming cooperation.

2.6.4.5 EUSO at the Mission Board meeting for the Mission 'A Soil Deal for Europe'

On 5 March, an overview of current activities of the EUSO were presented at the joint meeting of the Mission Board and the Strategic Configuration of the Horizon Europe Programme Committee on the Mission 'A Soil Deal for Europe'. With around 80 participants, the meeting showed a high level of interest in EUSO's activities and objectives. Of particular interest was the important cooperation between EUSO and the Mission-funded projects as well as the EUSO Soil Degradation Dashboard.

2.6.4.6 EUSO at ESA Symposium on Earth Observation for soil protection and restoration

The EUSO were heavily involved in the European Space Agency (ESA) <u>Symposium on Earth</u> <u>observation for soil protection and restoration</u> in Frascati, Italy (6-7 March 2024) as co-organisers and through keynote presentations, panel interventions and chairing sessions. The workshop marked the launch of a novel global soil organic carbon monitoring system based on data derived from Sentinel satellites. The programme made extensive use of LUCAS Soil data and spectral libraries.

2.6.4.7 EUSO at the African Fertilizer and Soil Health Summit

The EUSO, together withcolleagues from DG INTPA and DG AGRI, attended the high-level <u>African</u> <u>Fertilizer and Soil Health Summit</u> in Nairobi, 7-9 May 2024. Organised by the African Union Commission, the summit aimed to address the long-term decline in the quality of Africa's agricultural soils, which has resulted in lower agricultural production capacity and economic growth, food insecurity, with increased environmental degradation and rural poverty. The Summit brought together eight Heads of State, the Chair and Deputy-chair of the African Union Commission, over 40 Ministers, as well as around 1500 delegates.

During the summit, the EUSO organised a side event on Monitoring Soil Health and Soil Health Investments at difference scales. The meeting focused on the availability and need to invest in data and information to support sustainable soil management across diverse agricultural systems in Africa. The event was opened by a scene-setting video by JRC.D Director Alessandra Zampieri, followed by very interesting presentations and a discussion on efforts in Africa to develop soil information systems, including the work done by the Soils4Africa project (of which the EUSO is a partner). In addition to presenting an overview on how approaches to soil monitoring in the EU had evolved through the LUCAS Soil Module and the proposed Soil Monitoring and Resilience Directive, the Soil Mission Secretariat presented a new call under its 2024 Work Programme to support the assessment of soil health in Africa, which will build on EUSO work to develop a soil health dashboard for Africa.

The summit formally adopted the <u>Nairobi Declaration</u>, which endorsed the <u>Soils Initiative for Africa</u> (SIA) and a <u>10-year Action Plan</u> to review the state of Africa's soil health and recalibrate strategies for boosting the productivity of soils towards greater and sustainable gains in crop yields as well as economic growth and human well-being.

2.6.4.8 Soil monitoring in Ukraine

On 25 July 2024, the EUSO participated in the international conference "Soil Monitoring: Realities, Challenges, and Prospects", which was organised by the Institute of Soil Protection of Ukraine on its 60th anniversary. The event was opened by the First Deputy Minister of Agrarian Policy and Food of Ukraine, Taras Vysotskyi, and featured the participation of directors from the main State Research Institutions in Ukraine. The EUSO's presentation focused on the extensive collaborative work conducted with Ukrainian scientists over the past year in preparation of the <u>The State of Soils in</u> <u>Europe</u> Report 2024, which is a testament to their resilience and dedication to advancing soil science under challenging circumstances. The various presentations led to very rich discussions among the over 100 participants.

2.6.4.9 United Nations Convention to Combat Desertification (UNCCD) Conference of the Parties (COP)

The EUSO attended the 16th UNCCD COP in Riyadh (Saudi Arabia). This COP addressed the significant challenges related to land degradation and desertification, which was attended by over 20 000 participants. As part of the COP's Science Day on 9 December 2024, the EUSO co-organized with FAO and the European Space Agency a side event on "Leveraging Space Information and Earth Intelligence". At the event, the EUSO presented a draft proposal for a scientific methodology for

land degradation and desertification mapping in the EU. Emphasis was placed on the efforts of the EUSO to develop soil health indicators that are adapted to specific EU conditions.

2.6.4.10 Keynote presentations at several events

Keynote presentations on the work of the EUSO were given during several events, including among others:

- LIFE Platform Meeting on Soils (10-11 April 2024), link.
- Conference on Soil Health: Status and Future Needs (7-9 October 2024), <u>link</u>.
- International Soil Modelling Consortium Conference (5-11 May 2024), <u>link</u>.
- SaveOurSoil Conference (5 December 2024), link.
- Conference of the CERESiS project (April 2024), <u>link</u>.
- Global Symposium on Soil Information and Data (25-28 September 2024), link.
- Hungarian Soil Forum (4-5 December 2024), <u>link</u>
- ECOMONDO (5-8 November 2024), link

2.6.4.11 EUSO at the 10th meeting of CEN/TC 44

The CEN TC 444 (European Committee for Standardization Technical Committee on Environmental characterisation of solid matrices) held its annual meeting on 4-7 June 2024 in Milan, Italy. Over 47 experts from across Europe and guests from ISO TC 190 (International Organization for Standardization Technical Committee 190) and CENELEC (European Electrotechnical Committee for Standardization) collaborated for four days in eight working groups to develop new standards (actual 19 work items) e.g. PFAS, micro plastics, Hexavalent chromium, biological parameters and sampling. The meeting focused on several joint working group meetings with the JRC to collaborate on European Standards for the proposed Soil Monitoring and Resilience Directive.

3 Working Group activities

The EUSO Working Groups (WG) are a key element of the EUSO. These WGs aim to advance the knowledge and data on specific aspects of EU-soils. The WGs are composed of relevant experts from academia, businesses or policy, and are co-chaired by EUSO staff and external partners. In 2024, seven WGs were active (Figure 21): (1) WG Soil erosion, (2) WG Data sharing and integration, (3) WG Soil pollution, (4) WG Soil monitoring, (5) WG Soil biodiversity, (6) WG Soil organic carbon monitoring reporting and verification, and (7) WG Nutrients. The latter WG was launched in 2024. In the next sections, the activities and progress of all WGs during 2024 are described.

The main platform for interaction of the WGs was the Fourth EUSO Stakeholders Forum (see also section 2.6.1). Recordings and presentations of the Stakeholders Forum are available on the EUSO website.



Figure 21. EUSO Working Groups active in 2024.

Source: JRC analysis.

3.1 WG Soil erosion

The first major highlight of the WG Soil erosion in 2024 was the publication of the report on the off-site costs of removing sediments from the EU Reservoirs: Understanding the cost of soil erosion: An assessment of the sediment removal costs from the reservoirs of the European Union. One major cost of soil erosion originates from the sediments delivered to aquatic systems (e.g., rivers, lakes, and seas), which may generate a broad array of environmental and economic impacts (Figure 22). The report combines continental average and regionally explicit sediment accumulation rates with published remediation costs, integrating numerous figures reported in the grey literature. The cost of removing an estimated 135 million m³ of accumulated sediments due to water erosion is only likely to exceed 2.3 billion euro annually in the EU and UK, with large regional differences between countries. Considering the sediment delivered through all soil loss processes through extrapolating measured reservoir capacity losses, the sediment accumulation in the circa 5000 EU large reservoirs exceed 1 billion m³ with a potential cost of removal ranging between 5 and 8 billion

euro annually. These estimates, although not accounting for already implemented catchment mitigation measures, provide insights into one of the off-site costs of soil erosion at both the continental scale as well as the regional differences in economic burden. The provided estimates contribute to support policies such as the Soil Monitoring and Resilience Directive, the Zero Pollution Action Plan, the Farm to Fork strategy and the Water Framework Directive. The <u>data of this</u> <u>publication</u> are publicly available via ESDAC.





Source: Panagos et al., 2024d.

Secondly, following the <u>call for soil erosion plot data</u> in 2023 (EU_ERPlot data compilation), the WG Soil erosion was able to gather soil erosion data from 32 researchers under different formats needing harmonization. Moreover, we also performed a systematic review to understand the universe of data available in peer reviewed publications, resulting in the identification of 1019 individual publications using soil erosion data from field studies in EU (**Figure 23**). This analysis allowed us to better understand how much effort is required in this compilation process, but also to identify key-authors with the highest share of contributions for individual contacts. Once the final data integration is performed (spring 2025) we expect to submit and publish a study with the most complete dataset together with all contributors as co-authors (autumn 2025) on soil erosion measurements from different conditions all over Europe, but also on the efficiency of soil management practices in reducing soil erosion. Once the publication is accepted, we expect to have the data available in ESDAC and to update it with every new contribution.







Thirdly, members of the WG Soil erosion have collaborated in 2024 to publish following datasets:

- <u>Dataset on Land degradation assessment in Europe</u>. This dataset includes the Land Multidegradation Index for arable and agricultural lands and data for 12 indicators (land degradation processes including water and wind erosion) which were compiled to develop the index. This is also documented in the <u>relevant publication in Nature Communications</u>.
- The <u>Global gross soil erosion rates according to the Erosion Potential Model (EPM) and its</u> modified version (mEPM). This is also documented in the <u>relevant publication</u>.
- The <u>Global Soil Erodilbity Dataset</u> (K-factor). This dataset encompasses global soil erodibility (K) factor maps, with the K factor being estimated through the Wischmeier and Smith (1978) method. In addition, measured values of saturated hydraulic conductivity (Ksat) have been incorporated into the original method to formulate the Ksat-based soil erodibility (Kksat factor) map. This is also documented in the <u>relevant publication</u>.
- The <u>GloRESatE Global Rainfall Erosivity from Reanalysis and Satellite Estimates</u> dataset which contains merged global rainfall erosivity product at 0.1° × 0.1° spatial resolution. The dataset is an integrated product of satellite and reanalysis estimates with gauge rainfall erosivity datasets from 6 170 gauge stations across the globe. See also the <u>relevant publication</u>.

Fourthly, members of the WG soil erosion have also contributed to the estimation of costs of projected soil erosion rates by 2070. The headline result is that of a global economic contraction of up to 625 billion US dollars by the year 2070. Moreover, soil erosion represents an acute challenge to food security in vulnerable regions (Africa and some tropical regions) where for certain crops (particularly oilseeds) the threat of shortages is potentially significant. Under the worst-case scenario, global primary agricultural production losses could amount to 352 million tonnes by 2070. More information in the JRC science highlight and in the relevant publication.

Finally, more than 12 members of the WG Soil erosion contributed to the chapter on Soil Erosion for <u>the state of soils in Europe report</u>.

3.2 WG Data sharing and integration

The WG Data sharing and integration aims to provide relevant guidance on EU-wide soil data to promote best practices and convey data and knowledge into the EUSO and ESDAC to guarantee long-term availability. In 2024, the WG collaborated with Mission Soil funded projects within the framework of the Mission Soil Cluster on Data and Knowledge Management. This Mission Soil Cluster aims to achieve more structured research data management and templates for metadata for outcomes of Mission Soil funded projects. The role of the SoilWise project is important for this, as SoilWise will provide an integrated and actionable access point to scattered and heterogeneous soil data and knowledge in Europe and will design a repository for at least a decade to support EUSO and ESDAC evolvement accordingly.

Another key activity was the successful organization of a Soil Data session during the Young Soil Researchers Forum (Monday, 14th October 2024, 9:30–12:00; see also section 2.6.2). In this session, outstanding early career soil scientists presented their research on soil data and could interact with leading soil experts and policy makers. <u>Recordings and presentations</u> are available on the EUSO website. A comprehensive <u>book of abstract</u> was compiled, highlighting contributions such as:

- SHARInG-MeD: integrating expertise to promote Soil Health and Agriculture Resilience in Drylands – Ahlem Tlili
- Mapping the WRB 2022 soil types of Europe at 30 m resolution Robert Minarik
- XRPD Digital Soil Mineralogy Database for Environmental Monitoring and Sustainable Development – Urmi Ghosh

3.3 WG Soil pollution

Soil pollution in the European Union – An outlook

In the anticipation of future policy demands and towards a common strategy for tackling soil pollution in the EU, it seemed relevant to describe the limited knowledge and main uncertainties through the <u>Soil pollution in the European Union – An outlook</u>. This analysis aimed at providing evidence for the development of efficient policies, as well as updating current ones to better tackle the interdisciplinary of soil. This perspective provides our view on current knowledge on soil pollution at EU scale, by compiling the most updated assessments made at EU scale, identifying soil pollution drivers, impacts on health and the environment, and evaluating current state of knowledge. Allowing us to infer about current level of uncertainties and knowledge gaps and identify solutions through future research and policies. Our suggestions are in line with an increasing investment on research and innovation, but also more frequent updates of current legislation already tackling pollution and welcoming the new proposal for a SMRD as an important driver for soil knowledge development and implementation of a European monitoring system.

Participation in the RemTech Europe event

The EUSO soil team successfully chaired the opening session at this 2024 RemTech Europe - the International Conference and Exhibition on Land and Water Remediation Markets and Technologies (see also section 2.6.4.3). This session served as a collaborative platform uniting experts from academia, policymaking, and industry to focus on Soil Pollution: Policies and Data. Additionally, EUSO soil team chaired eight scientific sessions in person contributing to the scientific committee on relevant topics on soil pollution such as; Biochar and soil amendments, Healthy soil and the Soil

Monitoring Law, 3D and High Resolution Characterization Techniques, Compound-Specific stable Isotope Analysis and genetic in Soil Bioremediation, Oil and petroleum hydrocarbons, Risk assessment and Fate and transport models, and Advances in Ecotoxicology and Ecosystem evaluation. From the scientific perspective, four scientific contributions on soil pollution topics were presented and the scientific abstracts were submitted:

- Soil Pollution in the European Union. Diana Vieira, Felipe Yunta, Panos Panagos, Arwyn Jones, Piotr Wojda
- Assessment of accumulation of heavy metals in soils of Europe due to diffuse pollution. Felipe Yunta, Diana Vieira, Elise Van Eynde, Calogero Schillaci, Panos Panagos, Arwyn Jones, Piotr Wojda
- Identification of soils exceeding heavy metal concentrations in Europe by using the limit values from Sewage Sludge Directive. Felipe Yunta, Diana Vieira, Elise Van Eynde, Calogero Schillaci, Panos Panagos, Arwyn Jones, Piotr Wojda
- Assessment of pesticides residues in European agricultural soils. Diana Vieira, Antonio Franco, Felipe Yunta, Arwyn Jones, Piotr Wojda

Then, the EUSO team chaired some of the Sustainathon Sessions. It is a 24-hour event within Remtech Europe, going around the world non-stop.

Workshop on Soil Pollution

In 2024 a Workshop on "Soil Pollution and Remediation: Data and Knowledge Structuring, Harmonising and Sharing" was held in the JRC facilities. The main objective was to organize a comprehensive workshop, bringing together multiple Mission Soil funded projects on soil pollution (SoilWise, ISLANDR, ARAGORN, EDAPHOS, and BENCHMARKS), to harmonize data, metadata, and knowledge requirements for addressing soil pollution in Europe and, ultimately, contributing to the achievement of healthy soils in Europe by 2050 and the 2030 goals of the Green Deal. The active participation of the CEN/TC 444 in the workshop was essential for driving the standardization of methods for environmental characterization of soils. A dedicated survey was arranged and distributed to collect information, facilitate knowledge sharing, identify knowledge gaps, and foster collaboration among project coordinators and researchers involved in various soil pollution initiatives. The main conclusion was that standardized protocols and data formats are essential for comparing and integrating data from various sources, informing effective soil pollution management strategies.

Soil Pollution session at the Young Soil Researchers forum

In 2024 the 2nd Young Soil Researchers Forum a dedicated session on Soil pollution was organized. The session was organised in three different topics: Metals in soils, Emerging Pollutants and Soil Pollution Remediation. The session began by examining the impact of metals in soil pollution. Research presentations focus on the effects of soil contaminants on nutrient cycling and potential restoration measures (Ingrid Rijk, Örebro University, SE), cadmium-induced growth responses in various plant species (Christos Kikis, University of Thessaly, GR), and the role of arsenic as a soil health indicator in European topsoils (Arthur Fendrich, Laboratoire des Sciences du Climat et de l'Environnement, FR). The discussion then shifts to emerging soil pollutants, with a particular emphasis on microplastics. Presentations highlight the role of microplastics as vectors for metal(loid)s in industrial soils (Sara Alcorta, Czech University of Life Sciences, CZ) and the impact of microplastics on soil nutrients (Joanna Jesionkowska, The Open University, UK). Finally, the session explores strategies for remediating soil pollution. Researchers present findings on the urban phytoremediation potential of ornamental plants (Clara Conte, University of Genoa, IT), the application of nanoscale zero-valent iron combined with Betula pubescens to restore mining-polluted soils (Salvador Sánchez Martínez, Universidad de Oviedo, ES), and the use of stable biochar composites for complex soil remediation (María Aguinaga, Czech University of Life Sciences, CZ).

Overall, the research presented in the session on soil pollution emphasizes the need for policymakers to take a proactive approach to addressing soil pollution, and to prioritize the development of effective strategies to reduce pollution, promote remediation, and protect soil health. <u>Recordings and presentations</u> are available on the EUSO website.

Soil Pollution in Western Balkans

Soil contamination in the Western Balkans is a significant challenge, hampered by inadequate legal frameworks, lack of comprehensive field data, and insufficient site investigations. This work leading by JRC aimed to fill information gaps on soil pollution across the Western Balkans based on an extensive review of the current evidence base of the state of Western Balkans soils. The extent of pollution at country and regional level was assessed but also highlighting policy areas of concern. Establishing robust monitoring networks with standardized data collection is crucial for understanding soil health and developing effective remediation strategies. Harmonized soil monitoring and testing programs, aligned with the Green Deal and pan-EU soil initiatives, are essential for cross-border collaboration and policy implementation. This report (https://publications.jrc.ec.europa.eu/repository/handle/JRC138306) is part of the JRC project "Environment and Climate in Enlargement" and contributes to the Western Balkans Agenda on Innovation, Research, Education, Culture, Youth, and Sports, particularly in developing a soil pollution database and supporting capacity building for the Green Agenda (see also section 2.1.5.9). This work underscores the urgent need for integrated soil protection policies to ensure healthy soils and sustainable land use in the Western Balkans.

3.4 WG Soil monitoring

The Working Group on Soil monitoring aims to contribute to an integrated soil monitoring system at EU-level to assess the impact of the EU Soil Strategy for 2030 and related soil-policies.

In 2024, the WG Soil monitoring contributed to the development of a stratified sampling method that can assess soil parameters under different land uses, that gathers comprehensive data and that is minimising the cost of sampling (see also section 2.2.2). Furthermore, the WG contributed to new transfer functions. Transfer functions help the harmonisation of soil data, and consequent comparability at EU level and the possibility for integrating national and LUCAS datasets (see also section 2.2.3 and section 2.5.3.1). For these transfer functions, collaborations with EJP Soil were started. Part of this work was presented during the fourth EUSO Stakeholders Forum, with presentations from Christiano Ballabio (EUSO) on sampling design for the SMRD, and presentations on the experiences from the national soil monitoring scheme from France (Antonio Bispo, INRAE) and Finland (Aleksi Lehtonen, LUKE). <u>Recordings and presentations</u> are available on the EUSO website.

Other key activities were the visits of the Mission Soil funded projects BENCHMARKS (18-19 April 2024) and AI4SoilHealth (20 June 2024) to the JRC to discuss soil monitoring frameworks and indicators for soil health.

3.5 WG Soil biodiversity

In 2024, the Working Group on soil biodiversity fulfilled one of the actions on soil biodiversity reported in the EU Soil Strategy for 2030, namely the first-ever assessment of the distribution of antimicrobial resistance genes in the European Union's soils. The analysis was published in a highimpact journal (Dulya et al., 2024). Through an in-depth analysis of the metagenomes of 658 soil samples spanning Europe, the distribution of 241 prokaryotic and fungal genes responsible for producing metabolites with antibiotic properties and 485 antibiotic resistance genes was explored. The analyses revealed several nonparallel distribution patterns of the genes encoding sequential steps of enzymatic pathways synthesising large antibiotic groups, pointing to gaps in existing databases and suggesting potential for discovering new analogues of known antibiotics. Agricultural activity caused a continental-scale homogenization of microbial antibiotic-related machinery, emphasizing the importance of maintaining indigenous ecosystems within the landscape mosaic. Finally, general principles to facilitate the discovery of antibiotics, including principally new ones, establish abundance baselines for antibiotic resistance genes, and predict their dissemination were proposed.

Another research activity consisted in the evaluation of links between primary productivity and soil health including, for the first time, soil biodiversity parameters as measured in LUCAS Soil Biodiversity 2018 (Romero et al., 2024). Briefly, linkages between soil health and primary productivity across environmental gradients and land-use types remains poorly understood. To address this gap, a pan-European field study including 588 sites from 27 countries was examined. Among soil microbial diversity indicators, a positive association between the richness of some bacterial groups (i.e., Acidobacteria, Firmicutes and Proteobacteria) and primary productivity was found. Among microbial functional groups, primary productivity in croplands and grasslands was positively related to nitrogen-fixing bacteria and mycorrhizal fungi and negatively linked to plant pathogens. The results pointed to the importance of soil biodiversity for maintaining primary productivity across contrasting land-use types (i.e., croplands, grasslands and woodlands) in Europe. The results are published in <u>Nature Ecology & Evolution</u>.

Additionally, the Soil Biodiversity WG contributed to the <u>The State of Soils in Europe</u> report with a chapter dedicated to "Soil biodiversity change".

Finally, a session dedicated to soil biodiversity was organised as part of the 2nd Young Soil Researchers Forum. Nine early-career scientists coming not just form Europe but all over the world, had the opportunity to present their research activities and main findings. Once again, the session confirmed the increasing and lively interest in the biological component of soil and, thus, the need for its better inclusion in future soil health assessments. <u>Recordings and presentations</u> are available on the EUSO website.

3.6 WG Soil organic carbon monitoring, reporting and verification

In 2024, the WG Soil organic carbon monitoring, reporting and verification (WG SOC MRV) activities focused on supporting the Carbon Removal Certification Framework (CRCF) regulation. We organised a workshop in Ispra, bringing together modelers and carbon experts to present operational activities in carbon farming, aiming to establish a standardised baseline for the CRCF. Key projects involved included MARVIC and MRV4SOC. The workshop's objectives were to highlight operational approaches for quantifying emissions and removals in agricultural soils, present case studies demonstrating standardised baseline calculations, and facilitate interaction with JRC modelers developing the EU-standardized baseline.

Additionally, the working group fostered partnerships with key stakeholders, including Mission Soil funded projects, INRAE, and research institutions, to advance carbon farming and MRV methodologies. This collaboration led to a <u>peer-reviewed publication</u> on a modular MRV framework for soil organic carbon assessment.

Another key activity was the successful organization of a session during the Young Soil Researchers Forum – Soil Carbon Session (Monday, 14th October 2024, 14:00–16:30; see also section 2.6.2). This session featured outstanding early career scientists who presented cutting-edge research on soil carbon dynamics, from soil microbial diversity to machine learning-based carbon assessments. A comprehensive <u>book of abstract</u> was compiled, highlighting contributions such as:

- Contribution of Shoots and Roots of Legumes and Grasses to Soil Organic Carbon Stabilization Anouk Lyver
- Carbon Stock and Soil Microbial Diversity Dynamics Following Afforestation in Northeast Italy Speranza Claudia Panico
- Soil Organic Carbon Stock of Mediterranean Olive Groves: Influence of Soil Properties and Land Management – Victor Valenzuela Polo
- Assessing and Modelling Soil Organic Carbon for Healthier Soils in Temperate Agricultural Lands
 Carmen Segura Quirante
- Spatiotemporal Prediction of Soil Organic Carbon Density for Europe (2000-2022) in 3D+T Xuemeng Tian
- Benchmarking Soil Organic Carbon Concentration Provides More Robust Mineral Soil Health Assessment Across Europe than the SOC/Clay Ratio – Christopher Feeney
- Spatial Assessment of Soil Organic Carbon Storage Using XGBoost and Deep Learning on Fused Hyperspectral and TerraSAR-X Data for Agricultural Land – Harsha Vardhan Kaparthi
- Estimation of Cropland Soil Organic Carbon at National Scale in Greece Using Transformer-Based Feature Extraction – Sotirios Kechagias

The session provided a valuable platform for young researchers to engage with leading experts and foster discussions on the latest advancements in soil carbon research. <u>Recordings and presentations</u> are available on the EUSO website.

3.7 WG Nutrients

The working group on nutrients was launched in 2024 during the Fourth EUSO Stakeholder Forum. During this meeting, scientists as well as policy makers gave presentations, highlighting the broad relevance of nutrients as a topic. Presentations were given by:

- DG ENV on the evaluation of the nitrates directive.
- The Horizon Europe project NUTRIBUDGET.
- EUROSTAT on nutrient reporting and the Statistics on agricultural input and output.
- Horizon Europe project SOILMONITOR.
- Directorate General for Internal Market, Industry, Entrepreneurship and Small and mediumsized enterprises (DG GROW) on the EU Fertilizer Regulation.

- Three academic researchers presenting work on monitoring nitrogen fluxes, the European Sustainable Nutrient Initiative and micronutrient fertilizers.

<u>Recordings and presentations</u> are available on the EUSO website.

Another activity of the WG Nutrients was the organization of a session during the Young Soil Researchers Forum. Early career scientists presented their research on the impact of agronomic practices on nutrient cycles, modelling nutrients and greenhouse gas emissions and novel fertilizers. Also these <u>presentations and recordings</u> are available on the EUSO website.

4 Planned developments for the EUSO in 2025

Also in 2025, the EUSO will continue to work on fulfilling its main objectives, including (1) supporting policy making related to soils, (2) supporting the development of an operational EU-wide soil monitoring system (3) contributing to the monitoring of soil health and soil policies, (4) contributing to sharing data and knowledge about EU soils, (5) supporting soil research and innovation, and (6) supporting stakeholder interactions and citizen engagement regarding soils. Activities will also be aligned with the <u>EU Strategic Agenda for 2024-2029</u> and the <u>European</u> <u>Commission's priorities for 2024-2029</u>, such as competitiveness and sustaining our quality of life. Highlights of the EUSO's planned developments and activities in 2025 are listed in the next sections.

4.1 Policy support

The EUSO will further support EU soil-related policymaking. Some of the planned deliverables for 2025 are listed below:

- Standardized baseline for carbon farming: The EUSO will work on a methodology for quantifying a standardized baseline, to be used for Greenhouse Gas Inventories and the quantification of carbon farming activities. The methodology should be able to estimate the average regional emissions/removal of CO₂ from mineral soils for any given region in the EU. The deliverable will propose a data-driven, process-based and hybrid modelling approach to estimate the standardized baseline for mineral soils across the EU. In 2025, a new administrative agreement will be signed between the JRC and DG CLIMA to further develop the methodology underlying the Carbon Removal Certification Regulation. This work will contribute to the <u>EU Carbon Removal Certification Framework</u> (CRCF) as well as to the <u>4 per mille initiative</u>.
- Carbon Removal on Land: The pathway to climate neutrality foresees the contribution of the land to offset the residual sectorial greenhouse gas emissions by 2050, increasing the carbon removals from soils. The EU CRCF entered into force in December 2024, aiming to create a voluntary framework for certifying carbon farming, carbon storage products, and permanent carbon removals. Through the Carbon Removals on Land project, the JRC is supporting DG CLIMA in developing and evaluating carbon farming methodologies. At the end of the project (October 2025), the JRC will provide a final report describing the application of the methodology which results in an ensemble of models applying the standardised baselines and the results obtained in test areas across the EU. For these collaborations are ongoing with different Mission Soil funded projects.
- Soil pollution dashboard and possible pollution watch list. Development of the first fully dedicated soil pollution dashboard featuring the most up to date indicators on diffuse soil pollution and eco-toxicological risk, as well as the inclusion of potentially contaminated sites (see also section 4.3.2).
- First assessments to support the EU declaration as affected by desertification: Under the United Nations Convention to Combat Desertification (UNCCD), the EU has declared itself to be affected by desertification and will draw up an action programme at EU level to combat desertification. The EUSO will support both the EU and the Member States to apply the methodology for reporting desertification at the UNCCD. The support will include both the production of relevant datasets (e.g. loss of organic carbon, soil erosion, and land productivity losses) and the development of indicators suited for assessing desertification at the EU level.

- Impacts of changing diets to environmental conditions in the EU: <u>EAT-Lancet</u> healthy diets recommendations are the most extensive diet recommendation that has a potential EU adoption. The EUSO will address the environmental impacts of these recommendations and will develop scenarios for 2050 and 2100.
- Spectroscopy and innovative remote sensing-based techniques for soil monitoring: The EUSO will support Member States by supplying earth observation products to monitor soil descriptors listed in the SMRD. Radiometric data from the LUCAS soil databases will be used as a preliminary step to identify discriminant wavelengths and spectral indices that can be applied to data from earth observation. The results can aid the monitoring of soil descriptors listed in the SMRD through earth observation.
- Soil Health Dashboard for the Western Balkans: The adoption, implementation and enforcement of the EU acquis Chapter 27 on Environment and Climate Change is an obligation for accessing countries in the framework the "Stabilisation and association process". Moreover, the <u>Guidelines for the implementation of the Green Agenda for the Western Balkans</u> define priority areas for interventions and initiatives to fulfil the principles of the EU Green Deal in this region. Soil conditions are recognized as a vital element of these priorities. A new Soil Health Dashboard for the Western Balkans will provide an overview of soil health in the region.
- EU Soil Footprint Calculator: With a view to the Mission Soil's specific objective to reduce the EU's global footprint on soils, the EUSO will support actions to help track and measure the impacts of EU industrial and consumer demands on soils and their health, both within and beyond EU borders. This task will build on ongoing activities at the JRC that are investigating methods to calculate the environmental impacts of consumption patterns and how changes in lifestyle may affect people's personal footprint.
- Changes in soil health in Europe: Building on the State of Soils in Europe report (Arias-Navarro et al., 2024), the EUSO will produce a report that describes temporal changes in soil health in Europe. The report will provide a mechanism for tracking progress towards meeting the Mission Soil objectives. The report will address the change of soil health in the EU during the last 12 years and investigate the main reasons for the observed changes.
- Spatial Agricultural Information System (SAIS) Interoperability platform: The EUSO will produce a report focussing on the implementation choices for the SAIS system to become an interoperable platform with a selected number of systems and databases coming from other JRC Units and DG AGRI. This will include interoperability interfaces and mechanisms that will ensure smooth data exchanges provided some harmonisation mechanisms.

4.2 EU-wide soil monitoring

In 2025, the EUSO will process the first results of the laboratory analysis of the 2022 LUCAS Soil Module. The EUSO will also prepare a report presenting an overview of the used laboratory analysis, describing the spatial variability of soil properties by land cover class and presenting a comparative analysis of the soil properties.

In addition, the EUSO will adapt the current LUCAS Soil Module's approach to match the needs of the SMRD. For this, the EUSO will study how to change the current sampling design to ensure representative coverage while complementing developments in Member States monitoring capacities. In addition, new and modified soil descriptors need to be integrated in the upgraded LUCAS Soil Module. This will require the development of underpinning methodologies and logistical

solutions, including new sampling or measurement tools (e.g. subsoil compaction), as well as the training material for surveyors for the new or modified elements, define methodological details for adequate sample handling and testing, etc.).

4.3 Monitoring soil health and policies

4.3.1 EUSO Soil Degradation Dashboard

Further developments of the EUSO Soil Degradation Dashboard are planned in 2025. These developments are intended to complete the assessment of the state of soil degradation at the EUlevel, and to provide more functionalities and insight in the provided datasets for the dashboard users. Some of these planned developments are described below.

- Temporal datasets for more indicators will be included in the dashboard, as soon as they are available.
- New functionalities will be added to the EUSO Soil Degradation Dashboard, such as
 - a correlation matrix showing the correlation of two degradation processes (Figure 24), •
 - a graph comparing the percentage of degraded soils in the Member States (Figure 25),
 - a tool allowing users to set the thresholds determining healthy/unhealthy soils, and •
 - a tool providing more insights in source data and associated uncertainties.

Figure 24. Correlation matrix for the indicators in the EUSO Soil Degradation Dashboard.



Correlation matrix

Source: JRC analysis.

Highcharts.com

Figure 25. Comparison of the percentages of degraded soils in the Member States for each individual soil degradation indicator.



— The EUSO Soil Degradation Dashboard and the assessment of the state of soil degradation in the EU will be updated according to the availability of **new data** (e.g. output of Mission Soil funded projects) and with the implementation of EU and national soil policies. For this, the EUSO will work in close collaboration with the Mission Soil funded projects. The interactions will mainly be organised through the Mission Soil Cluster on Indicators and Monitoring, next to bilateral meetings, the EUSO Stakeholders Forum and the EUSO Working Groups. This collaborative work will focus on the further development and refining of the indicator framework for soil health in the EU. This includes refining and updating datasets for the soil degradation indicators, refining thresholds and developing a soil health index.

4.3.2 EU Soil Health Portal

In 2025, EUSO plan to upgrade the EUSO Soil Degradation Dashboard to a new portal, the **EU Soil Health Portal**. This to reflect the requirements of the digital soil health data portal specified in the proposed Soil Monitoring and Resilience Directive. For this, the EUSO dashboard should integrate data provided through the monitoring of soil health by Member States. On the basis of Members States harmonised data and other sources, aggregated maps and indicators should be developed for the policy level covering the whole set of minimum soil health indicators, in particular covering those descriptors where no maps are currently available (e.g. potential basal respiration, water holding capacity, certain pollutants, subsoil compaction, salinity, etc.).

As part of this EU Soil Health Portal, the EUSO will develop a **Soil Pollution dashboard and possible Pollution Watch list**, featuring the most up to date indicators on diffuse soil pollution and ecotoxicological risk and potentially contaminated sites. Based on LUCAS 2015-2018-2022 surveys, the first large-scale trends on soil pollution by metals and pesticides are also envisaged. As a complement, a technical report on the procedure and criteria for the selection and classification of soil polluting substances to be included in the SMRD and possible Watch lists will be produced in collaboration with Member States, with the aim to serve a guideline for soil monitoring system targeting soil pollution.

4.3.3 EUSO Soil Policy Actions Tracker

The EU Soil Strategy Actions Tracker (see section 2.3.2) is the first step towards a more complete **EUSO Soil Policy Actions Tracker**, monitoring all EU policy actions relevant to soils. The EUSO Soil Policy Actions Tracker will include all EU policy actions related to soils and will not exclusively focus on the EU Soil Strategy for 2030. This EUSO Soil Policy Actions Tracker will be updated twice a year to illustrate progress in policy implementation. As such, EUSO aims to develop a tool to regularly assess the progress on formal EU policy commitments on soil.

4.3.4 African Soil Health Dashboard

A new African Soil Health Dashboard is planned for 2025. It will contain the most updated datasets concerning threats to African soil health, including compiled global and local data, as well as model outputs. The African Soil Health Dashboard will allow users to interact with maps representing soil threats and to create soil health scores according to pre-defined or custom criteria. The tool will also contain socio-economic information, allowing users to define priority actions by comparing the current state of soils against relevant indexes. A policy roadmap section will also be included, facilitating the conversion of the calculations into practical actions.

4.4 Enhancing the functionality of the European Soil Data Centre

In 2025, further steps will be taken to enhance the capacity and functionality of the ESDAC. As such, it is aimed to consolidate ESDAC as the single-stop-shop for soil related data in the EU. Further activities include for instance adding new datasets coming from EUSO research activities and collaborations with Mission Soil funded projects. Also, EUSO will further promote ESDAC as the reference place for soil related data and knowledge. This to ensure that relevant stakeholders find their way to ESDAC for soil related data and knowledge.

Steps will also be taken to evolve towards ESDAC 3.0 to integrate existing and future data from Member States and LUCAS Soil Survey data (as well as data stemming from other parties) into a digital soil health data portal (see also section 4.3.2), in compliance with the proposed Soil Monitoring and Resilience Directive. ESDAC 3.0 would include data from Member States, relevant results from Mission Soil funded projects, as well as novel data flows from technologically innovative streams such as COPERNICUS, drones, sensors for precision agriculture and citizen science.

4.5 Supporting soil research and innovation

The EUSO will continue to contribute to advanced scientific knowledge on soils in the EU.

In-house research to be delivered in 2025 includes, among others:

- Impact of pesticides in soil biodiversity
- Changes in soil health in the EU during the last 15 years
- A soil carbon saturation index
- The impact of healthy diets in soil properties and biodiversity conservation
- The assessment of productivity trends and environmental benefits due to organic agriculture expansion
- Quantification of land degradation and vulnerability indexes
- A pan-European assessment of gully erosion
- Assessments on soil salinity
- The global impacts of forest fires in soil losses.

Next, the EUSO will also start a new **Collaborative Doctoral Partnership** (CDP), together with Aarhus University, Denmark. The CDP will be on peatland mapping at national and European scales. More information and call for applicants is available at this <u>link</u>. Moreover, in the 2025 CDP call, higher education institutes and universities can apply to partner up with the JRC on one of 25 collaboration topics. Successful higher education institutes or universities will then proceed to jointly design, host, and supervise PhD projects with the JRC. Successful applicants will have the opportunity to define a PhD project in collaboration with the JRC. The application deadline for this call is 18 March 2025. EUSO has proposed the Topic 12 (of 25): "Improving soil health to increase water quality and reduce eutrophication". More information at this <u>link</u>.

In addition, EUSO will continue to collaborate and interact in 2025 with relevant **Mission Soil funded projects**. This will include: (i) regular bilateral meetings with the projects, (ii) interactions and presentations during the EUSO Stakeholders Forum and EUSO Working Groups, and (iii) collaboration within the Mission Soil Clusters. Existing collaboration (see section 2.5.2) will be strengthened and new collaborations will be started. A few examples of planned activities and collaborations are listed below:

— Mission Soil Cluster on Indicators and Monitoring. Collaborations within this Mission Soil Cluster will result in (i) refining the work on soil health indicators and completing the assessment of soil health at the EU-level; (ii) identifying new indicators for soil health at the EU-level; (iii) identifying knowledge gaps; and (iv) elaborating a roadmap for the further development of indicators and soil health monitoring. Close collaborations are especially planned with the projects BENCHMARKS and AI4SoilHealth. — Mission Soil Cluster on Data and Knowledge Management. The work in the framework of this Mission Soil will result in a more structured research data management and templates for metadata for outcomes of Mission Soil funded projects. Close collaborations are especially planned with the SoilWise project. SoilWise will provide an integrated and actionable access point to scattered and heterogeneous soil data and knowledge in Europe and will design a repository for at least a decade to support EUSO evolvement accordingly (a EU-EUSO Projects Data Catalogue).

4.6 Supporting stakeholder interactions and citizen engagement

The EUSO will continue to engage stakeholders and citizens on soil-related topics. To do so, the EUSO will (co-)organise several activities to engage soil awareness among citizens and to bring together stakeholders. Highlights for 2025 include the Fifth EUSO Stakeholders Forum, which will be organised on-site in Ispra (Italy), and the third European Mission Soil Week, which will take place in Copenhagen (Denmark). Another important event is the workshop on advancing soil literacy, held on 13-14 March 2025 in Ispra (Italy) and coorganised by the EUSO, Mission Soil and the European Soil Awareness Network.

Furthermore, the EUSO will participate in many soil-related conferences in 2025, including among others:

- <u>2nd European Carbon Farming Summit</u> in Dublin (Ireland),
- EGU General Assembly 2025 in Vienna (Austria),
- 2025 Soil Health Now Conference in Wageningen (The Netherlands),
- EUROSOIL 2025 in Seville (Spain),
- <u>Remtech Expo 2025</u> in Ferrara (Italy),
- <u>19th international RAMIRAN Conference</u> in Wageningen (The Netherlands).

5 Conclusions

This report highlights the objectives of the EUSO and its main activities and outcomes in 2024. The EUSO aims to be the principal provider of soil-related data and knowledge at the EU-level. As such, it supports the implementation of all soil related objectives of the European Green Deal, and more specific the implementation of the EU Soil Strategy for 2030 and the proposed Soil Monitoring and Resilience Directive (SMRD).

Through its activities in 2024, the EUSO provided policy support to a wide range of soil related areas. This includes the proposed SMRD, the Carbon Removal Certification Framework, and the Mission Soil. Another highlight was the launch of the science for policy report 'The state of soils in Europe', discussing the interplay between drivers, pressures and impacts on soil in Europe. The EUSO also updated the EUSO Soil Degradation Dashboard, with new datasets and new functionalities. In addition, the EUSO launched in 2024 the EU Soil Strategy Actions Tracker, a new tool to track the progress of policy actions listed in the EU Soil Strategy for 2030. Furthermore, in 2024, the EUSO contributed to sharing data and knowledge about EU soils and supported soil research and innovation. Also in 2024, the EUSO supported stakeholders' involvement and citizen engagement regarding soils, through the (co-)organisation of the Fourth EUSO Stakeholders Forum, the Second Young Soil Researchers Forum and the EU Mission Soil Week.

Overall, in 2024, the EUSO has successfully taken up its role to be the principal provider of soilrelated data and policy support at the EU-level and has achieved its operational objectives. Also in 2025, the EUSO will continue to take up this role. The EUSO will further support EU soil-related policymaking and will help to monitor, safeguard and restore EU-soils, by providing data, tools and knowledge. As such, the EUSO will continue to play its significant role in the implementation of the EU policy objectives in relation to soils.

References

Arias-Navarro, C., Baritz, R., Jones, A., 2024. The state of soils in Europe – Fully evidenced, spatially organised assessment of the pressures driving soil degradation. Publications Office of the European Union. https://doi.org/10.2760/7007291

Ballabio, C., Jones, A., Panagos, P., 2024. Cadmium in topsoils of the European Union–An analysis based on LUCAS topsoil database. Science of the Total Environment 912, 168710.

Ballin, M., Barcaroli, G., 2013. Joint determination of optimal stratification and sample allocation using genetic algorithm. Survey Methodology 39, 369–393.

Bethel, J., 1989. Sample allocation in multivariate surveys. Survey methodology 15, 47-57.

Broothaerts, N., Breure, T., Belitrandi, D., Havenga, C., Peeters, B., Probst, C., Barbero, M., Panagos, P., Jones, A., 2025. EU soil strategy actions tracker – A tool to track the actions listed in the EU soil strategy for 2030.

Broothaerts, N., Panagos, P., Jones, A., others, 2024. A proposal for soil health indicators at EU-level. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/8953204

Das, S., Jain, M.K., Gupta, V., McGehee, R.P., Yin, S., de Mello, C.R., Azari, M., Borrelli, P., Panagos, P., 2024. GloRESatE: A dataset for global rainfall erosivity derived from multi-source data. Scientific Data 11, 926.

De Rosa, D., Ballabio, C., Lugato, E., Fasiolo, M., Jones, A., Panagos, P., 2024. Soil organic carbon stocks in European croplands and grasslands: How much have we lost in the past decade? Global Change Biology 30, e16992.

Dornik, A., Chețan, M.A., Crișan, T.E., Heciko, R., Gora, A., Drăguț, L., Panagos, P., 2024. Geospatial evaluation of the agricultural suitability and land use compatibility in Europe's temperate continental climate region. International Soil and Water Conservation Research.

Dulya, O., Mikryukov, V., Shchepkin, D.V., Pent, M., Tamm, H., Guazzini, M., Panagos, P., Jones, A., Orgiazzi, A., Marroni, F., others, 2024. A trait-based ecological perspective on the soil microbial antibiotic-related genetic machinery. Environment International 190, 108917.

Feeney, C.J., Bentley, L., De Rosa, D., Panagos, P., Emmett, B.A., Thomas, A., Robinson, D.A., 2024. Benchmarking soil organic carbon (SOC) concentration provides more robust soil health assessment than the SOC/clay ratio at European scale. Science of The Total Environment 951, 175642.

Fendrich, A., Ciais, P., Panagos, P., Martin, P., Carozzi, M., Guenet, B., Lugato, E., 2024a. Including land management in a European carbon model with lateral transfer to the oceans. Environmental Research 245, 118014.

Fendrich, A., Van Eynde, E., Stasinopoulos, D.M., Rigby, R.A., Mezquita, F.Y., Panagos, P., 2024b. Modeling arsenic in European topsoils with a coupled semiparametric (GAMLSS-RF) model for censored data. Environment International 108544.

Gupta, S., Borrelli, P., Panagos, P., Alewell, C., 2024. An advanced global soil erodibility (K) assessment including the effects of saturated hydraulic conductivity. Science of the Total Environment 908, 168249.

Panagos, Ballabio, C., Poesen, J., Lugato, E., Scarpa, S., Montanarella, L., Borrelli, P., 2020. A soil erosion indicator for supporting agricultural, environmental and climate policies in the European Union. Remote Sensing 12, 1365.

Panagos, P., Borrelli, P., Jones, A., Robinson, D.A., 2024a. A 1 billion euro mission: A Soil Deal for Europe. European Journal of Soil Science 75, e13466.

Panagos, P., Broothaerts, N., Ballabio, C., Orgiazzi, A., De Rosa, D., Borrelli, P., Liakos, L., Vieira, D., Van Eynde, E., Arias Navarro, C., others, 2024b. How the EU Soil Observatory is providing solid science for healthy soils. European Journal of Soil Science 75, e13507.

Panagos, P., De Rosa, D., Liakos, L., Labouyrie, M., Borrelli, P., Ballabio, C., 2024c. Soil bulk density assessment in Europe. Agriculture, Ecosystems & Environment 364, 108907.

Panagos, P., Matthews, F., Patault, E., Michele, C.D., Quaranta, E., Bezak, N., Kaffas, K., Patro, E.R., Auel, C., Schleiss, A.J., Fendrich, A., Liakos, L., Eynde, E.V., Vieira, D., Borrelli, P., 2024d. Understanding the cost of soil erosion: An assessment of the sediment removal costs from the reservoirs of the European Union. Journal of Cleaner Production 434, 140183. https://doi.org/10.1016/j.jclepro.2023.140183

Panagos, P., Van Liedekerke, M., Borrelli, P., Köninger, J., Ballabio, C., Orgiazzi, A., Lugato, E., Liakos, L., Hervas, J., Jones, A., others, 2022. European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies. European Journal of Soil Science 73, e13315.

Prăvălie, R., Borrelli, P., Panagos, P., Ballabio, C., Lugato, E., Chappell, A., Miguez-Macho, G., Maggi, F., Peng, J., Niculiță, M., others, 2024. A unifying modelling of multiple land degradation pathways in Europe. Nature Communications 15, 3862.

Romero, F., Labouyrie, M., Orgiazzi, A., Ballabio, C., Panagos, P., Jones, A., Tedersoo, L., Bahram, M., Guerra, C.A., Eisenhauer, N., others, 2024. Soil health is associated with higher primary productivity across Europe. Nature ecology & evolution 8, 1847–1855.

Schillaci, C., Jones, A., Vieira, D., Munafò, M., Montanarella, L., 2023. Evaluation of the United Nations Sustainable Development Goal 15.3. 1 indicator of land degradation in the European Union. Land Degradation & Development 34, 250–268.

Van Eynde, E., Fendrich, A.N., Ballabio, C., Panagos, P., 2023. Spatial assessment of topsoil zinc concentrations in Europe. Science of the Total Environment 892, 164512.

Van Eynde, E., Yunta Mezquita, F., Panagos, P., Jones, A., others, 2024. Soil fertility in the EU taxonomy for the construction of new buildings.

Vieira, D., Borrelli, P., Jahanianfard, D., Benali, A., Scarpa, S., Panagos, P., 2023a. Wildfires in Europe: Burned soils require attention. Environmental research 217, 114936.

Vieira, D., Franco, A., De Medici, D., Martin Jimenez, J., Wojda, P., Jones, A., 2023b. Pesticides residues in European agricultural soils – Results from LUCAS 2018 soil module. Publications Office of the European Union. https://doi.org/doi/10.2760/86566

Vieira, D., Yunta, F., Baragaño, D., Evrard, O., Reiff, T., Silva, V., de la Torre, A., Zhang, C., Panagos, P., Jones, A., others, 2024. Soil pollution in the European Union–An outlook. Environmental Science & Policy 161, 103876.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses: a guide to conservation planning. Department of Agriculture, Science and Education Administration.

Yunta Mezquita, F., Van Liedekerke, M., Fernández Ugalde, O., Németh, T., Balázs, R., Keresztes, M., Weiszburg, T., Rábl, E., Királyné Tóth, J., Gazsi, Z., others, 2024. Clay mineral inventory in soils of Europe based on LUCAS survey soil samples.
List of abbreviations and definitions

Abbreviations	Definitions
 As	Arsenic
AT	Austria
BE	Belgium
САР	Common Agricultural Policy
CDP	Collaborative Doctoral Partnership
CENELEC	European Electrotechnical Committee for Standardization
CEN TT	European Committee for Standardization Technical Committees
CN	China
СН	Switzerland
CO ₂	Carbon dioxide
СОР	Conference of the parties
CRCF	Carbon Removal Certification Framework
CZ	Czech Republic
DE	Germany
DG AGRI	Directorate-General for Agriculture and Rural Development
DG CLIMA	Directorate-General for Climate Action
DG CNECT	Directorate-General for Communications Networks, Content and Technology
DG ENV	Directorate-General for the Environment
DG GROW	Directorate General for Internal Market, Industry, Entrepreneurship and Small and medium-sized enterprises

	Abbreviations	Definitions
-	DG INTPA	Directorate-General for International Partnerships
	DG RTD	Directorate-General for Research and Innovation
	DK	Denmark
	DNA	Deoxyribonucleic acid
	EEA	European Environmental Agency
	EGU	European Geoscience Union
	EIONET	Environment Information and Observation Network
	EJP	European Joint Programme
	EMSW	European Mission Soil Week
	ENSA	European Network for Soil Awareness
	ES	Spain
	ESA	European Space Agency
	ESDAC	European Soil Data Centre
	EU	European Union
	EU-HYDI	European Hydropedological Data Inventory
	EUSO	EU Soil Observatory
	FAO	Food and Agriculture Organization
	FR	France
	GB	United Kingdom
	GHGI	Greenhouse Gas Inventory
	GR	Greece
	На	hectare

Abbreviations	Definitions
 IACS	Integrated Administration and Control System
IE	Ireland
IN	India
ISO TC	International Organization for Standardization Technical Committee
IT	Italy
JRC	Joint Research Centre
К	soil erodibility
Ksat	hydraulic conductivity
LUCAS	Land Use/Cover Frame area Survey
LULUCF	Land use, land use change and forestry
MRV	Monitoring, reporting and verification
MS	Member State
Ν	Nitrogen
NL	Netherlands
O/T SOC	observed/typical soil organic carbon
PFAS	Per- and polyfluoroalkyl substances
PMEF	performance monitoring and evaluation framework
POC	Particulate organic carbon
PL	Poland
РТ	Portugal
RO	Romania

Abbreviations	Definitions
SAIS	Spatial Agricultural Information System
SDG	Sustainable Development Goals
SE	Sweden
SMRD	Soil Monitoring and Resilience Directive
SOC	Soil organic carbon
t	tonne
UNCCD	United Nations Convention to Combat Desertification
UK	United Kingdom
UN	United Nations
US	United States of America
WG	Working Group
WPE	Working Party on the Environment
yr	year
YSRF	Young Soil Researchers Forum
ZPMO	Zero pollution monitoring and outlook

List of boxes

Box 1. Scopus-indexed journal papers published by the EUSO in 2024. EUSO team members are underlined	34
Box 2. JRC technical reports published by the EUSO team in 2024. EUSO team members are underlined	.38
Box 3. Science for policy reports, published by and contributed to the EUSO team in 2024. EUSO team members are underlined.	38
	50

List of figures

Figure 1. EUSO's main activities and outcomes in 2024.	7
Figure 2. The main objectives of the EU Soil Observatory	9
Figure 3 . Framework for a standardised baseline development from repeated LUCAS that were used to train a regression model (upper panel) and a meta-model built upor pan-European simulations (lower panel), both extrapolated at a regional scale (EU-wic approach).	soil samples n DayCent le ensemble
Figure 4. The state of soils in Europe report	
Figure 5. Thematic posters developed based on the key findings of the state of soils i report.	in Europe 15
Figure 6. Overview of the LUCAS Soil Module	20
Figure 7 . EUSO Soil Degradation Dashboard and its convergence of evidence map (ind number of soil degradation processes likely to be present) and speedometer (indicatin proportion of land likely to be affected by one or more soil degradation processes or b in the EU)	dicating the Ig the Dy soil sealing 23
Figure 8 . Map indicating changes between two versions of the dashboard, i.e. version 2023 (including 15 indicators) and version of June 2024 (including 19 indicators)	of February 25
Figure 9. Summary of the status of the actions included in the EU Soil Strategy for 20	030 26
Figure 10. Datasets added to ESDAC in 2024	
Figure 11. Number of downloads of the datasets added to ESDAC in 2024	
Figure 12. Trend in ESDAC distributed datasets	
Figure 13 . Number of ESDAC distributed datasets per country in 2024 (county codes in the list of abbreviations).	can be found 32
Figure 14. Number of ESDAC distributed datasets in 2023 according to institutional t	ype33
Figure 15. Share of ESDAC distributed datasets according to category	
Figure 16. Most downloaded ESDAC datasets in 2024	
Figure 17. Fourth EUSO Stakeholders Forum	
Figure 18. Second Young Soil Researchers Forum.	
Figure 19. Graphical summary of the European Mission Soil Week 2024	
Figure 20. New formatted EUSO/ESDAC newsletters.	
Figure 21. EUSO Working Groups active in 2024	
Figure 22. Methods and input for estimating sediment remediation costs.	
Figure 23. Status of the EU_ERPlot data compilation	

Figure 24. Correlation matrix for the indicators in the EUSO Soil Degradation Dashboard.	62
Figure 25. Comparison of the percentages of degraded soils in the Member States for each	
individual soil degradation indicator	63

List of tables

Table 1 . Soil degradation indicators included in the EUSO Soil Degradation Dashboard, and their	
respective thresholds and data sources	.24

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (<u>european-union.europa.eu/contact-eu/meet-us_en</u>).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
- at the following standard number: +32 22999696,
- via the following form: european-union.europa.eu/contact-eu/write-us_en.

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (<u>european-union.europa.eu</u>).

EU publications

You can view or order EU publications at <u>op.europa.eu/en/publications</u>. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (<u>european-union.europa.eu/contact-eu/meet-us_en</u>).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (<u>eur-lex.europa.eu</u>).

EU open data

The portal <u>data.europa.eu</u> provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society



EU Science Hub Joint-research-centre.ec.europa.eu

