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A review of 2022 activities

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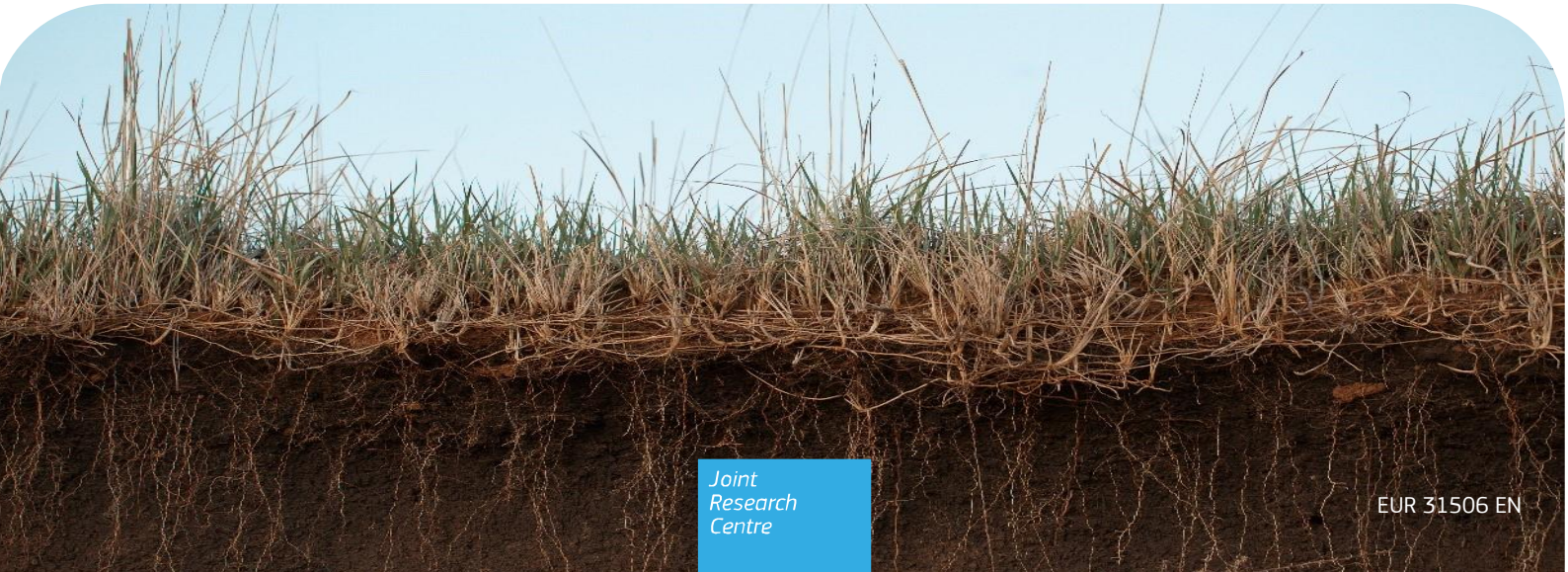
2023



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Contents

Abstract

This report presents the activities of the EU Soil Observatory (EUSO) that took place during 2022. Through its five main objectives, the EUSO contributes to improving the monitoring of soils, to creating and sharing knowledge and data about EU soils, in particular producing tailored outputs in support of policy development and to the wider public. These activities feed into the overarching knowledge management objective under which the EUSO provided extensive policy support to a range of policy areas, notably the upcoming Soil Health Law and the Horizon Europe's Soil Mission.

A key element of the EU Soil Observatory are the six EUSO Working Groups (WG) that aim to discuss policy or technical advances on a particular topic. Their activities in 2022 were diverse and ranged from providing policy support (Soil Monitoring, Soil Pollution WGs), technical progress on integration of soil data (Soil Data WG) or advancing scientific knowledge about soils (Soil Erosion WG).

This report also highlights the developments to be expected in 2023. In particular, the EUSO will produce reports on soil pollution, soil organic carbon trends, pesticides in soils, land degradation and a soil fertility index and work on the state of soil health in the EU. A key development will be the publication of the EUSO soil health dashboard. The EUSO will support dedicated Soil Mission research projects and will continue to provide support for the upcoming Soil Health Law proposal. The EUSO is also planning a 2023 EU Soil Week.

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Authors

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Executive summary

This report presents the activities of the EU Soil Observatory (EUSO) that took place during 2022. It also highlights main messages drawn from these activities and the developments to be expected in 2023.

Context

The EU Soil Observatory aims to be the primary knowledge and data hub on soil for European institutions and external stakeholders. Through its five main objectives, the EUSO contributes to improving the monitoring of soils (2.1.1 EU-wide soil monitoring system), to creating (2.1.2 Research & Innovation) and sharing (2.1.3 ESDAC) knowledge and data about EU soils, in particular producing tailored outputs in support of policy development (2.1.5 policy monitoring) and to the wider public (2.1.4 citizen engagement). These activities feed into the overarching knowledge management objective of EUSO (2.1.6 knowledge management).

EUSO outcomes towards its objectives

The EUSO supports the development of an **EU-wide harmonised soil monitoring system**, by supporting work to develop, compare and integrate national or regional soil monitoring activities at EU level whilst providing an EU-wide monitoring service through the LUCAS Soil Module. In 2022, the EUSO coordinated the soil module of the 2022 survey, which following a focus on soil organic carbon accounting saw a doubling in the number of targeted locations. In close coordination with the EJP-Soil Programme, the EUSO, supported a joint sampling exercise with a selection of Member States to facilitate the comparison of LUCAS and national soil monitoring systems. In 2022, the EUSO also published the results of the 2018 LUCAS Soil campaign. With the LUCAS Soil survey, the EU Soil Observatory continues to provide an essential and unique soil monitoring service at the EU level. Strategically timed between the publication of the EU Soil Strategy and the upcoming Soil Health Law, the LUCAS 2022 soil campaign could be used to establish a baseline from which to measure the success of the European Green Deal policies.

In support to its **Research & Innovation** objective, the JRC EU Soil Observatory team directly contributed to advance scientific knowledge and understanding about soils in the EU with 38 new scientific publications in 2022. In addition, the EUSO is actively involved in the implementation of the Horizon Europe Mission 'A Soil Deal for Europe'. In addition to supporting the development of topics under the research calls issues as part of the Mission's Annual Work Programme, the EUSO is responsible for the Mission's soil monitoring operational objective. Discussions are ongoing regarding the role of the EUSO in preserving the legacy and usability of the outcomes of projects funded by the Horizon Europe Soil Mission. In 2022, the EUSO started to develop collaboration agreements with some of the Mission's initial research projects - whose activities most align with EUSO's objectives – with a view to engage in a steering role to ensure alignment and synergies of research outcomes.

ESDAC is at the core of the EU Soil Observatory. The ESDAC platform provides the scientific and data management foundation on which other activities can build. An ever-evolving platform, ESDAC has grown substantially over the past years, both in terms of content hosted and number of users. In 2022, ESDAC continued to be updated and improved to support growing knowledge needs: 14 new datasets were added to the ESDAC platform while 17% more datasets were distributed than in 2021, in response to a growing user demand. This reflects the increasing policy relevance of soil.

A key development in terms of **monitoring the state of soil health** has been the efforts on the EUSO soil health dashboard. A prototype of the EUSO soil health dashboard, developed in the autumn 2022, provides, for the first time, a spatial perspective into the state of soil health in the EU. Currently based on a limited set of indicators, the EUSO soil health dashboard prototype will be improved and enriched as new evidence becomes available.

With regards to **policy support and knowledge management,** the EU Soil Observatory contributed extensively throughout the year to the preparation of the legislative proposal of the EU Soil Health Law (due in June 2023). It also contributed to the development of the Horizon Europe Soil Mission Work Programme for 2023-2024, as well as a wide range of soil-related policy developments and high-level reports, by providing evidence or supporting their implementation. The EUSO provided a contribution to the Nature Restoration Law proposal, led the development of the soil component of the JRC's Zero Pollution Outlook Report and the EEA's Zero Pollution Monitoring Assessment, carried out an assessment of policy options for the Sewage Sludge Directive as well as providing indicators for the Common Agricultural Policy. The EUSO team also contributed to international reports such as the IPCC's Sixth Assessment Report, the Global Peatlands Assessment and the Soil Atlas of Asia.

The EUSO activities to support **citizen engagement** are diverse and take place throughout the year. To bring its community together, the EUSO organises annually the EUSO Stakeholder Forum, an open and inclusive event which provides an opportunity to engage with the European soil community, in its broadest sense – from soil scientists, policy makers, regional, national and international bodies, to interested citizens. The second edition of the EUSO Stakeholder Forum took place over three days, from Monday 24th to Wednesday 26th October 2022. In 2022, the EUSO Stakeholder Forum was attended by almost 1,000 participants. It included the participation of the Slovak State Secretary for Agriculture and Rural Development, several Commission services and a total of over 50 presentations addressing topics from soil health to Living Labs. The event received very positive feedback. With participants from over 70 countries, the EUSO Stakeholder Forum demonstrated the high level of interest in efforts by the EU and Member States to develop policies to protect soils while enhancing the ecosystem services that they provide. For the next edition, the EUSO is investigating options to incorporate the EUSO Stakeholder Forum within a 2023 EU Soil Week

Activities of the EUSO Working Groups

A key element of the EU Soil Observatory, the EUSO Working Groups (WG) aim to discuss technical advances on a particular topic. They are chaired by EUSO staff and are composed of relevant topical experts from academia, businesses or policy experts. The EUSO Working Groups develop their own work agenda with a view to provide relevant advances to current scientific and policy questions.

Five Working Groups were established during the 2021 EUSO Stakeholder Forum on the following topics: Soil Erosion, Soil Data Sharing and Integration, Soil Pollution, Soil Monitoring and Soil Biodiversity. A Working Group on Soil Carbon Monitoring, Reporting and Verification was additionally created in 2022.

The work programme of the EUSO Working Groups in 2022 was diverse and ranged from providing policy support (Soil Monitoring WG in support to the Soil Health Law, Soil Pollution WG in developing the Clean Soil Outlook report), to technical progress on integration of soil data (Data Sharing WG) or advancing scientific knowledge about soils (Soil Erosion WG).

Related and future EUSO work

In 2023, the EUSO will work across a number of topics, in the framework of the JRC Work Programme for 2023-2024, including on soil pollution, soil organic carbon trends, pesticides in soils, land degradation, soil fertility index and on the state of soil health in the EU. Several developments are also foreseen for the EUSO soil health dashboard, including adding new datasets and functionalities to improve the accuracy and transparency of the current EU soil health assessment. The EU Soil Observatory is also expected to grow with the support of dedicated Soil Mission research projects, with which the EUSO team will closely engage to ensure alignment of their activities. The EUSO team will continue to provide direct support to DG ENV, by building the evidence base to support the development of the upcoming Soil Health Law proposal, planned to be adopted in June 2023. Finally, from a stakeholder perspective, the EUSO is planning an EU Soil Week that would bring together the EUSO Stakeholder Forum and Soil Mission communities.

1 Introduction – The EU Soil Observatory

1.1 What is the EU Soil Observatory

Launched in December 2020, the EU Soil Observatory (EUSO) is the principal provider of reference data and knowledge at EU level for all matters relating to soil.

The EUSO is evolving to be a dynamic and inclusive platform that supports EU soil-related policymaking. It provides the relevant Commission services and the broader soil user community with the knowledge and data flows needed to safeguard and restore soils. The EUSO supports EU policies by ensuring that the Commission is able to fully capitalise on the information made available through integrated data flows by transitioning from simply monitoring to understanding. In this manner, the EUSO supports the implementation of all soil related objectives of the European Green Deal.

The EU Soil Observatory is also a hub for research on soils. It both supports, and benefits from, EU Research & Innovation on soils.

Finally, the EUSO aims to raise societal awareness of the value and importance of soils to the lives of citizens.

During 2022, the EUSO was hosted within the JRC Unit D3 (Land Resources).

1.2 Policy context

With the creation of the EU Soil Observatory, the European Commission turned the spotlight on the central role of soils in achieving several objectives of the European Green Deal, including climate change, halting biodiversity or achieving zero pollution.

Soil-related targets are found in many of the strategies published as part of the European Green Deal, in particular:

- The Farm to Fork Strategy[1]
- The 2030 Biodiversity Strategy[2]
- The Zero Pollution Action Plan[3]
- The Fit for 55 Package[4].

The publication of the EU Soil Strategy[5] in November 2021 marked a major milestone in the field of soil protection in the EU. Importantly, the Strategy announced the proposal to establish an EU Soil Health Law (due in 2023), which could grant soils a similar legal protection as that provided to air or water.

In parallel, the Horizon Europe research programme (2021-2027), structured around missions, includes a Mission on soil titled 'A Soil Deal for Europe'. Its research activities are expected to significantly advance the state of knowledge and data available on soils in the EU and beyond.

Two years after its creation, the European Soil Observatory has matured and is playing an active role notably in supporting the soil policy development (see 2.1.5), interacting with the research activities (2.1.2) and raising the public's awareness of the need for soil protection (2.1.4).

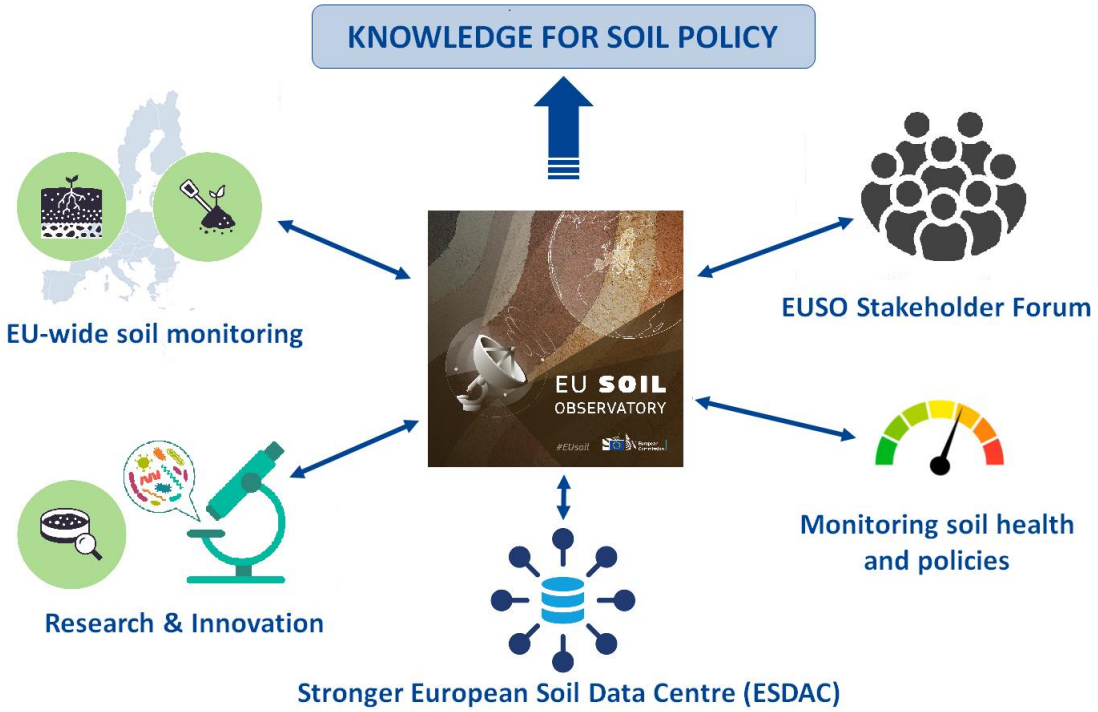
[1] COM/2020/381 final
[2] COM/2020/380 final
[3] COM/2021/400 final
[4] COM/2021/550 final
[5] COM/2021/699 final

1.3 Objectives of the EU Soil Observatory

The EU Soil Observatory has five main objectives that underpin its vision to be the principle knowledge hub on soils for the European Union. These include:

1. Support the development of an operational **EU-wide Soil Monitoring System**
2. Support **Research and Innovation** through the implementation of Horizon Europe's Mission 'A Soil Deal for Europe'
3. Further consolidate and enhance the capacity and functionality of the current **European Soil Data Centre (ESDAC)**
4. **Monitor** the state of **soil health and the policies** in place to enhance soil protection through a Soil Health and Policy Dashboard.
5. Provide an open and inclusive **EUSO forum** that supports the drive towards a societal change in the perception of soil

Figure 1. The five objectives of the EU Soil Observatory



1.4 Purpose of this report

This report presents the activities of the EU Soil Observatory that have taken place in 2022. It also highlights main messages drawn from these activities and the developments to be expected in 2023.

2 EUSO activities and outcomes in 2022

2.1 EUSO outcomes towards objectives

Through its five objectives, the EU Soil Observatory contributes to improving the monitoring of soils (2.1.1 EU-wide soil monitoring system), to creating (2.1.2 Research & Innovation) and sharing (2.1.3 ESDAC) knowledge and data about EU soils, in particular producing tailored outputs in support of policy development (2.1.5 policy monitoring) and to the wider public (2.1.4 citizen engagement).

These activities feed into the overarching knowledge management objective of EUSO (2.1.6 knowledge management). They contribute to its vision to become the reference point for all data and knowledge concerning EU soils.

The team of the EU Soil Observatory is presented in Annex 1.

2.1.1 Developing an operational EU-wide soil monitoring system

The EUSO supports the development of an EU-wide harmonised soil monitoring system, by supporting work to develop, compare and integrate national or regional soil monitoring activities whilst providing an EU-wide monitoring service through the LUCAS Soil Module.

A notable achievement for the EUSO, was the successful coordination of the soil component of the **2022 LUCAS field campaign.** The LUCAS Soil survey is currently the only EU-wide harmonised and regular soil survey. It covers the entire territory of the European Union, addressing all major land cover types simultaneously, in a single sampling period. The 2022 survey included a target of 41,000 soil samples, a doubling from the previous 2018 campaign (with just under 19,000 soil samples collected), to provide statistically robust assessments of soil organic carbon stocks in croplands at NUTS 2 level while at NUTS 0 level for woodland and grasslands. A fixed pool of 17,000 points (made up of locations that had been revisited at least twice in the surveys of 2009/2012-2015-2018) were supplemented by 24,000 new points, which also included additional points over an elevation of 1,500 m for the Alpine region – an area under-represented in previous LUCAS campaigns (with the support of the Alpine Convention Working Group for Soil Protection). A novel approach was the selection of new sampling locations based on a prediction of soil organic carbon concentrations.

Other significant developments included an increase in sampling depth to 30 cm, a doubling of the number of soil biodiversity sites including from green areas for the EU capital cities, improved sampling of woodland sites including the collection of the litter layer and the collection of 4,000 bulk density samples.

In addition to providing practical support and a dedicated helpline during the survey, the EUSO provided:

- detailed guidance to surveyors on the collection of soil, land management and erosion elements (LUCAS C1 document);
- two training sessions of field surveyors in Luxembourg (February 2022);
- assembled and shipped dedicated soil sampling equipment to surveyors (including printing > 110,000 unique labels);
- increased the JRC's LUCAS Soil Archive (for both dry and frozen samples);
- redefined biodiversity shipping protocols to reflect feedback from 2018;
- the reception and storage of final samples (dedicated storage facility) prior to analysis.

With the LUCAS Soil 2022 campaign, the EU Soil Observatory continues to provide an essential and unique soil monitoring service at the EU level. Strategically timed between the publication of the EU Soil Strategy and the upcoming Soil Health Law, the LUCAS 2022 soil campaign could be used to establish a baseline from which to measure the success of the European Green Deal policies.

To achieve this, a number of practical considerations needed to be taken into account, notably concerning sampling design for the monitoring network: geographical location of sample points, the parameters that are measured, both qualitatively and quantitatively, the laboratory methods used, etc.

In close coordination with the **EJP-Soil Programme**, the EUSO has supported a study on the intercomparison of LUCAS and national soil monitoring systems in place in the EU Member States. The EJP-Soil Programme will assess to what extent current national soil monitoring systems and databases are comparable (examining their distributions, means, spatial representations, statistical designs) to that of LUCAS, with a view to propose options for a further integration/harmonisation of soil data in the EU. The EJP-Soil Programme is also investigating the possibility of applying transfer functions to seek harmonisation of soil data coming from different soil monitoring systems.

In parallel, in 2022, the EUSO released a report and the corresponding data of the results of the **2018 LUCAS Soil survey**. Almost 19,000 samples from the LUCAS 2018 campaign were made available as a CSV file. To facilitate the use of these data, an ESRI shapefile based on the LUCAS grid is also available. The measured properties on the LUCAS soil samples include: pH ($CaCl_2$ and H_2O methods), organic carbon content, $CaCO_3$ content, nitrogen, phosphorus, potassium, EC (electrical conductivity), oxalate extractable Fe and Al. In addition, the published 2018 LUCAS dataset includes other soil-relevant modules of the wider LUCAS survey: a) visual erosion assessment b) assessment of organic soils and bulk density.

In 2022, the EUSO team has started to use these data for scientific analyses and publications on several topics: nutrients (phosphorus), soil erosion, soil biodiversity, soil contamination and soil organic carbon (see section 2.1.2).

In the coming years, in line with the implementation of the EU Soil Strategy and the work programme of the Mission 'A Soil Deal for Europe', the EUSO will support Member States in establishing and operating national or regional monitoring systems and support them in ensuring an exchange of harmonised information about the state of soils, for their integration at EU level. The EUSO will aim to build an **EU harmonised data infrastructure** to integrate pan-European national/regional soil monitoring data as well as reporting obligations This shared data infrastructure will be developed based on INSPIRE principles to collect, transmit, share, disseminate soil monitoring and reporting data. The reporting information by Member States which could be integrated include those stemming from the CAP, the Sustainable Use of Pesticides legislation, the Nitrates Directive, the LULUCF Regulation, the future Soil Health Law and Nature Restoration Law. Data and information from relevant regional initiatives could also be included (e.g. Alpine Convention, devolved responsibility for soil protection). In turn, the eventual EU integrated monitoring system should contribute to indicators of soil and soil-related policy targets (e.g. soil organic carbon MRV, Soil Pollution Watch List, biodiversity, erosion, etc.).

2.1.2 Supporting Research & Innovation

Through its in-house research activities, the EU Soil Observatory directly contributes to advance scientific knowledge and understanding about soils in the EU.

In addition, the EUSO is actively involved in and responsible for elements of the implementation of the Horizon Europe (HE) Mission 'A Soil Deal for Europe'. Discussions are ongoing regarding the role of the EUSO in preserving the legacy and usability of the outcomes of projects funded by the HE Soil Mission. In 2022, the EUSO became a partner in the PREPSOIL project and started to develop collaboration agreements with projects whose activities most align with the objectives of EUSO – with which the team will engage more closely in a steering role to ensure alignment and synergies of research outcomes.

The EUSO also engages with project funded under final Horizon 2020 call for proposals (ORCASA and SMS) as well as the PRIMA Programme (Partnership for Research and Innovation in the Mediterranean).

2.1.2.1 Research at EUSO

In 2022, the scientists working in the JRC EU Soil Observatory have published 38 papers in Web of Science indexed journals, as presented in Box 1.

Box 1. JRC EU Soil Observatory team's soil-related publications in 2022

1. Panagos, P., Köningner, J., Ballabio, C., Liakos, L., Muntwyler, A., Borrelli, P. and Lugato, E., 2022. Improving the phosphorus budget of European agricultural soils. *Science of the Total Environment*, *853*, p.158706.

2. Panagos, P., Montanarella, L., Barbero, M., Schneegans, A., Aguglia, L. and Jones, A., 2022. Soil priorities in the European Union. *Geoderma Regional*, *29*, p.e00510.
3. Panagos, P., Van Liedekerke, M., Borrelli, P., Köninger, J., Ballabio, C., Orgiazzi, A., Lugato, E., Liakos, L., Hervas, J., Jones, A. and Montanarella, L., 2022. European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies. *European Journal of Soil Science*, *73*(6), 13315.
4. Panagos, P., Muntwyler, A., Liakos, L., Borrelli, P., Biavetti, I., Bogonos, M. and Lugato, E., 2022. Phosphorus plant removal from European agricultural land. *Journal of Consumer Protection and Food Safety*, *17*(1), pp.5-20.
5. Panagos, P., Borrelli, P., Matthews, F., Liakos, L., Bezak, N., Diodato, N. and Ballabio, C., 2022. Global rainfall erosivity projections for 2050 and 2070. *Journal of Hydrology*, *610*, p.127865.
6. Köninger, J., Panagos, P., Jones, A., Briones, M.J.I. and Orgiazzi, A., 2022. In defence of soil biodiversity: Towards an inclusive protection in the European Union. *Biological Conservation*, *268*, p.109475.
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9. Liakos, L., & Panagos, P. (2022). Challenges in the Geo-Processing of Big Soil Spatial Data. *Land*, 11(12), 2287.
10. Diodato, N., Borrelli, P., Panagos, P. and Bellocchi, G., 2022. Global assessment of storm disaster-prone areas. *PLoS one*, *17*(8), p.e0272161.
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13. Matthews, F., Panagos, P. and Verstraeten, G., 2022. Simulating event-scale rainfall erosivity across European climatic regions. *Catena*, *213*, p.106157.
14. Efthimiou, N., Psomiadis, E., Papanikolaou, I., Soulis, K.X., Borrelli, P. and Panagos, P., 2022. A new high resolution object-oriented approach to define the spatiotemporal dynamics of the cover-management factor in soil erosion modelling. *Catena*, *213*, p.106149.
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In 2022, the EUSO team made contributions or led specific research projects. These include:

Internal JRC activities

- **SOLACE,** an exploratory research project investigating the potential links between soil pollution and cancer occurrence. Since January 2022, the EUSO team has hosted a dedicated researcher leading and carrying out research activities on this topic which directly contributes to advance the state of knowledge on soil pollution. Coordinated by the EUSO, this project is strengthening previously unconnected activities in the JRC in relation to health, soil and food security by bringing EUSO together with the Knowledge Centre on Cancer (JRC F1), IPCHEM (JRC F3), and the Digital Rural Landscape Laboratory (JRC D5). Using heavy metal concentrations from the LUCAS 2009 topsoil database, the project is working to identify links between the distribution patterns of soil pollution by heavy metals and regional cancer registries. Pollution indices were built for risk assessment of heavy-metal accumulation in soils and crops growing on contaminated sites were identified using bioaccumulation factors. Additionally, the impact assessment of the cumulative application of sewage sludge in agricultural soils was analysed as diffuse pollution factor.
- In 2022, the EUSO team won the JRC's **Antoine Royer award** with a project proposal on quantifying and improving soil health in Africa. The project, due to start in 2023, will contribute to boosting safe and sustainable food systems in Africa by assessing and quantifying soil functions and health of agricultural soils and identifying underlying pressures and drivers. It will address the following research questions: (1) How healthy are agricultural soils in Africa (2) Which soil functions are at risk and what are the major threats, and (3) Which measures should be taken to improve soil health, taking into consideration the specific environmental and socio-economic context on the African continent.
- The **Collaborative Doctoral Partnerships (CDP)** is an initiative of the Joint Research Centre to establish strategic collaborations with higher education institutions (HEIs/universities) that grant doctoral degrees (PhD). The CDP is characterised by research excellence and high international reputation. In the EUSO, six PhD candidates are hosted in the context of the Collaborative Doctoral Training Programme (CDTP). The topics, names and collaborating institute are listed below:

  a) Dynamic modelling of soil erosion and sediment delivery in Europe (delivery Q4 2023) – Francis Matthews (in collaboration with KU Leuven, Belgium)

  b) Soil microbial diversity and ecosystem functioning assessment across Europe (delivery Q1 2025) – Maeva Labouyrie (in collaboration with Zurich University, Switzerland)

  c) Towards a reliable European assessment of soil biodiversity status under current land-use changes (delivery Q3 2023) - Julia Köninger (in collaboration with Vigo University, Spain)

  d) Erosion effects on carbon and nutrients balance (delivery Q2 2024) - Arthur Fendrich (in collaboration with Paris-Saclay, France)

  e) Modelling the Phosphorous cycle in EU agricultural soils and assessing land impact and mitigation options of organic agriculture (delivery Q1 2024) - Anna Muntwyler (in collaboration with the Swiss Federal Institute of Technology in Zürich - ETHZ, Switzerland)

  f) Delivery Q3 2025 - Vasilis Michailidis (in collaboration with Aarhus University, Denmark)

External JRC activities

- The EUSO team also contributed to **Bio4A**, a H2020 research project on Advanced Sustainable Biofuels for Aviation coordinated. In particular, a significant contribution was made to a report, titled "The assessment of environmental sustainability indicators for advanced biojet fuel value chains on marginal lands in the Mediterranean". This work was built around a modelling exercise used to make predictions about camelina yields in rotation with barley in Mediterranean marginal land. The objective was to assess the potential of this drought-resistant oil crop in marginal land of Southern Europe.
- The EUSO team contributed to **SOILS4AFRICA**, a H2020 research project that implements the approaches developed under the LUCAS Soil Module for continental Africa. Coordinated by ISRIC,

SOILS4AFRICA aims to establish a baseline of soil condition against which agricultural intensification can be assessed. The project aims to collect samples from 20,000 locations all African countries. The EUSO is a member of the Project Executive Team and participated in the first in-person project meeting in Tunisia (September 2022). Testing of field methodology was carried out in 2022 and the major sampling programme will be undertaken in 2023.

- The EUSO contributes to the **European Space Agency** **WorldSoils Project**, which is developing a global Earth Observation monitoring platform for soil carbon. EUSO is member of the Project Steering Committee.

2.1.2.2 Soil Mission research

The Horizon Europe Mission 'A Soil Deal for Europe' (the 'Soil Mission') funds a series of R&I Actions to support the EU's path to sustainable and regenerative soil management as part of the wider green transition in both urban and rural areas. The EUSO is a key component in the implementation of the Soil Mission as well as the beneficiary of several outcomes.

The EUSO is actively involved in the implementation of the Soil Mission. It is notably responsible for the Mission's soil monitoring operational objective. In addition, in 2022, in close collaboration with DG AGRI, DG RTD and the Soil Mission Owners Group, the EUSO contributed to the selection and **development of relevant topics of the 2023 Soil Mission Annual Work Programme** (research calls), which are presented in Table 1. Table 2 presents the topics of calls published in 2022 which were evaluated and selected in 2022.

Table 1. 2023 work programme of the Soil Mission

	Topics
HORIZON-MISS- 2023-SOIL-01-01	Discovering the **subsoil**
HORIZON-MISS- 2023-SOIL-01-02	**Soil pollution processes** – modelling and inclusion in advanced digital decision-support tools
HORIZON-MISS- 2023-SOIL-01-03	**Onsite digital technologies to monitor** nutrients and chemical or biological stressors in soil and plants with relevance for food safety and nutrition
HORIZON-MISS- 2023-SOIL-01-04	Innovations to prevent and combat **desertification**
HORIZON-MISS- 2023-SOIL-01-05	Soil-friendly practices in **horticulture**, incl. alternative growing media
HORIZON-MISS- 2023-SOIL-01-06	Soils in **spatial planning**
HORIZON-MISS- 2023-SOIL-01-07	Back to earth: bringing **communities and citizens** closer to soil
HORIZON-MISS- 2023-SOIL-01-08	**Co-creating solutions for soil health in Living Labs**
HORIZON-MISS- 2023-SOIL-01-09	**Carbon farming** in living labs

Table 2. 2022 work programme of the Soil Mission

	Topics
HORIZON-MISS-2022-SOIL-01-01	Building the mission's **knowledge repositor**y and advancing the European Soil Observatory
HORIZON-MISS-2022-SOIL-01-02	Improving food systems sustainability and soil health with **food processing residues**
HORIZON-MISS-2022-SOIL-01-03	**Soil biodiversity** and its contribution to ecosystem services
HORIZON-MISS-2022-SOIL-01-04	**Remediation** strategies, methods and financial models for decontamination and **reuse of land** in urban and rural areas
HORIZON-MISS-2022-SOIL-01-05	Monitoring, reporting and verification of **soil carbon and greenhouse gas balance**
HORIZON-MISS-2022-SOIL-01-06	Network on **carbon farming** for agricultural and forest soils
HORIZON-MISS-2022-SOIL-01-07	Foster **soil education** across society
HORIZON-MISS-2022-SOIL-01-08	Framework Partnership Agreement (FPA) for a **Living Lab network support structure**
HORIZON-MISS-2022-SOIL-01-09	**Citizen science** for soil health
HORIZON-MISS-2022-SOIL-01-10	Innovations for soil improvement from **bio-waste**

As research projects progress and start to produce results, the EUSO will become the repository of all HE Mission projects outputs and will benefit from the knowledge produced by EU-funded research actions. A dedicated 'EUSO R&I Portal' will be established to host R&I outcomes.

In 2022, research projects funded as part of the 2021 Soil Mission work programme started their activities (Table 3). The EUSO engaged with some of these projects whose activities most align with those of EUSO, with a steering role to ensure alignment and synergies of research outcomes.

Table 3. Research projects funded as part of the Soil Mission 2021 work programme

Topic	Selected project(s)	Coordinator	Info
HORIZON-MISS-2021-SOIL-01-01: Building capacities for engagement, outreach and knowledge	**PREPSOIL**: Preparing for the Soil Deal Mission	Aarhus University	https://cordis.europa.eu/project/id/101070045 https://prepsoil.eu/
HORIZON-MISS-2021-SOIL-02-01: From knowledge gaps to roadmaps on soil mission objectives	**SOLO**: Soils for Europe	Leipzig University	https://cordis.europa.eu/project/id/101091115

HORIZON-MISS-2021-SOIL-02-02: Validating and further developing indicators for soil health and function	**BENCHMARKS**: Building a European Network for the characterisation and harmonisation of Monitoring Approaches for Research and Knowledge on Soils	Wageningen University	https://cordis.europa.eu/project/id/101091010
	AI4SoilHealth: Accelerating collection and use of soil health information using AI technology	Aarhus University	https://cordis.europa.eu/project/id/101086179
HORIZON-MISS-2021-SOIL-02-03: Linking soil health to nutritional and safe food	**SOIL O-LIVE**: The soil biodiversity and functionality of Mediterranean olive groves – the influence of land management on olive oil quality and safety	Jaen University	https://cordis.europa.eu/project/id/101091255
HORIZON-MISS-2021-SOIL-02-05: Business models for soil health	**InBestSoil:** Monetary valuation of soil ecosystem services and creation of initiatives to invest in soil health	Vigo University	https://cordis.europa.eu/project/id/101091099
	NOVASOIL: Innovative business models for soil health	EVENOR TECH	https://cordis.europa.eu/project/id/101091268
	SOILVALUES: Enhancing soil health through value based business models	Leuven Catholic University	https://cordis.europa.eu/project/id/101091308
HORIZON-MISS-2021-SOIL-02-06: Engage with and activate municipalities and regions to protect and restore soil health	**HuMUS** - Healthy Municipal Soils	ANCI Toscana associazione	https://cordis.europa.eu/project/id/101091050
HORIZON-MISS-2021-SOIL-02-07: National engagement sessions and support to the establishment of soil health living labs	**NATIOONS** - National engagement activities to support the launch of the Mission 'A Soil Deal for Europe' 100 Living Labs and Lighthouses	Aarhus University	https://cordis.europa.eu/project/id/101090738

HORIZON-MISS-2021-SOIL-02-08: Next generation soil advisors	**NBSoil** – Nature Based Solutions for soil management	Institute of Soil Science and Plant Cultivation	https://cordis.europa.eu/project/id/101091246

2.1.3 Enhancing the capacity and functionality of the current European Soil Data Centre (ESDAC)

Created over a decade ago to harmonised and streamline the collection of environmental data by Commission services, the European Soil Data Centre (ESDAC), hosted by the JRC, has become the leading web platform for gathering and disseminating soil scientific data and knowledge in the EU. As such, ESDAC is at the core of the EU Soil Observatory by providing the scientific and data management foundation on which other activities can build. An ever-evolving platform, ESDAC has grown substantially over the past years, both in terms of content hosted and number of users. In 2022, ESDAC continued to be updated and improved to support growing knowledge needs: 14 new datasets were added to the ESDAC platform while 17% more datasets were distributed than in 2021, in response to an increased user demand.

2.1.3.1 New datasets

In 2022, the following datasets were added to the European Soil Data Centre (ESDAC):

Phosphorus plant removal

In a recent publication, we estimated the Phosphorus (P) removal from agricultural lands of EU and UK (ca. 173 million ha). This takes into account the P removed by crop harvesting and the plant residues. For P removed by crop harvesting, we used 7 major categories of crops and 37 crops in more than 220 regions of EU and UK. The total P removal was about 2.55 million tonnes (Mt) (± 0.23 Mt), with crop harvesting having the larger contribution (ca. 94%) compared to the crop residues removal. The mean P removal by crop harvesting is 14 kg ha^{-1} yr^{-1}. Data are available. https://esdac.jrc.ec.europa.eu/themes/phosphorus-budget-topsoils

Glucose-induced priming effects in soils across Europe

This new ESDAC dataset includes a quantification and comparison of glucose-induced priming effects in soils with contrasting land uses and under different crop types. On average, priming effects (PEs) were negative in semi-natural and cropland soils, meaning that microbial communities preferentially switched from soil organic C (SOC) decomposition to glucose mineralisation. The data were obtained from samples of LUCAS 2018. In the publication, it was concluded that PEs were driven by soil basal respiration, microbial biomass C, and SOC. Data available https://esdac.jrc.ec.europa.eu/content/priming-effects-soils-across-europe

Gully erosion based on LUCAS

We integrated a soil erosion module in LUCAS 2018 Soil Module for the EU and UK, which consisted of soil sampling (0–20 cm depth) and erosion observations conducted in 24,759 field survey sites. Gully erosion channels were detected for ca. 1% (211 sites) of the visited sites. The results presented in the publication indicate that LUCAS visual assessment is effective to map permanent gullies, whereas it appears less effective to detect short-lived forms like ephemeral gullies. The dataset includes the points with gully erosion channels and selected pictures.

https://esdac.jrc.ec.europa.eu/content/gully-erosion-based-lucas

Soil biodiversity conservation literature and legally binding instruments

This meta database includes a review of 54 articles addressing soil biodiversity conservation at an EU or Member State level. In addition, Member States policy documents which address soil biodiversity conservation

were presented. These can be either strategies for soil protection at the Member State level or legally binding instruments (i.e. hard law) implicitly and explicitly addressing threats to soil biodiversity. More information can be found in the published study. The meta database is available: https://esdac.jrc.ec.europa.eu/content/soil-biodiversity-conservation-literature-and-legally-binding-instruments

Global rainfall erosivity projections for 2050 and 2070

We present a comprehensive set of future erosivity projections at a 30 arc-second (~1 km2) spatial scale using 19 downscaled General Circulation Models (GCMs) simulating three Representative Concentration Pathways (RCPs) for the periods 2041–2060 and 2061–2080. The future rainfall erosivity projections were obtained based on a Gaussian Process Regression (GPR) approach relating rainfall depth to rainfall erosivity through a series of (bio)climatic covariates. In the new study, we estimate a potential average increase in global rainfall erosivity between 26.2 and 28.8% for 2050 and 27–34.3% for 2070 compared to 2010 baseline. The results of 102 simulations and 6 aggregated datasets are available:

https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity-projections-2050-and-2070

Satellite-based global erosivity dataset

We developed a satellite-based R-factor dataset using the high spatial and temporal resolution global precipitation (30 min) estimates obtained from the National Oceanic and Atmospheric Administration (NOAA) and applying the Climate Prediction Center MORPHing (CMORPH) technique. Alternatively, the erosivity density (ED) concept was also used to estimate global rainfall erosivity. The obtained global estimates of rainfall erosivity were validated against the pluviograph data included in the Global Rainfall Erosivity Database (GloREDa). In this study, we found that the CMORPH estimates have a marked tendency to underestimate rainfall erosivity when compared to the GloREDa estimates. The most substantial underestimations were observed in areas with the highest rainfall erosivity values. Data available at:

https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity

Post-fire soil erosion map for Portugal

Wildfires are a recurrent and increasing threat in mainland Portugal, where over 4.5 million hectares of forests and shrubland have burned over the last 38 years. This dataset contains the results of a study that mapped post-fire soil erosion in Portugal and identified the areas with higher post-fire erosion risk for past and future climate extremes. In this study, the Morgan–Morgan–Finney erosion model was applied to predict annual soil losses for a 38-year period, considering three scenarios of soil burn severity (low, moderate, and high) for three land cover types (Shrubland, Pine, and Eucalypt). Data available at:

https://esdac.jrc.ec.europa.eu/content/post-fire-soil-erosion-map-portugal

LUCAS 2018 dataset

Topsoil data for 18,984 samples from LUCAS 2018 are available as a CSV file and an ESRI shapefile corresponding to the LUCAS grid points where the samples were taken. The measured properties include: pH (CaCl2 and H2O), organic carbon content, the presence of carbonates, nitrogen, phosphorous, potassium, electrical conductivity (EC), and oxalate extractable Fe and Al. In addition, this dataset includes additional modules of LUCAS 2018: a) erosion b) depth of organic soils and c) bulk density. Further data on the LUCAS 2018 will follow in the future. Data available at:

https://esdac.jrc.ec.europa.eu/content/lucas-2018-topsoil-data

High resolution cropland global soil erosion (GloSEM 1.3)

GloSEM stands for Global Soil Erosion Modelling platform. The GloSEM 1.3 dataset, contains present (2019) and future (2070) scenarios on soil erosion at global scale. This covers almost 1.4 billion ha of global croplands at a resolution of 100m. The 2070 scenarios include the projections made with RCP2.6, RCP4.5 and

RPC8.5. GloSEM has been coupled with the cropland maps from ESA and Copernicus. The results of this study are also aggregated in a summary table per country. Data are available at:

https://esdac.jrc.ec.europa.eu/content/glosem

Phosphorus budget and P stocks

We estimate the Phosphorus (P) budget from agricultural lands of EU and UK (ca. 173 million ha). This takes into account the P inputs (fertilisers, manure, chemical weathering, atmospheric deposition) and the P outputs (crop production, plant residues removal, losses by erosion) for the period 2011–2019. The P budget and the P inputs/outputs are available at NUTS2 (regional scale) and NUTS 0 (country scale). In addition, we estimate the P displacement and losses due to water erosion at catchment scale and aggregate them at sea outlet. We make also the datasets for both Total P and Available P (Olsen) concentration and stocks available. More details of the empirical model is given in the published study. Data available at:

https://esdac.jrc.ec.europa.eu/content/phosphorus-budget-and-p-stocks

Global assessment of storm disaster-prone areas

Rainfall Erosivity Density (RED) is a measure of rainstorm aggressiveness and a proxy indicator of damaging hydrological events. By using measured Rainfall Erosivity Density (RED) for 3,625 rain gauges worldwide and applying kriging methodologies, we could identify the damaging hydrological hazard-prone areas that exceed warning and alert thresholds (1.5 and 3.0 hm^{-2} h^{-1} yr^{-1}, respectively). In this study, we analysed the spatial pattern of hydrological hazard associated with rainfall erosivity with a global-scale visualisation. The results indicated that about 31% and 19% of the world's land area have a greater than 50% probability of exceeding the warning and alert thresholds. Data available at:

https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity

Multiple concurrent soil erosion processes

Using a multi-model approach, we show the spatial risk of soil erosion by water, wind, tillage and harvesting and where the co-occurrence of these different processes is observed. Moreover, in a study in Nature Sustainability, we analysed where these locations of multiple erosion co-occurrence are likely to intersect with the projected increase of dry/wet climate conditions. Of the circa 110 million hectares (M ha) of arable land in the European Union, our estimates show that 43 M ha are vulnerable to a single driver of erosion, 15.6 M ha to two drivers and 0.81 M ha to three or more drivers. About 3.2 M ha of arable land are vulnerable to the possible interaction of increased flood, drought, water and wind erosion. For first time, we also present the data on tillage erosion. Data for all erosion processes are available:

https://esdac.jrc.ec.europa.eu/content/multiple-concurrent-soil-erosion-processes

Historical reconstruction of soil erosion in Europe (1860-2018)

This dataset includes the reconstruction of soil erosion rates in Europe (including UK, Switzerland and Western Balkans). The data provided have been aggregated per decade starting from 1860. The soil erosion change is driven by changes in land use and rainfall erosivity. The annual variations do not follow a linear pattern through time (because of fluctuations in rainfall). Long-term changes indicate an overall increase in erosion rates from 1860 to 1960 mainly due to land cover changes and agricultural intensification. We also make available the annual historical soil loss rates by water erosion (period 1860 - 2018). Advanced users may also download the monthly files (12 bands per file). The annual and monthly soil erosion reconstruction data (1860-2018) can be useful inputs for Earth System Models. Data of this research study are available at:

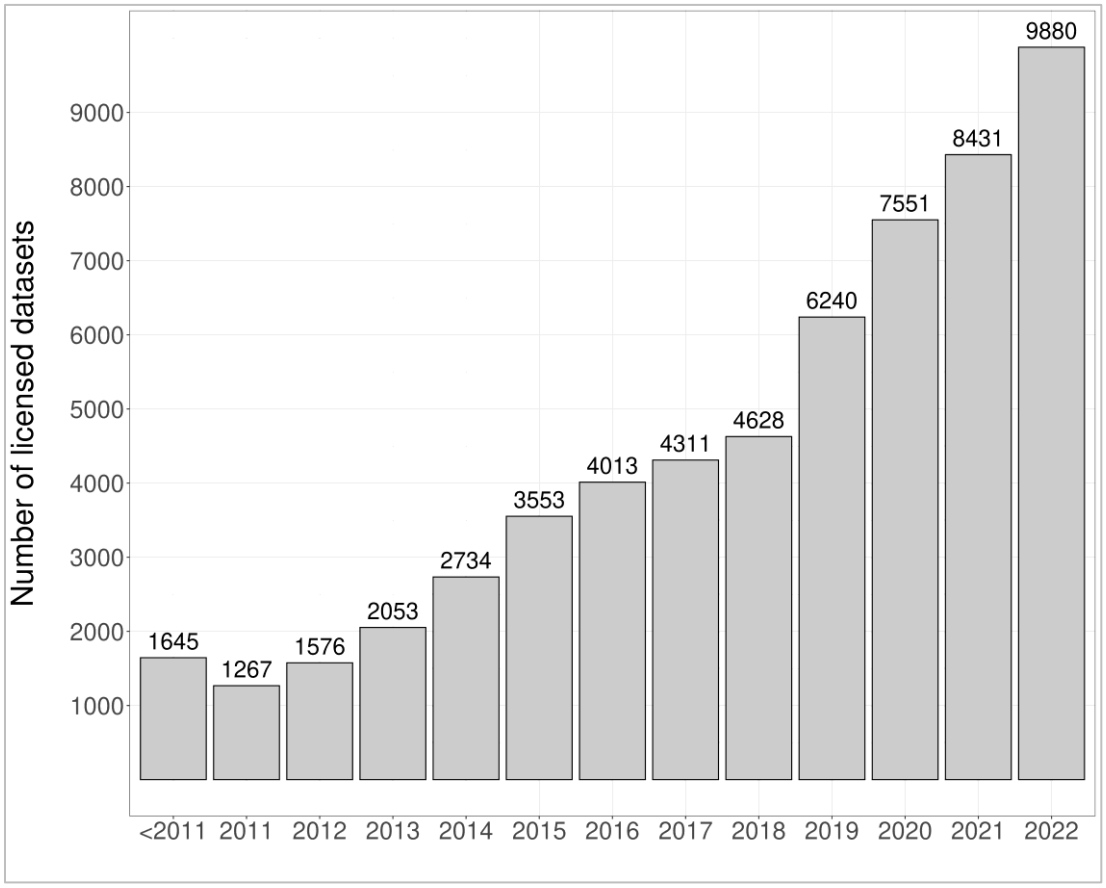
https://esdac.jrc.ec.europa.eu/content/historical-reconstruction-soil-erosion-europe

2.1.3.2 ESDAC performance (metrics) in 2022

The European Soil Data Centre (ESDAC) currently hosts 90 datasets, over 6,000 maps, six atlases, 500 scientific publications and a wide range of soil related material.

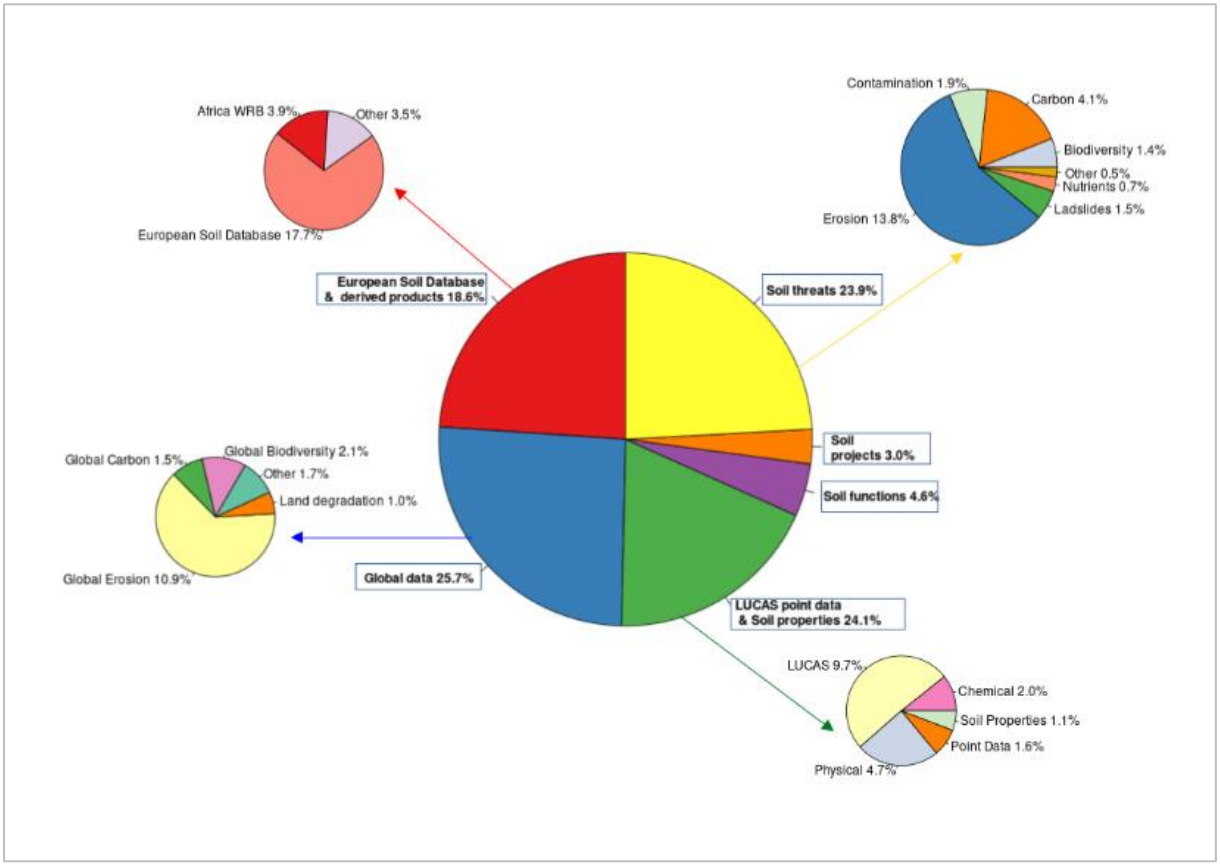
In 2022, ESDAC published 14 new data blocks (listed in the previous section). In terms of usage, ESDAC distributed 9,880 datasets during 2022 which is 17% higher than in 2021 (Figure 2). The number of licensed datasets is almost 60% higher compared to 2019.

Figure 2. Trend in the datasets distributed by ESDAC



Following the current trends in ESDAC requests (a 15-20% annual increase) and increasing policy relevance of soil, EUSO expects to deal with more than 28,000 data requests per year by 2030. In addition, the datasets available in ESDAC are projected to double as new data flows from Earth Observation systems, innovative modules in LUCAS (soil biodiversity, pesticides, microplastics, PFAS) and EU research framework programmes (Horizon Europe) will become available.

Figure 3. Data distribution per category of dataset in ESDAC



In terms of categories of data distributed in 2022, "Global Data", "Soil threats" and "LUCAS point data & Soil properties" have a share of around 25% each (**Figure 3**). The release of the 2018 LUCAS Module (Fernandez Ugalde, O. et al. 2022) contributed to a significant number of requests for the LUCAS point data. In 2022, the launch of global scale datasets such as the GLOSEM 1.3 (Borrelli et al., 2022) and the global rainfall erosivity projections 2050 (Panagos et al., 2022) had a major impact on the share of global data requests.

In 2022, the main users of ESDAC were universities (57%), followed by research organisations (17%) and private companies (16%). Compared to the past, there has been an increase in requests originating from the private sector.

In 2022, the EUSO team consolidated and enhanced ESDAC in terms of its capacity and functionality to support growing knowledge needs, towards so-called 'ESDAC 2.0'. Besides the introduction of new datasets, under ESDAC 2.0, the platform will start to integrate new data flows coming from large-scale research projects, monitoring schemes, technological advancements and policy developments (Panagos et al., 2022). The 2018 LUCAS Module will contribute with data aiming to measure soil biodiversity, pesticides and microplastics (Orgiazzi et al., 2022). The pesticides module includes the analysis of 118 different active ingredients and metabolites in 3,400 locations, mainly from croplands. This analysis was concluded in the autumn of 2022 and a report is under preparation for Q2 2023. These data represent some of the largest pools of soil biological and pesticide pollution information available at EU scale, showing great integration potential for indicator development and monitoring of environmental and agricultural policies.

In addition, a study on the presence of AMR in selected LUCAS samples was concluded and the outcomes will be published in 2023.

Many of the future ESDAC 2.0 developments could depend on the forthcoming Soil Health Law (2023), as this policy instrument will influence the future needs for soil data in the European Union. In addition, the implementation of the Zero Pollution Action Plan and the Farm to Fork Strategy require assessments on a range of soil contaminants (e.g. cadmium, arsenic, PFAS, plastics, antibiotics etc.), nutrient balances (NPK), sediment transport, etc. The EU Soil Observatory, and the ESDAC 2.0 within it, will become the cornerstone of an eventual integrated EU soil monitoring system that builds on data collected through LUCAS and by

Member States. Technically, ESDAC could incorporate additional functionality such as a Web Mapping Application and Services (WMS) to allow users a more direct interaction with ESDAC datasets. The new EUSO Soil Health Dashboard is such an example.

2.1.4 Supporting citizen engagement and the drive towards a societal change in the perception of soil

Every year, the EU Soil Observatory organises the **EUSO Stakeholder Forum**, an open and inclusive event which provides an opportunity to engage with the European soil community, in its broadest sense - from soil scientists, policy makers, regional, national and international bodies, to interested citizens.

The EUSO Stakeholder Forum a) provides mechanisms to inform the EUSO stakeholder community of developments, b) supports enhanced soil literacy and c) collects feedback on the operations of the Observatory.

The second edition of the EUSO Stakeholder Forum took place over three days, from Monday 24th to Wednesday 26th October 2022.

The first day was dedicated to the latest soil policy developments in the EU.

The second day discussed the concept of Soil Health Districts, and the initial research projects funded under the Mission "A Soil Deal for Europe".

During the third day, the five EUSO Working Groups met to discuss technical advances and policy developments relating to soil pollution, soil data sharing, soil monitoring, soil erosion and soil carbon (see section 2.2).

The full agenda and presentation titles of the 2022 EUSO Stakeholder Forum are available in Annex 2. Recordings of the session are also available at this link: https://esdac.jrc.ec.europa.eu/euso/second-euso-stakeholders-forum

The EUSO Stakeholder Forum was attended by almost 1,000 participants, over the three-day period. It included a high-level address from Martin Kováč, the Slovakian State Secretary of the Ministry of Agriculture and Rural Development o, as well as presentations from several Commission services. In total of over 50 presentations were given, addressing topics from soil health to Living Labs. In particular, the 2022 EUSO Stakeholder Forum:

- presented the initial findings of the first-ever Clean Soil Outlook,
- presented changes in soil carbon stocks for the EU over the past decade,
- facilitated the first gathering of projects funded under the Soil Mission,
- presented the outcomes of Working Groups on Monitoring-Data-Pollution-Erosion,
- launched a new activity on soil carbon MRV (Measuring-Reporting-Verifying), and
- revealed the prototype of the EUSO Soil Health Dashboard.

The event was very positively received. With participants from over 70 countries, the EUSO Stakeholder Forum demonstrated the high level of interest in efforts by the EU and Member States to develop policies to protect soils while enhancing the ecosystem services that they provide.

The EUSO team has started to discuss the next edition of the EUSO Stakeholder Forum. Building on the close relationship with the Soil Mission Secretariat, the EUSO is investigating options to incorporate the EUSO Stakeholder Forum within a 2023 EU Soil Week (see section 3).

In addition, a **citizen portal on soil awareness** will be developed as part of EUSO, to raise soil awareness, and engaging citizens on the importance of soil protection. A dedicated research project, PREPSOIL, kicked off in 2022 to start developing this online platform, to which the EUSO will also contribute. PREPSOIL will also build a coalition to connect diverse organisations, projects and people that contribute to soil literacy and the sustainable use and management of soils. Through this coalition, close links will be maintained with the

European Soil Partnership (ESP) and key research networks involved in soil awareness and literacy (e.g. EJP SOIL, SoilBON, ENSA, ELSA).

2.1.5 Monitor the state of soil health and soil policies

A key development in terms of monitoring the state of soil health has been the efforts on the EUSO soil health dashboard, a key component of EU Soil Observatory. A prototype developed in the autumn of 2022, provided a clear picture of the state soil health in the EU based on a limited set of indicators.

The dashboard includes a novel map, built using a 'convergence of evidence' approach, which, for the first time, spatially combines datasets to highlight the intensity and location of soil degradation processes in the EU. Another novelty is the use of threshold values to estimate when soils can be considered healthy or unhealthy. All data, sources and threshold values, are transparently provided alongside a discussion of the uncertainty inherent to this exercise.

The EUSO dashboard also presents the overlap observed between degradation processes, highlighting typical associations.

Finally, statistics and maps are presented for each indicator through an interactive display where users can select the soil degradation and the scale they are interested in (raster, NUTS 0 and NUTS 2 statistics and maps are available).

Further information on the evolution of the dashboard will be provided in the 2023 EUSO Bulletin.

The target audience of the EUSO dashboard are policy-makers (EU, national or regional authorities in charge of soil protection) and the soil research community (access to databases, maps, graphs). Land users (e.g. farmers, foresters), NGOs and citizens may also see the EUSO soil health dashboard as a useful source of information to understand prevailing soil issues in the country or region they are interested in, and possibly benchmark with other areas. However, it should be noted that the EUSO soil health dashboard is not to be used as a tool to perform local soil health assessments, given the uncertainty of the models used and the use of EU-wide thresholds to determine the soil health status.

The EUSO soil health dashboard will be updated regularly and enriched with new indicators as new evidence becomes available. Future versions will also aim to include additional functionalities such as sliders to allow users to set soil health thresholds as they see fit, or the possibility to select only subsets of indicators.

In the future, the EUSO dashboard will also include a soil policy dashboard page, to report on the state of implementation of EU soil policy.

The EUSO soil health dashboard can be accessed through the following link: https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/

2.1.6 Applications of knowledge management

With regards to **policy support and knowledge management,** the EU Soil Observatory contributed extensively throughout the year to a wide **range of policy areas**, including the preparation of the legislative proposal of the EU Soil Health Law (due in June 2023) and the implementation of the Horizon Europe's Soil Mission. In addition, substantial progress was made on the creation of a new EUSO soil health dashboard, which will provide a spatial perspective into the state of soil health in the EU (see previous section).

Support to the EU Soil Strategy 2030 and to the development of the EU Soil Health Law

2022 marked the first year of the implementation of the EU Soil Strategy 2030, which promised, amongst a range of actions, the preparation of an EU Soil Health Law. Throughout the year, the EUSO team worked very closely with DG ENV and provided extensive support to the development of the law. In particular, the team provided support on definition and key concepts, together with reports, data, and knowledge on the concept of soil health districts, proposed a methodology to perform soil health assessments through relevant indicators and possible thresholds for the definition of healthy soils, as well as possible soil monitoring and reporting systems. The EUSO made several contributions (through presentations, interventions and scoping papers) to the EU Soil Expert Group and the Extended Soil Expert Group. The EUSO also supported the development of the Impact Assessment of the proposed Law, which will be submitted in February 2023.

Contribution to the Horizon Europe's Soil Mission Work Programme 2023-2024

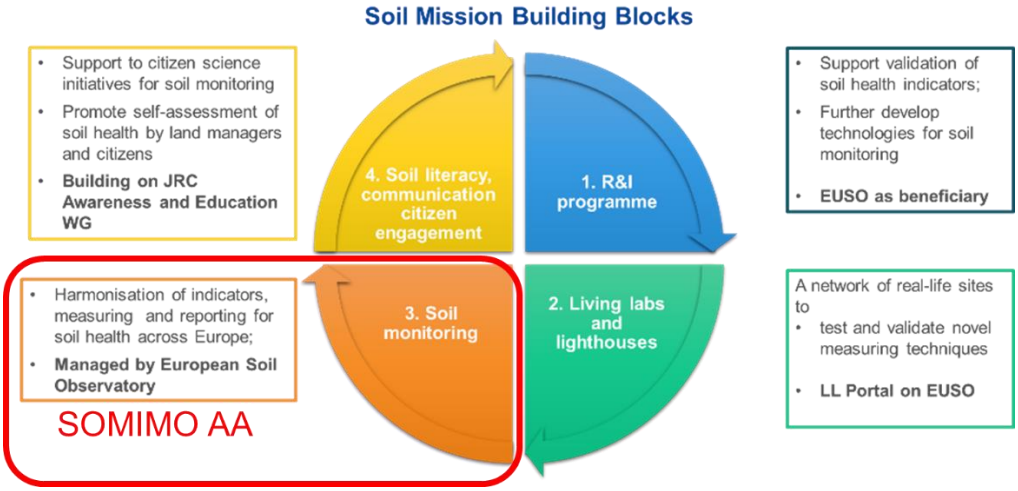
In 2022, the EUSO contributed to the development of the Horizon Europe Soil Mission Work Programme for 2023 and 2024. The EUSO has been involved in drafting calls on subsoil, soil pollution modelling, desertification and spatial planning as part of the Soil Mission Owners Group, while providing definitions and reviewing other topical calls as well. In the Soil Mission calls, the EUSO Observatory is mentioned as a beneficiary of the projects' outcomes. Proposals are required to develop a roadmap to ensure the open access, longevity, sustainability and interoperability of the knowledge and outputs they will produce, through close collaboration with the Joint Research Centre's EU Soil Observatory (EUSO).

A major development towards the end of 2022 was the start of the Soil Mission Monitoring (SoMiMo) project, an Administrative Agreement between the JRC, DG RTD and DG AGRI, for the EUSO to coordinate one of the Mission's four operational objectives relating to monitoring. Specifically, this includes:

- Leading and overseeing the Mission's activities in relation to soil monitoring. This will include coordinating and steering the development of Horizon Europe Work Programmes in relation to soil monitoring;
- The development and implementation of novel approaches to soil monitoring, building on R&I activities funded by the Mission (e.g., on specific targets or new methods for data acquisition, sensing technologies and metrics for measuring the performance of indicators);
- Providing technical expertise and operational capacity to support the coordination of activities and exchanges with Member States, Associated Countries (AC), Eurostat, the EEA and the wider scientific community. This is in view of supporting the move towards an integrated soil monitoring system initially for the EU that can potentially be expanded to AC countries;
- Developing activities to ensure a step change in our ability to monitor soils more efficiently and effectively and thus track the impacts of the actions taken and the Mission's overall success. This includes exploring and exploiting new opportunities for soil monitoring coming from advances in the fields of Earth observation, remote sensing, and machine learning including artificial intelligence (AI).

Further details of this initiative will be provided in the 2023 EUSO Bulletin.

Figure 4. The four operational objectives of the Soil Mission and the engagement with EUSO



Highlighting the considerations for soil in the Nature Restoration Law proposal

The EUSO team led the discussion on how soils could be considered within the ambitions of the Nature Restoration Law. A series of themes addressing the restoration potentials of organic soils, soil carbon in croplands, soil erosion, and contaminated sites were developed and presented. A series of detailed fiches were prepared and submitted for inclusion in the impact assessment report, alongside evidence for the consideration of soils within individual habitats (such as forests and agricultural land). In the end, only proposals for organic soils and soil carbon in croplands were retained as targets within the Law. Reference to

the LUCAS Soil methodology, developed by JRC, was made to support soil carbon stock assessments. The EUSO contributed to the development of soil elements of EU-wide methodology to map and assess ecosystem condition. DG ENV sent a letter of appreciation in view of the support provided by the JRC in this process.

Contribution to EEA report "Soil monitoring in Europe - Indicators and thresholds for soil health assessments"

This EEA report provides recommendations for soil monitoring and implementing soil-related indicators. This is an important input for the upcoming Soil Health Law. The focus is on soil threats, and indicators were selected in view of their appropriateness for assessing the condition of soil, its degradation, its resilience and its valuable services. For each indicator, a rationale is provided for using thresholds as critical limits to indicate that soil is in good condition, i.e. healthy soil, in front of specific soil functions and local conditions. The EUSO contributed by reviewing the Soil Threats chapters and providing data, scientific evidence and knowledge in many parts of the report such on soil erosion, soil organic carbon, soil biodiversity, soil contamination and diffuse pollution.

Zero Pollution Monitoring and Outlook Report 2022

In December 2022, the Commission published its first Zero Pollution Monitoring and Outlook Report (COM(2022) 674)[6] setting pathways to cleaner air, water and soil. The zero pollution ambition is a cross-cutting objective contributing to the United Nations 2030 Agenda for Sustainable Development and complementing the 2050 climate-neutrality goal in synergy with the clean and circular economy and restored biodiversity goals. To that end, the zero pollution action plan sets key 2030 targets to speed up pollution reduction. The report was supported by a monitoring assessment, coordinated by the European Environment Agency, while the Joint Research Centre provided the basis for the outlook part, which undertook analyses on synergies and trade-offs between different EU policies with the view of translating 'early warnings' into recommendations on pollutants of increasing concern. Specifically, the EUSO contributed to:

- two chapters in the monitoring assessment on: "Soil Pollution and Ecosystems" and "Soil pollution and health".
- the soil component of the 2022 Zero Pollution Outlook report, which highlighted the substantial knowledge gaps regarding the levels of several contaminants in soil, reflecting a lack of coherent monitoring and legally binding EU frameworks on soil. The adoption of the integrated nutrient management action plan and the proposal for the safe use of processed manure above the threshold established for nitrate-vulnerable zones by the nitrates directive should lead to a more efficient use of nutrients, and hence a reduction in the loss of nitrates and phosphates from soil to water and air. In addition, the target of increasing organic farming in the EU to at least 25 % of agricultural areas should lead to a reduction in the use of synthetic pesticides. However, the outlook flagged that the global pollution of terrestrial and aquatic environments by plastics is substantial and increasing.

In the future iterations of the report, the ambition is also to integrate analyses, projections and forecasts across air, soil and the aquatic realm.

The Monitoring Assessment is available online at: https://www.eea.europa.eu/publications/zero-pollution/zero-pollution

The Outlook is online available online at:
https://publications.jrc.ec.europa.eu/repository/handle/JRC129655

Evaluation of the Sewage Sludge Directive (86/278/EC)

The Directive on the Use of Sewage Sludge in farming, adopted in 1986, aims at encouraging the use of sewage sludge in agriculture while preventing harmful effect on soil, water, vegetation, animals and humans. Since the adoption of the Directive, there have been changes on the definition of sewage sludge and on the

[6] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A674%3AFIN&qid=1670510444610

risks and opportunities linked to its use, as well as changes in the wider environmental legislative and policy framework. In particular, no up-to-date risk assessment studies was available for metals present in sewage sludge. This called for an in-depth evaluation of the Directive.

The EUSO contributed to the discussions through a series of reports, brought together in a JRC Science for Policy Report and to the Staff Working Document for the Evaluation of the Sewage Sludge Directive. The climate change mitigation potential of sludge applications were assessed through a biogeochemical model that calculated fluxes in organic carbon and nitrogen in relation to land use and soil characteristics. Land spreading of sewage sludge containing pollutants was assessed using modelling, based on current concentrations of metals in soils and estimated metal inputs from long-term sewage sludge applications. The findings indicate that the land spreading of sewage sludge with content of heavy metals aligned to maximum limits laid down in the Sewage Sludge Directive for 10 consecutive years at 5 Mg ha-1 rate will largely affect soil quality.

This is available online at: https://publications.jrc.ec.europa.eu/repository/handle/JRC129690

Contribution to the "State of the world's land and water resources for food and agriculture" (SOLAW-FAO)

The "State of the world's land and water resources for food and agriculture" (SOLAW) 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 chapter 1.5 "Soil under pressure", chapter 3.3 "Land degradation risk" and chapter 3.3.1 on "progressive erosion" with text, modelling outputs, scientific evidence and publications. The EUSO also established the Global Soil Erosion Modelling platform, which assessed global soil erosion using a combination of remote sensing, GIS modelling and census data (Borrelli et al., 2022).

This is available online at: https://www.fao.org/land-water/solaw2021/en/

Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

The Sixth Assessment Report of the IPCC presents a comprehensive assessment of the current state of knowledge of the observed impacts and projected risks of climate change as well as the adaptation options. Use of data and scientific outputs from JRC publications in relation to soil were cited in this report. In particular, scientific knowledge produced by EUSO on soil erosion was used in Chapter 4 - Section 4.2.8 (Water) and while Chapter 13 (Europe) also uses EUSO data and publications for the comparison of the "risks on climate change" between Europe and other parts of the world.

Sustainable development in the European Union — Monitoring report on progress towards the SDGs in an EU context — 2022 edition

In 2022 the EUSO further developed the indicator the 'estimated soil erosion by water' for SDG 2 'Zero hunger' and SDG15 'Life on Land' to show trends in soil erosion. While this is a major threat for land degradation, there are signs of improvement across Europe. The total area at risk of severe soil erosion by water in the EU has shrunk slightly since 2010. In 2016, 5.3% of EU land was estimated to be at risk of severe soil erosion by water. The share of non-artificial erosive area (16%) estimated to be at risk of severe soil erosion by water fell from 6.1% to 5.3% between 2000 and 2016. In addition, modelling results up to 2070 show that water erosion could rise by up to two-thirds compared with today.

This is available at: https://ec.europa.eu/eurostat/web/products-flagship-publications/-/ks-09-22-019

Eurostat regional yearbook — 2022 edition

The Eurostat regional yearbook 2022 provides a detailed picture relating to a broad range of statistical topics across the regions of the EU Member States. Each chapter presents statistical information in the form of maps, figures and infographics, accompanied by a descriptive analysis highlighting the main findings. The work of the EUSO is included in the Environment chapter (Map 12.5) to show changes in soil organic carbon stocks in agricultural soils 2009-2018. This assessment involved the preparation and analysis of data produced from the LUCAS 2009 and 2018 soil surveys and their subsequent elaboration by in house

modelling capacity. The inputs from the JRC can be used to assess developments in relation to the European Green Deal and the implementation of the United Nations (UN's) 2030 Agenda for Sustainable Development.

This is available at: https://ec.europa.eu/eurostat/web/products-flagship-publications/-/ks-ha-22-001

Contribution to the EU Agricultural Outlook 2021-2031

DG AGRI's EU Agricultural Outlook report for 2021-2031 presents the medium-term outlook for EU agricultural markets, income and environment to 2031, based on a set of macroeconomic assumptions deemed most plausible at the time of the analysis. The JRC/EUSO contributed to the analysis of the Environmental Impacts of Nutrient Surplus with the analysis on phosphorus. Given the relevance of soil erosion in adding phosphorus to the soil content, estimated potential phosphorus losses due to erosion were also estimated. Phosphorus mineral fertilisers, however, are produced from phosphate rock, a non-renewable natural resource that is not substitutable. The EU has less than 1% of the production capacity and less than 1% of the world's reserves of phosphate rock. Therefore, estimating phosphorus losses is important for agriculture where efforts should take place to minimise losses.

Available: https://agriculture.ec.europa.eu/system/files/2023-01/agricultural-outlook-2021-report_en_0.pdf

Common Agricultural Policy (CAP) context indicators

The European Commission has set up the common monitoring and evaluation framework (CMEF) to assess the performance of the 2014-20 common agricultural policy (CAP) and improve its efficiency. The CAP objectives include among others the sustainable management of natural resources and climate action, with a focus on greenhouse gas emissions, biodiversity, soil and water. In the current CMEF, a number of indicator types were defined to support the assessment of the CAP's performance (Context Indicators). This includes Indicator C40 "Soil organic matter in arable land" which estimates the total organic carbon content in arable soils and Indicator C41 "Soil erosion by water" which access the rate and agricultural area affected by water erosion. On the 6 December 2021, Regulation (EU) 2021/2115 of the European Parliament and of the Council establishing rules on support for CAP Strategic Plans was adopted. This regulation establishes the performance monitoring and evaluation framework (PMEF), which applies for the CAP from 2023 until 2027.

This is available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC132234

Contribution to Staff Working Document SWD(2023)4 final on "Analysis of main drivers on food security".

EUSO developed a chapter on "Soil Health" and the interactions with other food security drivers. About 60-70% of EU's agricultural soils are currently either losing organic carbon, receiving more nutrients than they need (affecting also water resources and natural habitats), eroding or compacting, suffering secondary salinisation, or some combination thereof.

This is available at: https://commission.europa.eu/publications/analysis-main-drivers-food-security_en

Contribution to the Global Peatlands Assessment (GPA)

The GPA is the most comprehensive global assessment of peatlands to date. It has been developed by the UNEP-led Global Peatlands Initiative. The EUSO contributed to the Regional Assessment for Europe (Chapter 5). It is estimated that about 10% of the former European peatland area has already been completely lost through drainage for agriculture, forestry and peat extraction and about 46% of the current European peatland area (50% for the EU alone) is classified as degraded. The contribution to the assessment is an action under the EU Soil Strategy 2030.

Soil Atlas of Asia

The EUSO continued the preparation of the Soil Atlas of Asia, which started in 2018 and has involved over 100 soil experts under the facilitation of the Global Soil Partnership (GSP-FAO). The Atlas builds on collaboration with experts from the regional North African and Near East, Eurasian and Asian Soil Partnerships

to highlight the diverse arrangement of soils across the continent of Asia, the ecosystem services they support and the degradational pressures they face. During 2022, the EUSO coordinated several online meetings with experts across Asia, including two multi-regional editorial panels. The Atlas was introduced at the World Soil Day celebrations at FAO in December. The Atlas will be published in the first quarter of 2023.

A brochure introducing the Soil Atlas of Asia is available at: https://www.fao.org/documents/card/fr/c/cc3298en/

'4 per 1000' day at UNFCCC COP27, Sharm el Sheik

16 November 2022 saw the 6th Day of the "4 per 1000" international Initiative, which was held as a hybrid meeting under the umbrella of UNFCCC COP27. The EUSO supported the JRC Director-General, Mr Stephen Quest, to prepare a plenary address as part of the opening forum. During 2022, the EUSO evaluated the options for the European Commission to join the '4 per 1000' initiative as a Member. Further details will be provided in the 2023 Bulletin.

Contribution to soil in the Western Balkans

As part of the Green Agenda for the Western Balkans, the EUSO team contributed to a major JRC report on the "Status of environment and climate in the Western Balkans". This study summarised for the first time the status of air, climate, water and soil in the Western Balkans. The evidence collected for the assessment on soils was compiled into a technical report titled "Soil health in the Western Balkans". This document attempts to benchmark a range of issues affecting soil health with considerations on the accession progress for an eventual Soil Health Law under the 2030 Soil Strategy.

Available at: https://esdac.jrc.ec.europa.eu/public_path//shared_folder/doc_pub/KJNA31163ENN.en_.pdf

EUSO developments for the Integrated Nutrient Management Action Plan (INMAP)

The Commission works with Member States to develop an Integrated Nutrient Management Action Plan (INMAP). The plan will cover all sectors and environmental compartments involved in the nitrogen (N) and phosphorus (P) cycles.

The 'Knowledge for INMAP' project, developed by the JRC during the year 2021-2022, aimed to gather scientific knowledge and data available in the EU to support the discussion and preparation of the Integrated Nutrient Management Action Plan. In particular, the work focused on three major tasks: 1) the description of the current flows of nitrogen and phosphorus in the EU considering all sources and sectors involved (agriculture, industries, urban, energy and transport) and all environmental losses in air, water, and soils; 2) the evaluation of the distance to environmental targets, considering the EU legislation and strategies; 3) the analysis of measures to reduce nutrient pollution at different intervention points in the nutrient cycle.

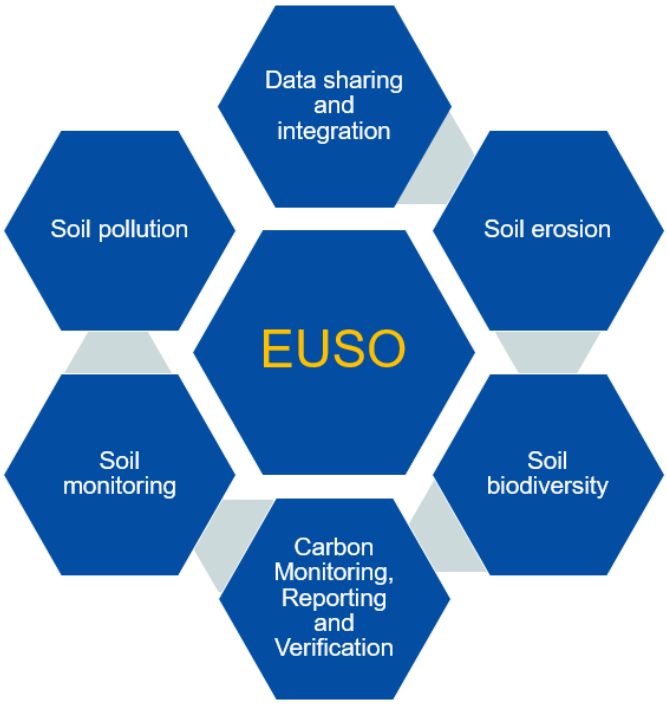
The EUSO has contributed to the INMAP project by a) developing scenarios of reduction of nitrogen fertilisers in agriculture (DayCent model) and b) estimating phosphorus budget in European agricultural soils with an empirical model. The EUSO has developed a state-of-the-art process-based European biogeochemical modelling platform that simulates carbon (C) and nitrogen (N) flows within soil and between soil, the atmosphere and vegetation. In addition, the EUSO developed an improved Empirical Model Phosphorus Balance (EMPBa) framework to investigate the main inputs and outputs of phosphorus in European agricultural topsoils, assess the phosphorus budget and simulate the phosphorus budget at regional levels (NUTS2).

2.2 Working Group activities

A key element of the EU Soil Observatory, the EUSO Working Groups aim to discuss technical advances on a particular topic. Co-chaired by EUSO staff and external partners, the Working Groups are composed of experts from academia, businesses or policy experts with recognised experience in the topic. The EUSO Working Groups (WG) develop their own work agenda with a view to provide relevant advances to current scientific and policy questions.

Five Working Groups were established during the 2021 EUSO Stakeholder Forum. A Working Group on Carbon Monitoring, Reporting and Verification was created in 2022. Together, they cover the topics shown in Figure 5. The following sections describe their activities and progress in 2022.

Figure 5. The six Working Groups of the EU Soil Observatory in 2022



2.2.1 Soil erosion

The Soil Erosion Working Group consists of 52 members. It is chaired by Panos Panagos and co-chaired by Diana Vieira, Pasquale Borrelli and Petra Deproost. .

The objectives of the WG aim to develop an object oriented (bottom-up) approach for estimating soil erosion and erosion-related soil health indicators at farm scale. In addition, it will look to integrate soil erosion with complementary issues such as soil contamination, carbon loss and food security. The WG will look to improve large-scale assessments. Sub-groups will be created to address specific research questions or policy requests.

In 2022, the WG has been very active in a) organising the online workshop "Soil erosion for the EU" in June, b) summarise the main outputs of the workshop in the Stakeholder Forum of October 2022 and c) develop new "products" such as the "Multiple concurrent soil erosion processes in the EU" (published in Nature Sustainability and the EUropean SEDiments collaboration (EUSEDcollab) database.

2.2.1.1 Soil erosion for the EU – online workshop 20-22 June 2022

In June 2022, the WG organised a 3-day workshop with 333 participants from 63 countries addressing the following challenges in relation to soil erosion: climate change, farm/field scale modelling, large scale modelling, mitigation options & management practices, linking landslides to erosion, sediments dynamics,

early career research on land degradation, soil organic carbon and food security. The 70 presentations from this workshop are available at this link: https://esdac.jrc.ec.europa.eu/euso/euso-wg-soil-erosion-europe

The workshop hosted three high-level key note speakers (**Figure 6**):

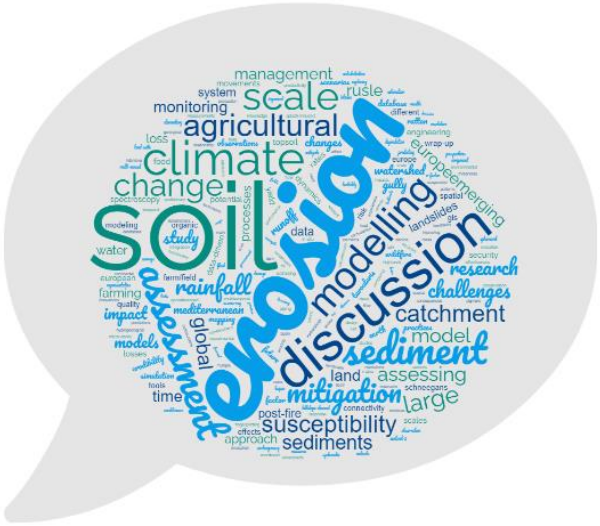
- **Philippe Ciais** (Laboratoire des Sciences du Climat et de l' Environment, Paris – France) presented the global carbon cycle and how this can be affected by the soil erosion.
- **Annette Scheegans** (European Commission - DG AGRI, Brussels - Belgium) presented the recent developments in the Horizon Europe's Soil Mission "A Soil Deal for Europe" and the opportunities for research funding.
- **Rattan Lal** (Ohio University, United States) presented the global challenges on land degradation, carbon losses and the future projections.

Figure 6. Soil Erosion workshop flyer

The workshop reflected over several relevant scientific and policy issues (**Figure 7**). The proceedings of the workshop are available online at:

https://esdac.jrc.ec.europa.eu/public_path/public_path/EUSO/proceedings_ALL_2023.pdf

Figure 7. Main scientific and policy issues discussed at the EUSO WG Soil Erosion workshop



As a follow-up of the workshop, the EUSO created a special issue in the Environmental Research journal dedicated to the outcomes of the Soil Erosion workshop. Submissions will be open until end of April 2023. The peer review process is expected to be completed by the summer of 2023,

2.2.1.2 Soil Erosion Working Group meeting at the EUSO Stakeholders Forum 24-26 October 2022

The Soil Erosion WG held a meeting as part of the EUSO Stakeholders Forum 2022. Sessions' leaders on the main topics of the 2022 June workshop presented their outcomes:

a) Nejc Bezak – Sediments. Sediments are an important element of the erosion-sedimentation cycle and can be indicator of the increased soil erosion or landslides activity in the catchment. Sediments are mostly associated with negative consequences as high-concentrations can be harmful for aquatic biota or they can transport pollutants. However, it is often forgotten that floods and sediments were crucial for the survival of ancient civilisations and are still very important element in the erosion-sedimentation cycle since disruption in the sediment transport can accelerate erosion process in rivers downstream. Therefore, compiling and maintaining sediments database is of huge importance since the data from such databases can be used to calibrate soil erosion model or evaluate the potential changes in rivers from the climate change perspective. Having that in mind, these databases should also incorporate historical data and information that are often not digitalised but can provided valuable information about temporal dynamics. Moreover, the community should aim to harmonise and merge the existing databases that should be made freely available (e.g., ESDAC). Furthermore, the focus should not be only on the suspended load but bed load information should be included as well in order to obtain the insights about the sediment dynamics. The sediment transport measurements are associated with the uncertainty that should be better quantified and included in these databases. Hence, future work should also focus on limiting the uncertainties related to sediment quantification with the combination of field work and lab experiments. Finally, the community should also try to monitor the extreme catastrophic (compound) events that are becoming more frequent and that can generate the majority of sediment transport. Hence, this would enable the society to better understand and predict soil erosion and sediment transport processes, which are essential for EU Soil Strategy for 2030 and EU Soil Deal.

b) Joris Eekhout – Soil erosion and climate change. The session on Soil Erosion and Climate Change included presentations from Europe, Asia and North America, hence, the research field can be considered global, with contributions from many different countries and under different climate conditions (from arid to snow dominated regions). While most studies apply RUSLE or related models (such as the R-factor and MUSLE), there is also a tendency of applying different models, such as G2 and Erosion 3D. Currently, all studies apply the RCP climate scenarios and there is a trend towards SSP scenarios, which

combines the RCP scenarios with global land use projections. Still, most studies focus on the climate change impact only, without a combined impact of climate and land use change, which is still mostly reserved for historical assessments. This can be seen as an important challenge for future research. Other challenges include proper validation of the model results, which is, of course, difficult because future projections cannot be validated. Other challenges have a more model conceptual origin, which include a focus on a wide range of soil erosion processes, including gully and channel erosion. But also the application of event-scale models. A move towards more complete models and time-scales most relevant for soil erosion could lead to more realistic model outcomes, but also to more difficulties in model validation. This trade-off will probably be the main focus of future research on the impact of climate change on soil erosion.

c) Marcella Biddoccu – Farm/field scale modelling. There is still a needing for soil erosion estimation at farm/field scale to increase the awareness/knowledge of farmers/stakeholders about the soil erosion risk in their properties and how to face this risk, since decisions at field level have relevant impact also at wider spatial scale. The modelling approach at this scale should consider: i) the high variability of the features affecting soil erosion, both temporal and spatial, due especially to the adopted soil management practices (including introduction of new tools for soil management), with a proper estimation/calibration of associated parameters (i.e.: CN, LS-factor, C-factor); ii) different "site-specific" processes that affect greatly the runoff and erosion risk, as gully and wildfires; ii) integration of different approaches, from proximal and remote-sensing, in-field assessment (visual checking and measurements), citizen (farmers and stakeholders) involvement in conjunction with modelling in order to have a site-specific erosion risk evaluation. Such integration of different approaches presents great potential in improving the awareness and knowledge of land users about the soil degradation processes and thus their decisions that could greatly contribute to have healthier soils. One limitation is the high heterogeneity of methods used, without common protocols or guidelines, i.e. in collecting data among citizens, which is natural consequence of investigation in specific land uses or regional features, but that results in difficulties in comparing data and results. Farm/field scale modelling could greatly benefit from new opportunities represented by citizen science, existing comprehensive databases (i.e. ESDAC), remote sensing, artificial intelligence, which in coming years could help to improve site-specific soil erosion assessment at field level, to be considered in farm and land management decisions at different levels from farmers/citizens to local landscape managers in order to prevent soil degradation.

d) Dan Evans – Early career researchers in the soil erosion community. The early career researchers have an important role to play in setting the future of the sub-discipline. Two sessions of the EUSO workshop on Soil Erosion were dedicated to sharing the research currently being carried out by early career soil erosion scientists. The topics covered were diverse, from surface soil erosion to subterranean piping processes, and often nodded to other sessions convened in the workshop. Early career research covered a wide range of spatial scales, from assessing the role of soil structure on splash-induced erosion, to the empirical monitoring of erosion at the catchment scale. Many presentations focused on developing and testing, or modifying existing, soil erosion models for the short- to long-term forecasting of soil erosion rates and trends, whilst others showcased the use of satellite data and deep learning techniques to improve soil erosion predictions. Based on the findings of their empirical or modelling-based work, researchers concluded with recommendations for changes to land use and/or land management practices to sustain soils, and the delivery of ecosystem goods and services, for future generations. These conclusions are important messages for policymakers at regional, national, and global scales, and should facilitate more effective decision-making in the future so that the principles of soil sustainability can be realised not solely as aspirational targets but in committed legislation. One of the challenges that has arguably always confronted soil erosion scientists is building effective bridges of communication between the research and policy communities. Given the proportion of the land surface which is already degraded, ensuring that evidence-based work is acknowledged and realised in effective policy making is of great urgency. Similarly, translating findings from research into accessible messages for farmers and land managers is also vital. As the next generation of soil scientists, perhaps these are some of the grandest tasks facing our early career research community at the present time.

e) Nick Tavoularis – Landslides and soil erosion. In the session of "Landslides and Soil Erosion", subjects such as landslide inventory and susceptibility mapping, landslide monitoring using Copernicus datasets, fatal flash flood events resulting in soil erosion types validated in a regional scale landslide susceptibility map, the interpretation of geological and geotechnical databases, as well as the presentation of a suite of tools for statistically based landslide susceptibility zonation implemented in R language, were the main highlights that focused on soil erosion issues in accordance with landslides. In coping with the above-mentioned, presenters of the particular session, referred to difficulties in acquiring the relevant landslide and thematic information, selecting the appropriate slope failure mapping unit as well the relevant landslide

statistical model. Based on the above, characteristic future challenges for the broader scientific community regarding landslides/soil erosion are the following: (i) Further validation of European Landslide Susceptibility Map (ELSUS) using more accurate regional susceptibility maps through evaluation of downloaded information from European Soil Data Centre (ESDAC), (ii) Utilisation of more quantitative, inventory-based statistical susceptibility modelling techniques, (iii) Preparation of landslide hazard scenario estimates using spatially distributed climatic and seismic data, (iv) Compilation of an open-access European landslide inventory applicable for continental, national, regional and site specific level landslide studies, (v) Implementing Artificial Intelligence and Machine Learning methodologies using (free) open-access Web-GIS platforms with a variety of geo – and soil data. In conclusion, the more soil- and geo- data every European Country through its geological research institute and public technical authorities acquires, the better it is, to lead to targeted studies which are fundamental to adapt models and to identify the appropriate combination of strategies to reduce vulnerability toward landslides and soil erosion. Those strategies should be explained in detail by the experts, to the decision makers (e.g., concerning policy issues) and to the different stakeholders in society.

f) Artemi Cerda – Mitigation & management practices. The meeting supported the exchange of key knowledge between the scientific and stakeholders participants. The section on soil erosion mitigation and management show examples of good practices to reduce and control the soil losses and to achieve a more sustainable agriculture. The research carried out demonstrated that soil erosion can be controlled if we apply proper management and mitigation strategies. A key point in our discussion was the cost of soil erosion and how the mitigation practices are a good investment for the farmers after some years. Then, there are not constrains due to the lack of strategies to reduce the soil losses or technical constrains. Most of the constraints are coming from the social, economic and perception spheres. Farmers are not always supportive of the new technologies as they increase the expenses and reduce their reputation within the farmer's community. To use catch crops is more expensive and also induce the complaints of other farmers as they see the field dirt due to the cover crops. Then, we can confirm that there are solutions to the high erosion rates we suffer in Europe, but we need more investment in education and subsidies to convince the farmers to apply them in the field. The main challenges for us now is to develop long-term soil erosion measurements in collaboration with farmers (living labs) that will make the results of the research of higher quality and will contribute to the dissemination of the findings within the farmer's community. Another challenge is that scientist must calculate the cost of the new management (cover crops, catch crops, mulches, strips…) and transfer this knowledge to the policy level to finally support the shirt of the farmer's management into a new agriculture, an agriculture with less chemicals and more biodiversity, with healthy soils and a low soil losses.

g) Pasquale Borrelli – Large scale modelling. The session on "Large scale modelling" included new findings on a) gully erosion at global scale and Africa b) sedimentation modules c) C-factor advancements d) advancements in soil monitoring and e) novel nuclear techniques to better estimate soil losses. The session conceded that promoted soil erosion modelling community should make a step towards intercomparison of global multi-models, gaining new insights from the advantages and disadvantages found in the compared models. This EUSO WG can promote this kind of model intercomparison.

2.2.1.3 2022 achievements of the Soil Erosion Working Group

In 2022, the following articles, in preparation or published, were informed by the work of the EUSO Soil Erosion Working Group.

Multiple concurrent soil erosion processes in the EU

Major part of EU arable land are vulnerable to the possible interaction of increased flood, drought, water, and wind erosion. The analysis, carried out by JRC scientists and 10 members of the Soil Erosion WG, is published in Nature Sustainability. This first-ever assessment at European scale combines the threat of water, wind, tillage and harvesting to reveal the cumulative impact on arable land. It is a basis for developing a comprehensive monitoring system for soil health.

New analysis using a multi model approach assesses impact of soil erosion not only by water but by other drivers: wind, tillage conditions and crop harvesting. The study indicates that 43 million hectares (M ha) out of approximately 110 M ha of arable land in the EU and the UK are estimated to be vulnerable to a single driver of erosion, 15.6 M ha to two drivers and 0.81 M ha to three or more drivers.

Reference: Borrelli, P., Panagos, P., Alewell, C., Ballabio, C., de Oliveira Fagundes, H., Haregeweyn, N., Lugato, E., Maerker, M., Poesen, J., Vanmaercke, M. and Robinson, D.A., 2022. Policy implications of multiple concurrent soil erosion processes in European farmland. Nature Sustainability. DOI: 10.1038/s41893-022-00988-4.

EUSEDcollab: a network of data from European catchments

The EUropean SEDiments collaboration (EUSEDcollab) database contains a compilation of data contributions from monitored catchments from across multiple European institutions. The focus of the database is small to medium catchments containing water discharge and sediment delivery time series measurements for soil erosion, sediment delivery and runoff studies. These measurements from various institutions provide insights into the processes governing soil erosion and sediment delivery across a spectrum of spatial and temporal scales. The data is aimed at multiple end-user applications, such as providing baseline information for further analytical studies and model application/development, allowing comparison with real measurements of process rates. As a user-orientated EUSO initiative, the contributed data is harmonised with a common metadata and time series structure to allow efficient reuse. This database aims to provide the research community with a starting point for new research opportunities in a range of sediment-related research avenues.

The ESEDCollab dataset will be finalised in the first quarter of 2023 and made available in ESDAC as soon as it is published.

Cost of off-site effects of soil erosion

The EUSO Working Group on soil erosion addresses the question of the costs of sediments removal. The WG decided to start a study on estimating the off-site costs of soil erosion. The WG on soil erosion made a call for data on the costs of removing sediments from dams, ports, rivers, etc. Scientists who were aware of studies or reports quantifying the costs of removing sediments (or energy revenue costs due to sedimentation) contacted the WG chair. The overall objective is to have a pan European estimation of sediments removal. This topic contributes also to the impact assessment of the forthcoming EU Soil Health Law with economic data on off-site costs of land degradation. The topic will be also addressed through a complete study in 2023.

2.2.2 Soil data sharing and integration

The EUSO Soil Data Sharing and Integration Working Group (WG) includes 49 members. It is chaired by Marc Van Liedekerke and co-chaired by Calogero Schillaci, both from the EUSO team.

The work areas of the Soil Data Sharing and Integration WG were used to define subgroups (in 2021). A first plenary meeting of the Working Group was held in February 2022 during which the subgroup leads explained their intentions on how to identify current and future relevant EU-wide soil datasets, as follows:

- EU-Projects (Christine Le Bas)
- EU Soil Monitoring and Indicators (Antonio Bispo)
- EJP Soil (Maria Fantappie')
- Literature (Calogero Schillaci)
- Hub (Fenny van Egmond)

A report of this meeting was prepared. After this plenary, the subgroups started to operate autonomously.

The preliminary results from the subgroup working on the literature data will be presented to the EGU general assembly on April 23rd-28th 2023 in Vienna, Austria, through two presentations:

- Soil data sharing in the EU, a survey of available soil datasets found in the scientific literature | On-site presentation, Authors: Calogero Schillaci, Iustina Popescu Boaja, Edita Baltrėnaitė-Gedienė, Ester Miglio, Simone Sala, Fenny van Egmond, Maria Fantappiè, Benoit Pereira, Lachezar Flichev, Sara Di Lonardo, Paul Henning Krogh, Michaela Hrabalikova, Estela Nadal-Romero, Anna Ladenberger, and Marc van Liedekerke.

— Review of the usage of LUCAS soil data for soil modelling and mapping via bibliometric analysis | On-site presentation, Authors: Fuat Kaya, Calogero Schillaci, Gordana Kaplan, and Levent Başayiğit.

As the work to be performed by the subgroups is the identification of EU-wide/relevant digital soil datasets, a metadata-template for storing the soil datasets metadata was designed by the chair and the subgroup leads. This template will be adopted in 2023 by the whole Working Group, not only to store the metadata of datasets identified through this exercise but also to be proposed as a template for the soil datasets that will be developed in future Horizon Europe Soil Mission projects.

The work envisaged at the outset of 2022 will be finalised in 2023, and presented in the 3rd EUSO Stakeholders Forum, after which new steps will be defined.

2.2.3 Soil pollution

Created during the first EUSO Stakeholder Forum, the Soil Pollution WG involves 51 members from academia, policy and industry. It is chaired by Piotr Wojda, Diana Vieira, Felipe Yunta, and Arwyn Jones from the EUSO. It is co-chaired by Dietmar Müller-Grabherr from the Common Forum on Contaminated Land in Europe and Frank Swartjes from the EEA/EIONET Working Group on Soil contamination.

The main objective is to provide support to the development of the Clean Soil Outlook Report and to investigate a contribution to the Zero Pollution Monitoring Report. Additionally, the Working Group aims to incentivise stakeholders' engagement and to support enhanced soil literacy.

2.2.3.1 Context

The Zero Pollution Outlook and Monitoring report, which the Clean Soil Outlook report is part of, is an initiative taken in the context of the EU action plan: "Towards a Zero Pollution Ambition for Air, Water and Soil" (COM(2021) 400) adopted by the Commission in May 2021. The Action Plan translates the zero pollution ambition for a toxic-free environment into an operational roadmap, together with the chemicals strategy for sustainability and in close synergy with other relevant European Green Deal initiatives, e.g. on climate, biodiversity and circular economy. The zero pollution ambition is a cross-cutting objective contributing to the United Nations 2030 Agenda for Sustainable Development and complementing the 2050 climate-neutrality goal in synergy with the clean and circular economy and restored biodiversity goals. To that end, the zero pollution action plan sets key 2030 targets to speed up pollution reduction.

The Joint Research Centre is linked to a number of activities under the zero pollution flagships (SWD(2021) 140) and was in particular responsible for the production of the first Zero Pollution Outlook report in 2022. From then onwards, it will be published every other year.

In this context, the main output of the EUSO and its Working Group on Soil Pollution during 2022 has been the contribution and development of the Zero Pollution Outlook Report (JRC129655), and within this, the Clean Soil Outlook 2022: high level summary contribution (JRC132367). The report marks a real milestone in the implementation of the zero pollution ambition of the European Commission. The Zero Pollution Outlook analyses synergies and trade-offs between different EU policies. It translates 'early warnings' into recommendations on pollutants of increasing concern based on the latest research findings. Its ambition is also to integrate analyses, projections and forecasts across air, soil and the aquatic realms.

2.2.3.2 Activities

The 2nd meeting of the EUSO Soil Pollution WG took place on 16th February 2022, in virtual mode, in two sessions. Both sessions seek direct contributions to the Clean Soil Outlook Report, whose objective is to provide a European overview on point-source and diffuse pollution. The missing knowledge, policy gaps, emerging risks should be identified, and early warnings issued. Some future scenarios were put forward.

The first session focused on the contaminated sites. Specifically, on whether the EU will be able to meet the following targets of the EU Soil Strategy for 2030: a) significant progress should be made in the remediation of contaminated sites by 2030, and b) the inclusion of legally binding provisions on contaminated sites identification, inventorisation and remediation. The session tried to assess the inputs required to complete a DPSIR (Driver Pressure State Impact Response) assessment for contaminated sites in order to develop headline messages for the Outlook Report.

The second session focused on the diffuse pollution aspects and whether the EU is able to create a toxic-free environment. A perceived obstacle is the lack of knowledge on the extent and impacts of diffuse pollution due to insufficient monitoring and research. Finally, the session provided the floor to discuss the advantages of multidisciplinary modelling to highlight synergies between air, soil and water pollution and to identify knowledge gaps and propose future actions.

A draft soil pollution watch list was presented. Its role is to help to provide a list of substances as potential or emerging contaminants. The watch list concept also needs a methodology to reach a consensus on its elements and to provide updates.

The inputs of this meeting directly fed into the Clean Soil Outlook Report. A 5-page extract, titled Soil: High Level Synthesis Report, proposed highlights from the main report, based on our expertise, observations and scientific evidence.

The 3rd meeting of the EUSO Soil Pollution WG was organised on 27th April 2022, again virtually, in two sessions. The Blueprint of the Clean Soil Outlook Report was presented, further suggestions and updates were collected and short-term objectives on what is next were defined. Additionally, we discussed the contaminated sites and other point type sources of pollution and touched upon diffuse pollution. The High level synthesis report was presented and next steps decided in that respect. Multidisciplinary modelling with its goals and needs were also further discussed. The final discussion focused on the soil pollution watch list.

A large consultation was done through the Soil Pollution WG members, EUSO team and DG ENV's soil and zero pollution teams to collect feedback on the 5-page High Level Synthesis Report.

The last meeting of the WG in 2022 took place in the framework of the second EUSO Stakeholder Forum on Wednesday 26th October. The scope of the meeting was to provide the final support to Clean Soil Monitoring & Outlook Report. We took stock of the progress made since the creation of the Working Group. The Soil Pollution Outlook High Level Synthesis Report was presented, then diffuse and point source Pollution were discussed. Phosphorus losses and heavy metals diffuse pollution current research was presented. The discussion continued on pesticides and contaminated sites. We also signalled the need for a broader Clean Soil Outlook version to be produced in the first half of 2023.

The meeting included a dynamic 'Pecha Kucha Lightning' session, i.e. a series of 3-minute impact-oriented presentations on the topics of soil pollution, soil remediation or contaminants of emerging concern. The Pech Kucha presentations included: a presentation of the Common Forum on Contaminated Land and its considerations on the land management, a presentation of the Zerovalent Iron (ZVI) as a soil remediation technique and environmentally-persistent free radical. Some results of the project Life Agremsoil were presented, which investigated a new method to remediate soils with pesticide residues combining solarisation and ozonation, reaching a degradation rate of 63% of soil pesticide content. Finally, a qualitative and quantitative comparison of field-based analytical technologies for petroleum hydrocarbons determination in soils was also presented.

After the Pecha Kucha presentations, the session continued with strong insights on emerging pollutants: PFAS, Watchlist reflection and other emerging pollutants. Conclusions were provided.

The WG on Soil Pollution actively contributed to the JRC Zero Pollution Outlook Report and to the Soil Monitoring Report.

The development of a Clean Soil Outlook could complement the implementation of the Soil, Biodiversity and Farm to Fork Strategies. While it was too early to have a comprehensive soil pollution dimension by 2022, discussions were launched about how existing instruments and initiatives (e.g. the ongoing European Soil Condition Assessment, LUCAS Soil) can support an outlook assessment focused on the soil pollution.

2.2.3.3 Ongoing activities and follow up

Work will continue in 2023 with a more in-depth analysis to extend the soil chapter to a self-standing Clean Soil Outlook Report. The report will be structured around the DPSIR approach (Drivers, Pressures, State, Impact and Response), proposing a framework for problem description and proposing valid solutions and policy responses.

2.2.4 Soil monitoring

The Soil Monitoring Working Group was established in October 2021, at the 1st EUSO Stakeholder Forum. It includes 36 members. It is chaired by Arwyn Jones, and co-chaired by Daniele De Rosa, both from the EUSO team, together with Rainer Baritz (EEA) and Antonio Bispo (INRAE).

In 2022, the WG worked to provide support to the development of the Soil Health Law, in particular, regarding the development of soil monitoring elements, and engagement with the EU Soil Expert Group. The WG also contributed to the Soil Mission's implementation.

2.2.4.1 Meeting of 3rd March 2022

Following the initial meeting in October 2021, the Soil Monitoring Working Group met for a second time on 3rd March 2022. The meeting aimed to develop a discussion paper for the EU Soil Expert Group that outlined possible options for a more integrated soil monitoring in the EU and to develop ideas to carry out soil health assessments in the EU.

The WG defined the challenges facing EU soil monitoring integration, as follows:

- Soil monitoring at Member State level is fragmented, incomplete and not harmonised.
- There is currently no systematic comprehensive monitoring of policy-relevant issues (as raised in the Soil Strategy) in many countries due to a lack of capacity or knowledge.
- Data are often not shared in accordance with the mechanism of the INSPIRE Directive.
- LUCAS soil is the only monitoring system that provides harmonised and systematic on-the-field measurements for all Member States. But it needs to be better integrated with activities in Member States and other data flows.
- The EEA provides harmonised indicators on soil sealing and land take, but the timeliness and resolution is not always harmonised.
- Some legislation with soil-related reporting are not working coherently (e.g. NEC Directive, Landfills, LULUCF Regulation, Sewage Sludge, …)
- A system approach for healthy soils is lacking

The meeting (and its subsequent briefing paper) addressed what should be monitored, how to assess and monitor soil health, reporting obligations and technical/practical considerations to take into account. Specifically, a tiered-approach to monitor 'soil health' was proposed. The methodology proposed envisaged using a mix of LUCAS, national and local soil data. It also proposed the scale at which soil health assessments could best be carried out. Finally it reviewed the technical feasibility of different concrete options for this assessment.

The outcomes of the discussion fed into a briefing paper which was submitted by DG ENV for comments to Member States. The briefing paper complemented with national comments directly influenced the drafting of the Soil Health Law components relating to soil districts and soil monitoring, and the associated Impact Assessment study.

2.2.4.2 Meeting of 26th October 2022

The Working Group met a second time in 2022 during the 2nd EUSO Stakeholder Forum. The objective of the meeting was discuss ways to achieve further soil monitoring integration in the EU. The agenda was built around a series of presentations introducing various aspects of the challenge of soil monitoring integration and successful experiences from which to draw lessons for the EU. The objective of the gathering was to identify ways to improve soil monitoring integration and promote greater awareness of the importance of this critical issue.

- Welcome and soil monitoring in EUSO, Arwyn Jones/Anne Maréchal, EUSO JRC
- Soil monitoring: a spatial and temporal variability problem, Daniele de Rosa, EUSO JRC
- Indicators and thresholds for monitoring soil health, Rainer Baritz, European Environment Agency
- Soil monitoring in EJP Soil, Antonio Bispo, INRAE
- Updates on German soil monitoring system, Frank Glante, UBA Germany

— Monitoring and upscaling soil derived GHG emissions with process-based models, Clemens Scheer, Karlsruhe Institute of Technology (KIT)

— Enhanced spatial soil health indicators with the synergy of Earth Observation technologies and artificial intelligence architectures to support national and European policies, Nikiforos Samarinas, Aristotle University of Thessaloniki (AUTH)

— Dynamic Soil Properties, Francine Lheritier, USDA-NRCS

The event concluded with a discussion and the next steps for the WG on monitoring. It was noted that the pace of the development of the Soil Health Law and the associated Impact Assessment study resulted in a very heavy workload for the EUSO team, which to some extent hampered the work of the WG in 2022 on other topics. In 2023, the WG will focus its efforts on further developing the monitoring and reporting elements of the proposed Soil Health Law and structuring the implementation of the monitoring elements of the Soil Mission. Another strand of work for the Soil Monitoring Working Group will be on monitoring of urban soils, natural habitats, or organic soils. New experts were also invited to join the Working Group. With these expanded efforts and collaborations, the group aims to advance soil monitoring integration across the EU and address the challenges facing soil health and management in various contexts.

2.2.5 Soil biodiversity

The Soil Biodiversity Working Group was launched in 2021. However, in 2022, its activities were paused due to a lack of specialised staff within EUSO to lead a Working Group on the topic of soil biodiversity.

The EUSO Soil Biodiversity WG is expected to resume its activities in 2023.

2.2.6 Soil carbon monitoring, reporting and verification

The Working Group on Soil Carbon Monitoring, Reporting and Verification includes about 40 members. It is chaired by Cristina Arias-Navarro and vice-chaired by Elise Van Eynde, both from the EUSO team.

Soil organic carbon (SOC) has gained international attention due to its relevance to food security and climate change mitigation and adaptation. Rapid expansion of the voluntary carbon market is evidenced by the number of carbon registries and private companies that have recently published measurement, reporting, and verification (MRV) protocols with important differences in their approaches to measurement and estimation of SOC and to key accounting issues. These differences pose a risk of non-equivalent credit creation, which would undermine confidence in the integrity of crediting programs. To upscale carbon farming successfully and to establish long-term business perspectives, it will be essential to standardise the methodologies and rules for MRV the gains or losses in carbon sequestered.

The Working Group was launched during the 2nd EUSO Stakeholders Forum, in October 2022. This Working Group will aim to engage with stakeholders involved in the MRV of SOC from a range of perspectives to address the technical challenges in establishing an eventual monitoring system that address a range of policy needs. The purpose of the event was to gather insights from a broad range of stakeholders to inform the future activities of the EUSO TWG. The input will be taken into account as we further develop and fine-tune the TWG.

The creation of this new WG was enthusiastically embraced by the soil community, with more than 400 people registered in the event. Speakers included policymakers, researchers, and the industry sector representatives. Among participants, researchers were the largest group consisting of 68 % of all participants, followed by private sector (18 %) and policy makers (13 %). These were the most strongly represented stakeholder types. The smallest groups represented were farmers (3 %), NGO (2%) and other (6%). The interest/expertise of the participants was mainly Mineral soils under agriculture (60%) followed by Organic soils including peatland (14%) with no or little interest/expertise in other land uses (agroforestry 3 %, forest management 3 %).

Participants could discuss challenges and opportunities for designing robust carbon farming schemes that prevent emissions of GHG while at the same time being socially acceptable and economically viable. The importance of scaling up carbon farming and practical solutions (based on science) was recognised by the

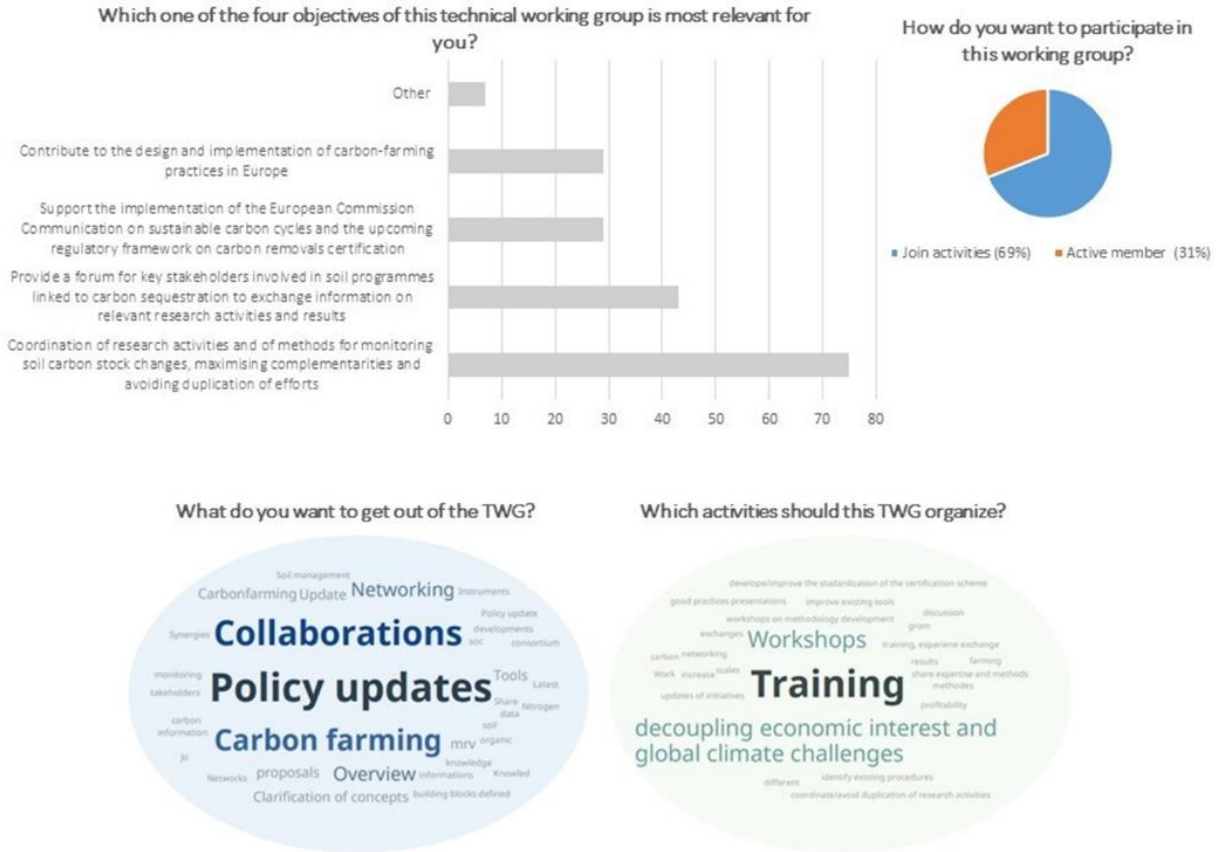
speakers during the event. Many highlighted the issues with regard to the sampling strategy and uncertainties related to SOC measurements and estimations.

2.2.6.1 Stakeholder engagement

Participants' views on the activities and modus operandi of the WG were collected during the event. The consultation process was an opportunity to raise issues and concerns, and to help shape the objectives and outcomes of the WG. Participants ranked as most important objective of the WG to act as coordinating body of research activities and of methods for monitoring soil carbon stock changes, maximising complementarities and avoiding duplication of efforts. Soil carbon MRV and carbon farming is a key area of research and innovation to be funded by the Soil Mission. Funded actions are foreseen to be linked and work together and should take into account and build on relevant previous initiatives on soil carbon monitoring and the EU Soil Observatory.

- This WG will work in close collaboration with EU funded projects such as ORCASA, SOLO project Think Tank "Conserve and increase soil organic carbon stocks", MRV4SOC project, etc.
- The WG will provide a forum for key stakeholders involved in soil programmes linked to carbon sequestration to exchange information on relevant research activities and results. In addition, organisation of workshops and trainings will be considered.
- The majority of the participants (69%) expressed preference to participate in the WG in an informal way, participating in activities organised by the WG. Participants who would like to become active members of the Working Group, i.e., suggesting and co-organising activities (31%) were requested to send an email to meeting organisers.

Figure 8. Participants' views on the activities and modus operandi of the WG on Soil Carbon Monitoring, Reporting and Verification (poll results)



2.2.6.2 Next steps

The next meeting will take place in Q2 of 2023. At this meeting, the organisation, of the Working Group, its tasks and the planning of work will be discussed.

3 Conclusions - Expected developments for the EU Soil Observatory in 2023

This section highlights the main activities planned for 2023. Outcomes will be reported in the 2023 EUSO Bulletin report.

The EU Soil Observatory is hosted at the Joint Research Centre. For the period 2023-24, an updated **JRC Work Programme** has been developed around a series of Portfolios reflecting key Commission priorities. Portfolios aim to ensure an optimal integration of the JRC's work to maximise support to policy and anticipation while providing a logical and coherent bridging between scientific and policy domains. The EUSO activities and deliverables reflect the cross-cutting aspects of soil by contributing to Portfolios dealing with biodiversity, sustainable food systems, zero pollution, climate mitigation, global perspectives of EU policies and data.

In this context, the EUSO team will work across a number of topics in 2023. Amongst the deliverables planned:

- A study assessing the state of soil health in the EU: This deliverable will be a fully evidenced, spatially organised assessment of pressures affecting soil health through engagement with MS experts and relevant institutions with high relevance to the implementation of the Soil Health Law. The report, undertaken in conjunction with Commission Services, the EEA, MS and the European Soil Partnership, will feed both the 2025 State of European Environment Report and the ITPS State of World Soil Resources Assessment (also planned for 2025).
- A study on soil pollution in the EU: This deliverable represents the in-depth study underpinning the soil assessment in the Outlook Report carried out in the framework of the Zero Pollution Action Plan.
- A policy brief on soil organic carbon trends: The quantification of current SOC stocks and possible future changes as a consequence of land use change in the EU is paramount in the preparation of agricultural policies that aim at enhancing the resilience of EU agricultural systems. Based on an innovative data-driven modelling framework, JRC will assess and predict the effect of carbon farming strategies as well as quantifying SOC stocks under current and future climate conditions.
- A policy document defining a methodology to assess soil fertility: The EU Taxonomy Regulation prescribes that new construction is not built on arable land and cropland with a moderate to high level of soil fertility. This deliverable will contribute to the Taxonomy Regulation FAQ with a methodology for users to be able to define whether land can be used for construction in light of its soil fertility status.
- A study defining a methodology and indicator for Land Degradation: The European Court of Auditors (ECA) has noted that the risk of desertification in the EU was not being effectively and efficiently addressed by the Commission or Member States. This deliverable will assess soil degradation and desertification in the EU and contribute to needs of the Commission in light of the ECA recommendations.
- A report on pesticide residues in EU soils: this deliverable will assess how observational data, such as those collected from the LUCAS Soil Module, could be used as a basis for developing supplementary indicators to support the Harmonised Risk Indicator under Directive 2009/128/EC.
- A report on IACS data sharing soil use cases: This report will summarise the current state of the IACS data sharing around Europe and the evolution of the data sharing based on a series of use cases addressing soil erosion, soil carbon fluxes, pesticide applications and land degradation.

In addition, the **EUSO Soil Health dashboard** will continue to evolve. The developments planned in 2023 include:

- adding new datasets, to complement the current picture of state of EU soil health
- developing new functionalities. In particular, the EUSO team will aim to develop sliders allowing users to set the thresholds determining healthy/unhealthy soils as they see fit. Another functionality would be to allow users to change the geography (e.g. one Member State only, EU only or beyond EU).
- adding information about trends, for those datasets where time series are available.
- developing a trend indicator for the EUSO soil health assessment as a whole, to document the evolution of the rolling assessment carried out in the dashboard.

In parallel, work will be ongoing on the development of the EUSO Soil Policy dashboard, to monitor the state of implementation of soil policies, including the EU Soil Strategy.

The EU Soil Observatory is also expected to grow with the support of dedicated **Soil Mission research projects**. In particular, in 2023, the work of the following projects should help EUSO in developing key tools, as follows:

- building of a repository for the Soil Mission projects' outcomes, in relation to data and knowledge (SOILWISE)
- developing citizen engagement and literacy about soils (PREPSOIL)
- developing a roadmap for soil research in the EU (SOLO)
- developing indicators for soil health assessments (AI4SOILS, BENCHMARKS)

Progress will also be reported on the implementation of the SoMiMo Project.

The EUSO will also collaborate with projects funded under the Horizon 2020 PRIMA Programme (Partnerships for Research and Innovation in the Mediterranean Area) 2022 call on developing integrated soil data for the Mediterranean Region. These projects will contribute to the JRC's planned Soil Atlas of the Mediterranean (planned for 2026).

The EUSO team will continue to provide direct support to DG ENV, by building the evidence base to support the development of the upcoming **Soil Health Law**. Following the conclusion of the Impact Assessment study, the legislative proposal of the EU Soil Health Law is expected to be adopted by the European Commission in June 2023.

Finally, from a stakeholder perspective, the EUSO will investigate with the Soil Mission Secretariat the options for a 2023 EU Soil Week that brings together the EUSO Stakeholder Forum and Soil Mission communities.

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List of abbreviations and definitions

Bio4A	Project on Advanced Sustainable Biofuels for Aviation
C	carbon
CAP	Common Agricultural Policy
CDP	Collaborative Doctoral Partnerships
CDTP	Collaborative Doctoral Training Programme
cm	centimetre
CMEF	Common Monitoring and Evaluation Framework
CMORPH	Climate Prediction Center MORPHing
COM	European Commission
CSV	comma-separated values file
DG AGRI	Directorate-General for Agriculture and Rural Development
DG ENV	Directorate-General for the Environment
DG RTD	Directorate-General for Research and Innovation
DPSIR	Driver Pressure State Impact Response
EC	electrical conductivity
ECA	European Court of Auditors
EEA	European Environmental Agency
EJP-Soil	European Joint Partnership on Soils
ELSA	European Land and Soil Alliance
ENSA	European Network on Soil Awareness
ESDAC	European Soil Data Centre
ESP	European Soil Partnership
ESRI	Environmental Systems Research Institute
EU	European Union
EUSEDcollab	EUropean SEDiments collaboration
EUSO	EU Soil Observatory
FAO	Food and Agriculture Organization
FAQ	Frequently Asked Questions
GCM	General Circulation Models
GloREDa	Global Rainfall Erosivity Database
GloSEM	Global Soil Erosion Modelling
GPA	Global Peatlands Assessment
GPR	Gaussian Process Regression
ha	hectares
HE	Horizon Europe
HEI	Higher Education Institution
IACS	Integrated Administration and Control System

INSPIRE	Directive 2007/2/EC establishing an Infrastructure for Spatial Information in the European Community
IPCC	International Panel on Climate Change
JRC	Joint Research Centre
JRC.D3	JRC's Unit D3 'Land Resources'
kg	kilogramme
km	kilometre
LD	Land Degradation
LUCAS	Land Use/Cover Frame area Survey
LULUCF	Land Use, Land Use Change and Forestry
M ha	million hectares
MRV	Monitoring, Reporting and Verification
Mt	million tonnes
MUSLE	Modified Universal Soil Loss Equation
NEC	National Emissions Ceiling directive
NGO	Non-Governmental Organisations
NPK	Nitrogen, Phosphorus, Potassium
NUTS	Nomenclature of Territorial Units for Statistics
P	phosphorus
PE	priming effect
PFAS	Per- and polyfluoroalkyl substances
PMEF	Performance Monitoring And Evaluation Framework
Q1-Q4	Quarters
RCP	Representative Concentration Pathways
RED	Rainfall Erosivity Density
RUSLE	Revised Universal Soil Loss Equation
SDG	Sustainable Development Goals
SOC	soil organic carbon
SoilBON	Soil Biodiversity Observation Network
SOLACE	Project on Understanding the links between Soil pollution and CancEr
SOLAW	State of the world's land and water resources for food and agriculture
SWD	Staff Working Document
UK	United Kingdom
UN	United Nations
UNEP	United Nations' Environmental Programme
WG	Working Group
WMS	Web Mapping Application and Services
yr	year

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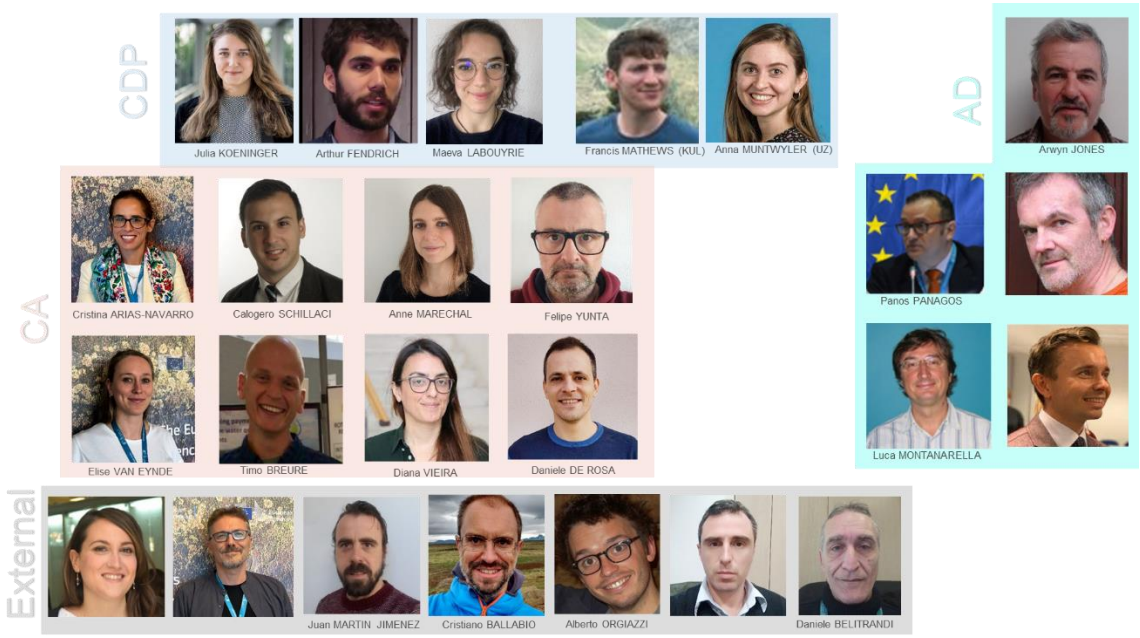
Annex 1: The EUSO team



During 2022, the EUSO bade farewell to Javier Hervas, its long standing expert on landslides. We wish him well in his retirement. We also wish Alberto Orgiazzi, our soil biodiversity specialist, all the best for the future on the conclusion of his contract. Best wishes also to Francis Matthews and Anna Muntwyler who are returning to KU Leuven and ETH Zurich, respectively, to complete their PhDs on soil erosion and nutrient fluxes.

The EUSO team also welcomed the arrival of:

- Felipe Yunta Mezquita, who will work on the SOLACE Exploratory Research Project on soil pollution and cancer.
- Elise Van Eynde, who will work mainly on soil nutrients and the LUCAS Soil Module
- Timo Breure, who will work on soil spectroscopy and sensing solutions for soil health assessments.

Annex 2: Second EUSO Stakeholder Forum agenda – 24th-26th October 2022

Second EUSO Stakeholders Forum

24-26 October 2022

AGENDA

All times are Central European Summer Time

Monday 24th October 2022

13:30 – Opening of Webex Room

14:00-17:30 – Towards healthy soils in the EU

Moderators: Arwyn Jones/Anne Maréchal, European Commission JRC
Scope: Towards healthy soils in the EU

14:00 – 14:10 Welcome and scope
Alessandra Zampieri, European Commission JRC, Director Sustainable Resources

14:10 – 14:30 EU Soil Strategy: towards a Soil Health Law
Mirco Barbero, DG ENV
14:30 – 14:50 Soil Health
Cristine Morgan, Chief Scientific Officer, Soil Health Institute

14:50 – 15:10 EU Mission: A Soil Deal for Europe: 100 living labs and lighthouses to lead the transition towards healthy soils by 2030
Orsolya Frizon-Somogyi, European Commission DG AGRI
15:10 – 15:30 Carbon farming in the EU
Valeria Forlin, DG CLIMA

15:30- 15:40 Break

15:40 – 16:20 Zero Pollution Monitoring and Outlook Report
15:40 – 16:00 Rainer Baritz, European Environment Agency
16:00 – 16:20 Jann Martinsohn, European Commission JRC
16:20 – 16:45 Soil and water carbon banks
Martin Kováč, Slovak State Secretary for Agriculture and Rural Development
16:45 – 17:05 Outcomes of the conference "The current state of the soil cover of Ukraine under conditions of the armed aggression of the Russian Federation"
Maxim Solokha, NSC ISSAR
17:05 – 17:20 EUSO activities update
Arwyn Jones, European Commission JRC

17:20 – 17:30 Discussion and Questions from the Audience
17:30 – Closing remarks

Tuesday 25th October 2022

09:30 - 12:30 – Core EUSO objective: supporting research and innovation

Moderators: Cristina Arias-Navarro/Arwyn Jones, JRC European Commission
Scope: EUSO engagement with Horizon Europe research projects (Soil Mission)

09:30 – 9:40 Introduction
Cristina Arias-Navarro/Arwyn Jones, EC JRC

09:40 – 9:50 What's next for the Mission "A Soil Deal for Europe"
Paola Alejandra Eulalio, DG AGRI
9:50 - 10:05 SMS
Katharina Helming, ZALF and Peter Tramberend, Umweltbundesamt
10:05 – 10:20 ORCASA
Suzanne Reynders, INRAE
10:20 – 10:35 PREPSOIL
Niels Halberg, Aarhus University
10:35 – 10:50 Soil O-live
Antonio Jose Manzaneda Avila, University of Jaen

10:50- 11:00 Break
11:00 – 11:15 AI4SoilHealth
Mogens Humlekrog Greve, AU
11:15 – 11:30 BENCHMARKS
Rachel Creamer, WUR
11:30 – 11:45 EJP SOIL
Claire Chenu, INRAE
11:45 – 12:00 SOILS4AFRICA
Bas Kempen, ISRIC

12:00 - 12:25 Interactions with EUSO, panel discussion
12:25 – 12:30 Closing remarks

14:00-17:15 – Soil Health Districts

Moderators: Anne Maréchal / Elise van Eynde, European Commission JRC
Scope: To explore the usefulness of soil health districts and the potential of living labs in supporting the implementation the EU soil strategy 2030

14:00 – 14:05 Welcome

14:05 – 14:25 Exploring the concept of Soil Health Districts to achieve soil health in the EU
Luca Montanarella/Arwyn Jones, European Commission JRC
14:25 – 14:50 US Soil Conservation Districts – origin, vision, objectives and governance
Tim Palmer, National Association of Conservation Districts, USA
14:50 – 15:15 Soil Health Living Labs and their role in supporting implementation of EU soil strategy
Paola Alejandra Eulalio, DG AGRI

15:15 – 15:20 Break

15:20 – 15:40 Living Labs in the PREPSOIL project
Giulia Campodonico, Head of Projects ENoLL
15:40– 16:00 Initiative Sols Vivants
Anne-Sophie Leroy, Earthworm
16:00 –16:20 Living labs/lighthouses in Sweden: Farming in Balance
Lena Holm, Farming in Balance
16:20 – 16:40 A soil-based Living Lab integrating the supply chain for Belgium
Marc Rosiers, European landowners' organization
16:40 – 17:00 A country pilot of farmers and stakeholders upscaling soil health implementation on farms
Sophie Gardette, Director, APAD (Association pour la promotion d'une Agriculture Durable)

17:00 – 17:20 Discussion and Questions from the Audience
17:30: Closing remarks

Wednesday 26th October 2022

09:30-12:30 – Developing the EUSO Knowledge Base (Part 1)

09:30-12:30 Parallel Session 1a: Soil pollution

Moderators: Piotr Wojda/Felipe Yunta/Diana Vieira, JRC European Commission
Scope: Support to Clean Soil Monitoring & Outlook Report

09:30-09:35 Introduction
Piotr Wojda, JRC
09:35-09:50 Soil Pollution Outlook High Level Synthesis Report
Piotr Wojda, JRC

09:50 – 10:50 Diffuse and point source Pollution
09:50-10:05 Phosphorus losses and heavy metals diffuse pollution
Panos Panagos, JRC
10:05-10:20 Pesticides
Violette Geissen, WUR
10:20-10:35 Contaminated sites
Natalia Rodriguez Eugenio, FAO
10:35-10:50 Remediation technologies overview and IMPEL Water and Land Remediation Project
Marco Falconi, IMPEL

10:50-11:00 Break

11:00-11:30 – Pecha Kucha Lightning
A series of 3-minute-presentations making an impact on the topics of soil pollution, soil remediation or contaminants of emerging concern.

11:30 – 12:15 Emerging Pollutants
11:30-11:45 PFAS
Julie Lions, BRGM
11:45-12:00 Watchlist
Diana Vieira, JRC
12:00-12:15 Other emerging pollutants
Felipe Yunta, JRC

12:15-12:30 Conclusions: Piotr Wojda, JRC European Commission

Wednesday 26th October 2022

09:30-12:30 – Developing the EUSO Knowledge Base (Part 1)

09:30-12:30 – Parallel Session 1b: Soil data integration

Moderators: Calogero Schillaci/Marc van Liedekerke, JRC European Commission
Scope: Integration of relevant EU-wide data in EUSO/ESDAC

09:30 - 09:45 Introduction
Marc Van Liedekerke, JRC

09:45 – 12:30 Activities of EUSO Data Integration Working Group
09:45 - 10:00 Subgroup-1: EU-projects data
Christine Le Bas, INRAE
10:00 - 10:15 Subgroup-2: Data for EU Soil Monitoring and Indicators
Antonio Bispo, INRAE
10:15 - 10:30 Subgroup-3: Data from EJP
Maria Fantappie', CREA
10:30 - 10:45 Subgroup-4: Data from Literature
Calogero Schillaci, JRC
10:45 - 11:00 Subgroup-5: The creation of a hub with EU country soil data
Fenny van Egmond, WUR

11:00 - 11:10 Break

11:10-11:25 Integration of data, information and knowledge from new EU soil-related projects
Marie-Jose Amaral, REA
11:25-11:40 ESDAC 2.0
Panos Panagos, JRC
11:40-11:55 Establishing a soil data exchange partnership
Ester Miglio/Simone Sala, Varda AG
11:55-12:20 Discussion
12:20-12:30 Next steps & Conclusions

Wednesday 26th October 2022

09:30-12:30 – Developing the EUSO Knowledge Base (Part 1)

09:30 – 12:30 Parallel Session 1c: Soil monitoring

Moderators: Arwyn Jones/Daniele de Rosa, JRC European Commission
Scope: how to achieve further soil monitoring integration in the EU?

09:30 - 09:50 Welcome and soil monitoring in EUSO
Arwyn Jones/Anne Maréchal, JRC
09:50 - 10:10 Soil monitoring: a spatial and temporal variability problem
Daniele De Rosa, JRC
10:10 - 10:30 Indicators and thresholds for monitoring soil health
Rainer Baritz, European Environment Agency
10:30 - 10:50 Soil monitoring in EJP Soil
Antonio Bispo, INRAE
10:50 - 11:10 Updates on German soil monitoring system
Frank Glante, UBA Germany

11:10 - 11:20 Break

11:20 - 11.40 Monitoring and upscaling soil derived GHG emissions with process-based models
Clemens Scheer, Karlsruhe Institute of Technology (KIT)
11:40 – 12:00 Enhanced spatial soil health indicators with the synergy of Earth Observation technologies and artificial intelligence architectures to support national and European policies
Nikiforos Samarinas, Aristotle University of Thessaloniki (AUTH)
12:00-12:15 Dynamic Soil Properties
Francine Lheritier, USDA-NRCS
12:15 - 12:25: **Discussion**
12:25 - 12.30: **Next steps for the TWG on monitoring**

Wednesday 26th October 2022

14:00-17:00 – Developing the EUSO Knowledge Base (Part 2)

14:00 – 17:00 Parallel Session 2a: Soil carbon

Moderators: Cristina Arias-Navarro/Elise Van Eynde, European Commission JRC
Scope: How to develop a harmonized MRV framework of SOC stock changes?

14:00 – 14:10 Welcome
Luca Montanarella/Cristina Arias-Navarro, JRC
14:10 – 14:20 Carbon farming in the EU
Valeria Forlin, DG CLIMA
14:20 – 14:30 The role of the CAP in promoting carbon farming
Nicola di Virgilio, DG AGRI
14:30 – 14:40 CIRCASA legacy to ORCaSa
Jean-François Soussana/Suzanne Reynders, INRAE
14:40 – 14:55 Q&A

14:55 – 15:05 EJP Soil: Road4Schemes project
Martin Thorsøe, AU
15:05 – 15:20 Carbon payments by Soil Capital
Romain Boulet, Soil Capital
15:20 – 15:35 Q&A

15:35 – 15:45 SOC monitoring using LUCAS
Daniele de Rosa, JRC-EUSO
15:55 – 16:05 Innovative monitoring technologies
Eric Ceschia / Ahmad Albitar, CNRS CESBIO
16:05– 16:15 KP4SoilCarbon Knowledge Platform
Emilie Vrot/Carla Biscotti, CIRAD/VIZZUALITY
16:15 – 16:30 Q&A

16:30 – 16:50 Establishment of the EUSO Soil carbon MRV working group
Cristina Arias-Navarro/Elise Van Eynde, JRC European Commission
16:50 – 16:55 Closing
Luca Montanarella, JRC European Commission

Wednesday 26th October 2022

14:00-17:00 – Developing the EUSO Knowledge Base (Part 2)

14:00 – 17:00 Parallel Session 2b: Soil erosion in relation to land degradation, climate change & food security

Moderator: Panos Panagos/ Diana Vieira, JRC European Commission
Scope: What should the EU do to halt soil erosion?

14:00 – 14:05 Welcome / brief presentation of the activities of the WG
Panos Panagos/Diana Vieira, JRC
14:05 – 14:30 Policy implications of multiple concurrent soil erosion processes in European farmland
P. Borrelli, Roma Tre University, and EUSO WG members

14:30 – 15:35 June workshop on "Soil Erosion in the EU"
14:30 – 14:40 Challenges for sediments
Nejc Bezak, University of Ljubljana
14:40 – 14:50 Challenges in small scale erosion monitoring
M. Biddoccu, CNR Italy
14:50 – 15:00 Challenges in Landslides research
N. Tavoularis, Regional Authority of Attica
15:00 – 15:10 Soil erosion and Climate change
J. Eekhout, CSIC Spain
15:10 – 15:20 Young scientists in soil erosion and soil conservation
D. Evans, Cranfield University
15:20 – 15:35 Summary of the June workshop on "Soil Erosion in the EU"
Panos Panagos/Diana Vieira, JRC

15:35 – 15:45 Break

15:45 – 17:00 Launch of two initiatives of the WG: a) Sediments database b) estimating costs of sediment removal
15:45 – 16:05 EUSEDcollab: new opportunities presented by a collaborative database of monitored sediment yields from across the research community
F. Matthews, KULeuven/JRC
16:05 – 16:15 Can we evaluate the cost of off-site erosion? Insights from Normandy (France)
E. Patault, ALTEREO
16:15 – 16:25 Cost of soil erosion for Luxembourg: focus on sediment management
G. Fourvel, Luxembourg Environment Agency
16:25 – 16:35 Costs and management of sediments removal in reservoirs
C. Auel, Münster University of Applied Sciences
16:35 – 17:00 Renewal of membership, next steps & conclusions

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