# D1.4 Roadmap to EUSO

# Document information

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## Summary

This deliverable examines the harmonization and interoperability of soil contamination data from different sources and emphasizes on soil monitoring data flow to EUSO. The roadmap to EUSO gives an overview on the current and future data flow and role of EUSO. The ongoing EUSO development and future data sharing is closely related to the new Directive 2025/2360 on soil monitoring and resilience. In this deliverable, examples from other, older directives and related data sharing as well as existing soil contamination databases and their data flows and management on national level are given. The deliverable gives recommendations based on ISLANDR experience on the state of local and diffuse soil contamination data in EU, semantic interoperability, standards and the procedures to collect FAIR data. The deliverable also highlights the diverse needs for future soil data services through EUSO to not only cover policy makers and citizens but to answer also on the need soil experts have on soil contamination data in EU.

## Keywords

Data sharing, harmonising, interoperability, FAIR, European Soil Observatory





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# Abbreviations and acronyms

| Acronym | Description |
|---|---|
| AGROVOC | Agricultural Vocabulary |
| ANZSoilML | Australia and New Zealand Soil Mark-up Language |
| API | Application Programming Interface |
| ARDC | Australia Research Data Commons |
| BRGM | French Geological Survey |
| CEN/TC 444 | The European Committee for Standardisation / Technical Committee on Environmental characterization of solid matrices |
| C&D | Communication & Dissemination |
| CGI-IUGS | Commission on Geoscience Information of the International Union of Geological Sciences |
| CSV | Comma Separated Values (in the context of digital format) |
| EC | European Commission |
| EEA | European Environment Agency |
| EGDI | EuroGeoSurveys European Geological Data Infrastructure |
| EGR | European Geoscience Registry |
| EIF | European Interoperability Framework |
| EIONET | European Environment Information and Observation Network |
| EPOS | European Plate Observing System (EU research project) |
| ESA | European Space Agency |
| ESBN | European Soil Bureau Network |
| ESDAC | European Soil Data Centre |
| ESDB | European Soil Database |
| EU | European Union |
| EuroGeoSurvey | The Geological Surveys of Europe |
| EUSO | European Soil Observatory |
| FAIR | Findable, Accessible, Interoperable and Reusable |
| FAO | Food and Agriculture Organization of the United Nations |
| GEMET | General Multilingual Environmental Thesaurus |
| GeoERA | Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (EU Project) |
| Gis SOL | Scientific Interest Group for Soils |
| GloSIS | Global Soil Information System |
| GSEU | Geological Service for Europe |
| HVD | High Value Datasets |
| I-ADOPT | InteroperAble Descriptions of Observable Property Terminology |
| INRAE | National Research Institute for Agriculture, Food and Environment |
| INSPIRE | INfrastructure for SPatial InfoRmation in the European community (EU Directive) |
| ISO | The International Standardization Organization |
| ISO OBP | ISO Online Browsing Platform |
| ISO/TC190 | ISO Technical Committee specialized in the domain of Soil quality |
| IUGS-CGI | Commission on Geoscience Information of the International Union of Geological Sciences |





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| IUSS | International Union of Soil Sciences |
| JRC | Joint Research Centre |
| JSON-LD | JavaScript Object Notation for Linked Data |
| LUCAS | Land Use/ Cover Area frame Survey |
| MS | EU Member State |
| NSIMS | National Soil Information Monitoring System |
| OBP | Online Browsing Platform |
| OECD | Organisation for Economic Co-operation and Development |
| OGC | Open Geospatial Consortium |
| OWL | Web Ontology Language |
| RDA | Research Data Alliance |
| RDF | Resource Description Framework |
| SIEUSOIL | SIno-EU Soil Observatory for Intelligent Land use management (EU project) |
| SKOS | Simple Knowledge Organization System |
| SML | Soil Monitoring Law; Directive of the European Parliament and of the Council on Soil Monitoring and Resilience |
| Soil IE | Soil data Interoperability Experiment |
| SoilWise | An open access knowledges and data repository to safeguards soils (EU project) |
| SOSA | The Sensor, Observation, Sample, and Actuator ontology |
| SPARQL Endpoint | SPARQL Protocol and RDF Query Language. SPARQL is an RDF query language, i.e. a semantic query language for databases. To access the data of data.europa.eu, a machine-readable SPARQL endpoint allows querying the RDF descriptions of datasets. |
| SRBLM | Sustainable Risk Based Land Management |
| SSN | The Semantic Sensor Network ontology |
| SWEET | Semantic Web for Earth and Environmental Terminology |
| TC | Technical Committee (in the context of ISO) |
| TTL | Terse RDF Triple Language (also called Turtle) |
| UML | Unified Modeling Language |
| W3C | World Wide Web Consortium |
| WebVOWL | Visual Notation for OWL Ontologies |
| WMO | World Meteorological Organization |
| WP | Work Package |
| XMI | XML Metadata Interchange format |
| XML | eXtensible Markup Language |





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## ISLANDR project in brief

The Information-based Strategies for Land Remediation, in short ISLANDR, is a multidisciplinary project, which is foremost aimed at supporting the execution of the EU mission: A Soil Deal for Europe.

More specifically, the ISLANDR research activities are designed to provide tools and methods so as to support: (1) the delineation of polluted soils across Europe, (2) an evidence-based assessment of the risks posed by polluted soils, (3) the promotion of sustainable and risk-based land management practices, (4) the inclusion of a wider valuation approach in financial and investment cases, and (5) a closer integration of land contamination and spatial planning decision-making. Lessons learnt and experience gained throughout the project duration will be used to (6) deliver key policy-relevant findings related to the Soil Strategy, the proposed Soil Health Law, and other areas of policy where soils are crucial.

In order to road-test the project's findings, seven test areas across Europe have been identified. To begin with, the ISLANDR Test Areas (ITAs) will provide a real-world context for the planned research activities. More concretely, the ITAs have been selected to cover different land use types, such as urban, peri-urban, rural, agro-forestry, mining, wetlands and coastal areas. Furthermore, the ITAs are characterized by both point source and diffuse pollution, as well as by different soil pollution types, such as organic, inorganic, as well as contaminants of emerging concern.

Furthermore, ISLANDR brings a dedicated focus to low input remediation, by including test areas impacted by the consequences of the green transition, such as former mining areas. This will ensure that soil remediation will be facilitated even when the cost of remediation is economically marginal or may even be negative. On the one hand, this necessitates a more thorough understanding of low input remediation approaches from a technological perspective, yet it also requires a wider value proposition for investment cases and financial planning.

Key actors, stakeholders and end-beneficiaries are at the epicentre of ISLANDR. Through roundtables in the respective ITAs, the foremost assignment of local actors will be to provide feedback and offer insights as to the robustness and effectiveness of the strategies, frameworks and decision-support tools, as well as on the wider valuation approaches and financing mechanisms to be developed over the course of the project's lifetime. Thus, the Roundtables are foreseen to bring an iterative feedback loop to the research process, with a view to ensure the wider uptake of the project's outcomes and achievements.

Last but not least, local communities in the respective ITAs will be invited to participate in a survey organized both during the early stages and towards the end of the project, as a means to document soil literacy among society thereby bringing insight as to whether the exposure of society to the project's activities on the ground can bring about a strongly desired 'awareness pull' to the benefits to be reaped from healthy soils, thereby leveraging society at large to subscribe to the projects' motto: ISLANDR for Soil Health!



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# Introduction

Despite the creation of the European Soil Database (ESDB) by ESDAC in 2006 as a platform for dissemination and coordination, soil data remains highly heterogeneous, both in terms of soil data acquisition methodology and the spatial and temporal distribution of this acquisition, as well as in terms of data processing and information dissemination (Yunta et al., 2025). The state of local and diffuse soil contamination databases and their availability in EU is described in ISLANDR deliverable report D1.1 "Data summary – Overview of Soil Pollution in Europe" (Nuottimäki et al., 2025), that also highlighted the data gaps on EU international, national and regional databases regarding their technical details, management, availability, coverage and indicators.

This heterogeneity cannot be completely resolved since soil data acquisition methodologies are subject to change for example within the working groups of Technical committee on Environmental characterization of solid matrices, CEN/TC 444 WG, and acquisition contexts can be volatile (regulatory requirements, changes in soil management techniques, changes in digital tools for storing and disseminating soil data). The needs of the data producers and users also dictate how the sampling is conducted and according to which standards and methods the sample analysis is performed. Furthermore, soil data is acquired by several stakeholders having different interests in the kind of data acquired. The interests have varied also in the EU Member States (MS) and their soil monitoring systems. In the future, in accordance with the Directive on Soil Monitoring and Resilience (Soil Monitoring Law) (European Parliament, 2025), the framework is set for monitoring of soil quality and land management in more harmonized way. Many EU Member States have soil monitoring systems, but they are either linked to certain land use or their specific properties vary considerably. Now the national monitoring dataset are faced with the demands of reporting in accordance with the Soil Monitoring Law (SML).

Due to the complexity, there is a need for a roadmap aiming to facilitate consistent soil data navigation through databases and dashboards at the EU Member State level and European level to support soil management by the different stakeholders. The European Soil Observatory (EUSO), a platform working under Joint Research Centre (JRC), aims to be the principal provider of reference data and knowledge at EU-level for all matters relating to soil. In the future, the upcoming EU Soil Health Data Portal addressed in SML is providing all data related to SML. Soil contamination data is one of those soil indicators included in SML to assess the health of soils for which soils are sampled and analyzed and further reported through the EU Soil Health Data Portal. EUSO's role will be to support soil user community through data and knowledge sharing.

This deliverable "Roadmap to EUSO" (D1.4) presents examples on how to make the nationally or regionally collected soil contamination data comparable and harmonized with the data from other countries as well as Findable, Accessible, Interoperable and Reusable (FAIR) regarding soil contamination. Harmonized data is the key to take the next steps towards healthier soils. In this deliverable we will focus on recommendations to





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support data producers providing data to EUSO in a technically usable way for further data users. This deliverable addresses existing obstacles to gather harmonized and interoperable monitoring soil contamination data from MS along SML guidelines. This deliverable also highlights the several needs for soil data services that end-users, from citizens to soil experts, could have and that could be provided by EUSO through the upcoming EU Soil Health Data Portal or ESDAC.





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# 1. European soil observatory EUSO

## 1.1. EUSO - key entity among European soil data management structures

The EU Soil Observatory (EUSO) was launched in December 2020 and is currently the European Commission's main operational tool under the Joint Research Centre for collecting, organizing, and sharing soil data. EUSO is not just a data repository—it actively develops indicators, analytical tools, and dashboards to support policy implementation, being a principal provider of knowledge at EU-level for all matters relating to soil.

EUSO hosts ESDAC, the European Soil Data Centre, developing it to be the single reference point for all soil related data and information on the European level (Figure 1).

EUSO has seven working groups focusing on soil erosion; data sharing and integration; soil pollution; soil monitoring; soil biodiversity; soil organic carbon monitoring reporting and verification; and nutrients. The working groups consist of experts of these topics from academia, business and policy and keep EUSO updated on the latest developments and technical advances of each field.

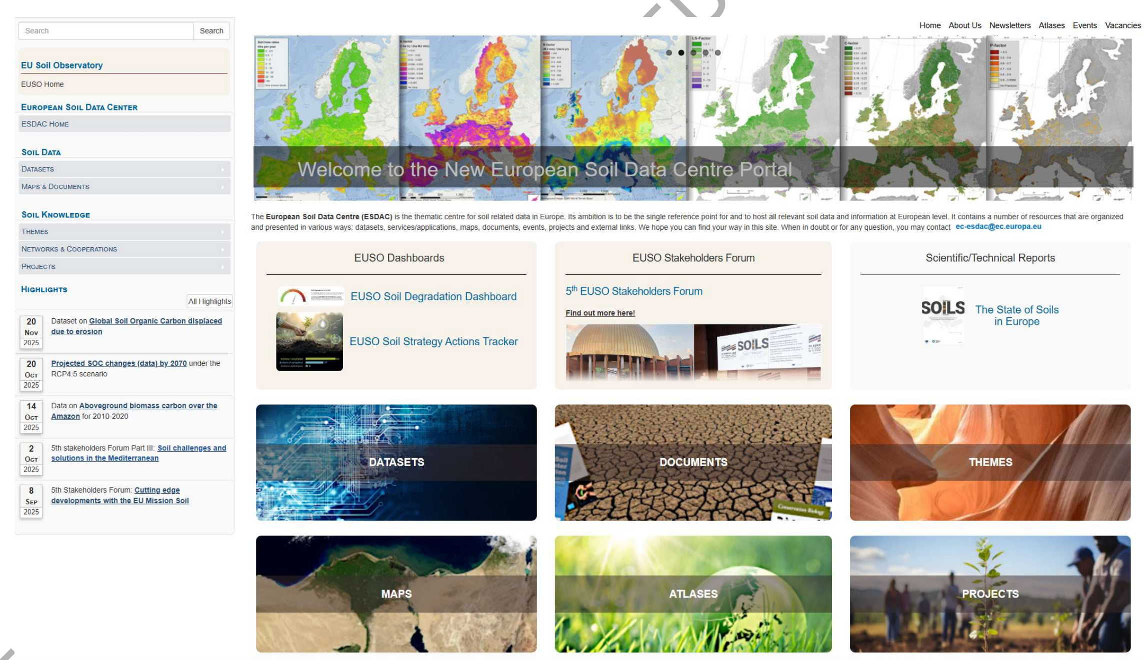


**Figure 1: Main page of ESDAC with access to several types of soil information resources (https://esdac.jrc.ec.europa.eu/).**

EUSO is currently very active in providing data and knowledge, organizing stakeholder events, advancing soil research through its LUCAS soil sampling module, and offering up to date information through the EUSO Soil Degradation Dashboard. In 2024, EUSO





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strengthened its position by adding 15 new datasets to ESDAC, publishing 47 scientific articles, and updating the Soil Degradation Dashboard (Broothaerts et al., 2025a).

According to EUSO web page, they are aiming to become a dynamic and inclusive platform that aims to support policymaking by:

- Providing the Commission Services and the broader soil user community with the soil **knowledge** and **data flows** needed to safeguard soils,
- Supporting EU **Research & Innovation** on soils,
- Raising societal **awareness** of the value of soils.

EUSO will achieve these by supporting the development of EU-wide monitoring system, monitoring soil health using the LUCAS module for data collection and EUSO Dashboard for sharing, enhancing the capacity of ESDAC for data sharing, supporting soil research and innovation within the Mission 'A Soil Deal for Europe' and providing EUSO stakeholder forum as a discussion platform for citizens and scientists and supporting soil awareness (Panagos et al., 2024).

EUSO collects and shares data from multiple sources, including EEA, LUCAS, Copernicus, national monitoring programs, and citizen science.
The Table 1 below summarises the main EU entities and their roles and actions in EU soil data management.



**Table 1: Main European structures responsible for soil data management**

| Organisation or structure | Nature | Main ambitions | Main data related actions |
|---|---|---|---|
| EEA | An agency of the European Union providing insight on the state of Europe's environment. | To support European environment and climate policies, to collect and validate data, analyse trends, produce policy-relevant analyses. | - GEMET the EU Ontology<br>- EEA offers publications, maps and charts, indicators, country fact sheets and manages a datahub on environmental topics. These are accessible through EEA website.<br>The European Environment Information and Observation Network (Eionet) is a partnership network of the European Environment Agency (EEA) and its 38 member and cooperating countries. EEA and Eionet gather and develop data, knowledge, and advice to policy makers about Europe's environment. |
| ESDAC | Data portal of the EUSO | Disseminating scientific soil data and knowledge in the EU | **- Datasets shared on request**<br>- Hosts European Soil Database (ESDB), |



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| | | | |
|---|---|---|---|
| | | | - Hosts links to Soil Mission projects and some of their data[1], etc.<br>- Repository for EU Mission Soil projects' data[2] |
| EUSO | The **EU Soil Observatory (EUSO)** is a platform that aims to be the **principal provider of reference data and knowledge at EU-level for all matters relating to soil**. | 1) Providing the Commission Services and the broader soil user community with the soil **knowledge** and **data through a web platform**<br>2) Supporting EU Research & Innovation on soils<br>3) Raising societal **awareness** of the value of soils | **Public data sharing**<br>- Develops EU Soil Health Data Portal (ESDAC 3.0)<br>- Soil degradation dashboard concept note[3]<br>- EUSO soil degradation dashboard EUSO Dashboard<br>- EU action tracker[4] (Broothaerts et al., 2025b)<br>- Publications and reports<br><br>**7 Technical Working groups[5]**<br><br>**Annual stakeholder forum**<br><br>Stratified sampling for SML |
| JRC | The Directorate-general of the EU responsible for independent, evidence-based knowledge and science | Supporting EU policies to positively impact society.<br><br>European science hub | - Supports ESDAC, EUSO, LUCAS soil module<br>- compilation of databases<br>- development of for example modelling tools<br>- data catalogue including ESDAC datasets |
| LUCAS soil module | Topsoil survey carried out across the European Union (23 MS), organised by EUROSTAT with the support of JRC | Contributes to build a consistent spatial database of the soil cover across the EU based on standard sampling and analytical procedures.<br>Harmonized and aggregated open access dataset of topsoil properties derives policy-relevant statistics on the effect of land management on soil characteristics. | - Soil samples stored by JRC (Ispra)<br>- Raw dataset stored by JRC - Aggregated maps shared on request via ESDAC<br>- Photos and land cover data shared by EUROSTAT portal |



[1] https://esdac.jrc.ec.europa.eu/resource-type/datasets-list
[2] https://esdac.jrc.ec.europa.eu/content/esdac-projects
[3] https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/, EUSO Dashboard
[4] https://esdac.jrc.ec.europa.eu/esdacviewer/action-tracker/
[5] https://esdac.jrc.ec.europa.eu/euso/technical-working-groups



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## 1.2. The role of EUSO in data sharing

The EU Soil Observatory (EUSO) was launched in December 2020 by the JRC under the umbrella of the European Green Deal, with the vision to become the principal provider of reference data and knowledge at EU-level for all matters relating to soil. In the first EUSO Stakeholder forum in October 2021 five technical working groups were established to support the implementation and operation of the EUSO, one of them being Soil Pollution Technical Working Group. One task of the working group is to discuss the contaminated sites related issues. (Maréchal et al., 2022).

European Environment Information and Observation Network (EIONET), a partnership network of European Environment Agency (EAA), has a corresponding Working Group on Soil Pollution, which is responsible for updating the LSI003 indicator "Progress in management of contaminated sites in Europe" (see Deliverable 1.1., Nuottimäki et al., 2025). It is stated by Maréchal et al., (2022) that EUSO will collaborate with EEA in relation to indicators on soil sealing and contaminated sites and with OECD (Organisation for Economic Co-operation and Development) in relation to soil erosion. EUSO will continue collecting and sharing data produced in Mission Soil projects.

Also, in other soil related topics the data flow will likely go through the EEA first in the future, as it has established and functioning data collection methods in play. EEA uses EIONET for collecting data from the EU Member States. The soil related data will then be transferred to EUSO for further distributing to data consumers via ESDAC and EUSO dashboards. User forums will be important EUSO activities in the future. They are a way to engage both data providers and users alike, and an important part of sharing knowledge to all stakeholders on the services provided by EUSO. EUSO stakeholder forums are seen as a successful way to disseminate information and facilitate knowledge sharing. Several communication and dissemination activities are also set in the SML, for which the provider is the Commission, or in practice JRC and EUSO.

The following obstacles may hinder EUSO needs related to SML requirements and MS needs to support soil health in the EU. The future plan for EUSO requires increasing the volume of data collected and shared, while the data formats and the harmonized data collection process have not been confirmed yet. Existing standards will be used, but the final decision is currently in discussion between JRC/EUSO and CEN. ESDAC datasets are available on request. The current manual process on data request from ESDAC is time consuming and there is need for automated systems for rights recognition and data sharing in the future. From EUSO point of view it is important to have the data on request as the register on data usage gives valuable information.

Access to the data is also in discussion. It is likely that not all data will be provided publicly to everyone, and there might be different levels of access, or at least the access would require creating a user account and logging in to download data. In accordance with the SML, by 17 December 2027, the Commission will establish a digital Soil Health Data Portal that will provide soil health information on aggregated level.





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The Table 2 outlines the main use cases giving the main tools needed by the user for each context (i.e.: use case).

**Table 2: Main use cases identified related with EU soil data management and monitoring**

| Use case | User<br>**Bold: EU level to MS level**<br>*Italic: MS level to EU level* | User's main functionality and data management |
|---|---|---|
| Soil data acquired and produced related to MS or EU projects | *MS researchers and engineers* | • *FAIR ESDAC Datasets access*<br>• *Facilitated portal to store research results* |
| | **JRC/EUSO researchers (*EU to MS*)** | • **FAIR MS Datasets access**<br>• **FAIR access to list of soil related projects** |
| Soil monitoring and data diffusion at MS level<br>Land management | *MS policy entities (national, regional, local)* | • *EU Soil Health Data Portal*<br>• *FAIR inclusion of EU dashboard / catalogue / ontology at MS / regional / local level*<br>• *Facilitated portal to store their monitoring results* |
| Soil monitoring at EU level | **Soil Health Data Portal Manager** | **EU Soil Health Data Portal** |
| Soil monitoring and land management | *Landowners* | *FAIR EU Datasets*<br>*Facilitated portal access to store their monitoring at MS level* |

## 1.3. The current and future data flows to EUSO

With the new Directive on Soil Monitoring and Resilience, EUSO's role will expand significantly. It will host the new **EU Soil Health Data Portal,** which will become the central platform for regulatory soil monitoring and related data sharing and dissemination. This portal aims to include harmonized indicators, even for parameters that are currently lacking from EU-wide data (e.g. basal respiration, subsoil compaction, salinity).

Future EU Soil Health Data Portal is hoped to be the biggest data provider of soil information that collects all possible information, creates and makes available own LUCAS survey and provides policy advisory as well as information on the state of the soils in EU for citizens. It will also feature a dedicated **pollution dashboard** and a **watch list for contaminants**. In short, EUSO is transitioning from a scientific support role to becoming the technical backbone of EU soil policy implementation.

The current roadmap of EUSO is illustrated by the Figure 2. The main challenges identified by EUSO are data governance in the EU Member States, as well as data properties as a limit for sharing and technical issues related to database compatibilities.





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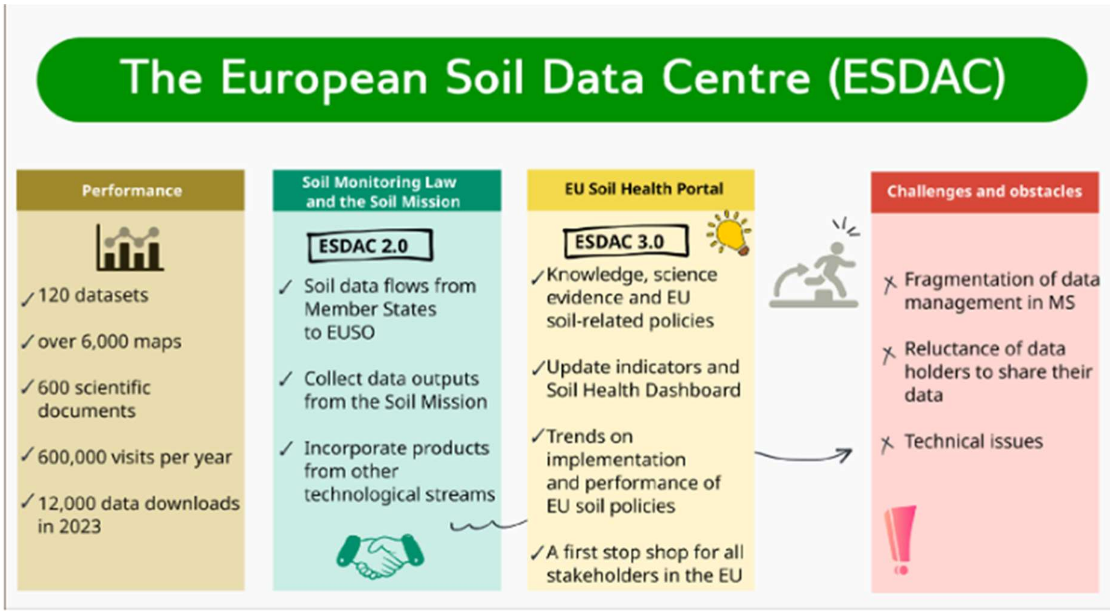


**Figure 2: Current roadmap of EUSO for ESDAC (https://ejpsoil.eu/wp-content/uploads/2025/03/Soil_Monitoring__1_.pdf)**

### 1.3.1. Changes brought by Directive on Soil Monitoring and Resilience (Soil Monitoring Law)

The Directive on Soil Monitoring and Resilience (SML) came into effect on 16 December 2025. The SML sets a framework to monitor the soil degradation and the state of the soils in EU to reach the objective to achieve the healthy soils by 2050. The MS can use existing national monitoring systems or build a new monitoring system. In the SML there are demands regarding LUCAS data, and its availability to the EU Member States to fill in any data gaps they might meet in their national soil monitoring obligations.

The EU Member States may collect the soil samples from different depths, analyse different sets of parameters (PFAS, pesticides and their metabolites) with different analysis methods and standards, which all contribute to making the collected data fragmented. When these data are then stored only partially available in varying data storage formats, considerable efforts will be required for data harmonisation to make them interoperable in the future. EUSO's oncoming EU Soil Health Data Portal will be, however, the main distribution channel to all SML related soil data collected by the MS. MS as well as other actors and especially Soil Mission projects can also present other datasets to be distributed through the portal, as long as their data formats meet set requirements.

The data types that EUSO will distribute in the coming years are many. SML imposed communication and dissemination activities include sharing of spatial chemical and sampling data, remotely sensed data in pre-processed form or in analysis ready format,





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knowledge, tools, methods and information on events. Typically, these could take the form of common data types used in GIS specific programs and applications, but also reports, videos, and tables. Some information is likely shared via the portal webpage itself, and tools or interactive platforms may take even other technical data forms. EUSO should thus be prepared to share many different data types. As at least a part of these is collected first by EEA, the formats should be compatible first with the EEA data format and storage requirements.

In Figure 3 is presented the complete list of activities in timeline related to SML demands. For the coming years between 2026 and 2029, the SML imposes development tasks for the EU Member States regarding the preparation of the SML related sampling network, list of contaminated sites, transfer functions and list of selected parameters and methods for analysis to allow dataflow from MS level to EU level. The most important activities for EUSO in the coming years are **the opening of the EU Soil Health Data Portal** by 17.12.2027 and **providing related support in the form of methods, tools, information, knowledge and data sharing** (Figure 3).

Following the SML, the soil health data portal should offer information for all users from citizens to authorities and scientists that all have diverse demands on the data. For scientists the possibility to use raw data and detailed metadata that has not been processed would be important and offer new possibilities for understanding soil and its processes, land use effect and on the other hand demand for soil quality as well as its edaphology. If data is only available for MS stakeholders on aggregated form, it might not have adequate qualities for further processing. From the raw data user end this requires naturally trust that the raw data is not misused in any way or ad hoc tools to track data flow and report results obtained from the data. An ideal EUSO would be transparent about how the data are handled by whom and to have an idea of the work in progress.





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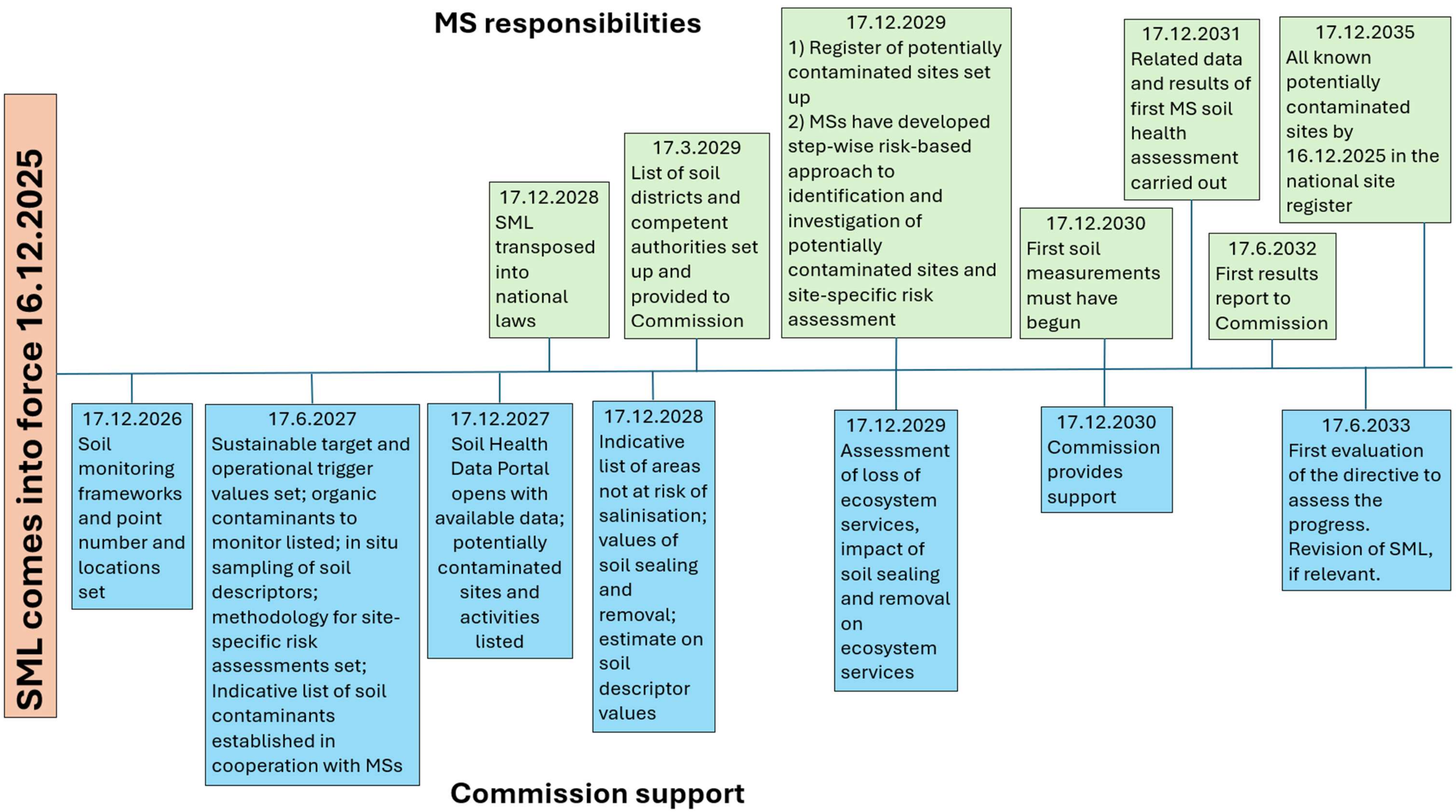


**Figure 3: Timeline of SML imposed responsibilities on the EU Member States and Commission.**





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## 1.4. Challenges, constraints and opportunities

### 1.4.1. Identified challenges

The challenges, constraints and opportunities with current ESDAC and future data sharing through EU Soil Health Data Portal were discussed (personal communication JRC (2025)). The implementation of data flow is still under discussion. Different working groups, DG Environment, JRC and EEA have started the discussion on SML related data details and flow from MS to EUSO. The MS data flow will be first directed to EEA in Copenhagen.

The MS´s are collecting their data based on predefined sampling method methodology and then producing comparable results. The level of how the data will be shared in the reporting is still under discussion and the individual agencies responsible still have something to say about it. The MS`s can have confidential data and different rules on data ownership protection that effects on the harmonization on data availability. Also, the potential selection of variable number of soil descriptor without criteria hampers the harmonization.

To reach more harmonized data, it is expected that more information coming from remote sensing is used, that can indirectly give information on some soil conditions. Many steps are currently taken by JRC, EEA and Soil Mission projects and clusters to achieve the goals set in SML and support the MS. For example, a report on standardization and prioritization of PFAS is under development (personal communication JRC (2025)), that reduces knowledge gaps on non-standardized contaminants for EU Member States. EUSO chose a sampling scheme (stratified random sampling) to be used by each EU Member State. Some MS (territory of Brussels) have tested this approach and outlined the need for adaptation to better suit and represent urban environments (Goidts et al., 2024). Also, the data formats need harmonisation, and some questions remain on the accessibility on aggregated or raw data for MS monitoring soil contamination data. The SML addresses, that the soil data will be made public in aggregated form by JRC and EUSO in EU Soil Health Data Portal. However, the MS can in some circumstances deliver the data in aggregated form to EEA or send raw data without restricted data. If the MS sends the data in aggregated form, it is important to pay attention on the unified methods during this critical step in data flow to transform the raw data to aggregated form. Standardized steps and possible challenges on harmonized data collection and flow on soil contamination descriptors from MS to public is presented in Figure 4.





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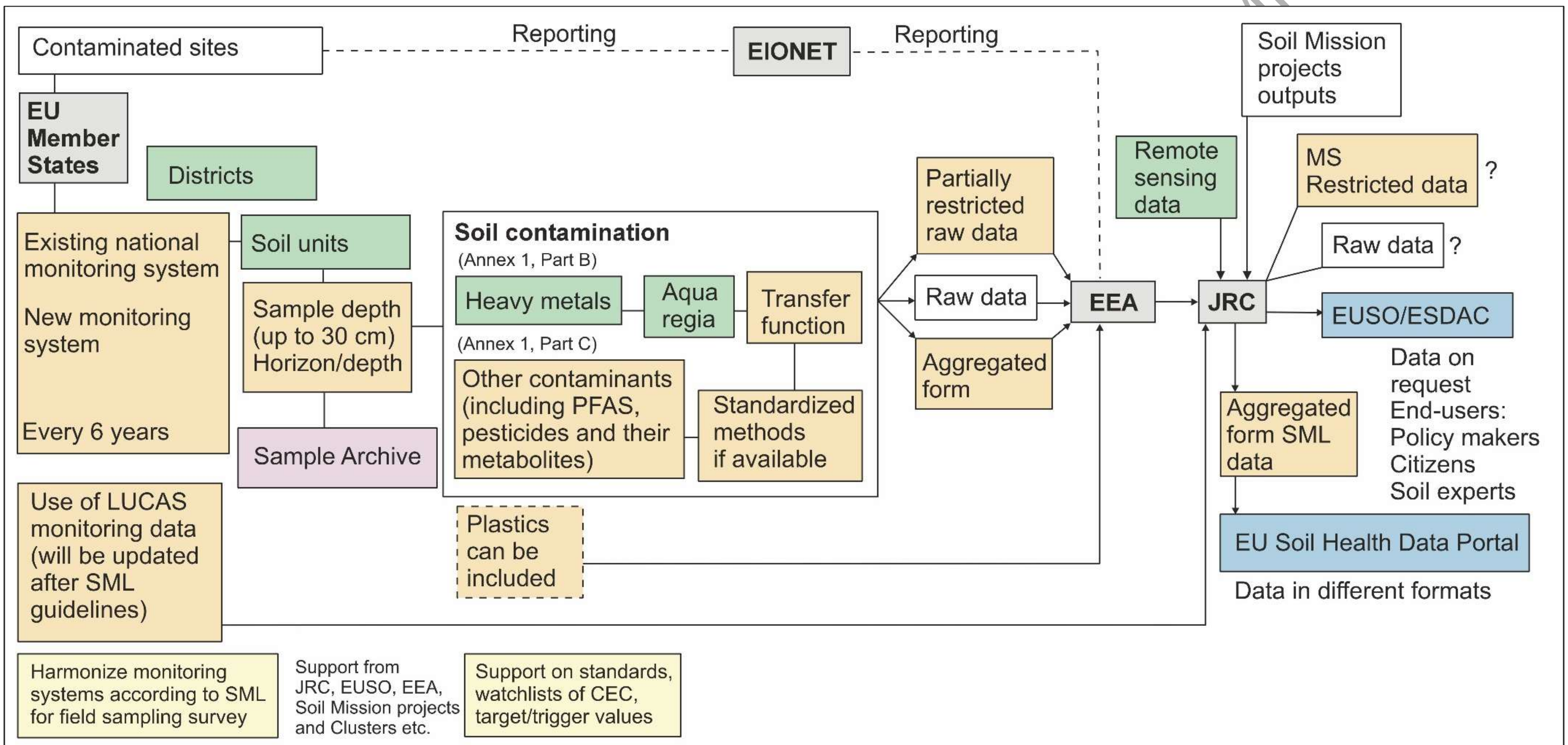


**Figure 4: Illustration on standardised steps (green boxes) and possible challenges (brown boxes) on harmonising monitoring soil contamination data and the data flow to EU Soil Health Data Portal according to SML. Institutions involved are marked with grey. According to SML the aggregated form data will be accessible through EU Soil Health Data Portal. Questions remain with the availability of raw data and restricted data storage.**





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### 1.4.2. Heterogeneity of soil contamination databases in EU

Extensive data search was conducted as a part of ISLANDR concerning available data on contaminated soil. ISLANDR "D1.1 Data Summary" summarised the current situation in EU on soil contamination databases availability, management and data gaps (Nuottimäki et al., 2025). The web search, literature review and questionnaire survey were conducted in 2024-2025. Questionnaires were sent in March 2024 and answers received in May 2024 with updates until November 2024. Questionnaire answers (altogether 45 answers) were received from the 18 EU Member States concerning local (N=17) or diffuse (N=14) soil contamination databases, meanwhile 13 responses stated that local or diffuse soil contamination databases do not exist. According to the literature review, web search and questionnaires all together 110 (local=45, diffuse related=65) databases were found of which some were not publicly available. Hence, 82 national or regional publicly available contaminated soil databases or databases containing raw soil sampling data or other related identified data were gathered in the ISLANDR Metadata catalogue.

Especially in diffuse related databases the heterogeneity of databases prevailed in geographical coverage, collecting method, indicators and availability. On diffuse and related contamination databases, the geochemical mapping was the most common database found in 18 countries. After the web and questionnaire survey, soil contamination monitoring databases could be found from 13 EU countries on national or regional level indicating that many countries already have operational soil monitoring systems. However, the soil contamination monitoring databases were public only in France, Poland and Slovenia. The Poland and Slovenia national monitoring databases sampling density is sparse. All other monitoring databases were not publicly available (Bulgaria, Croatia, Latvia, Luxembourg, Romania), part of the data was available (Estonia, Lithuania, Slovakia, Sweden) or available on request (Hungary). Also, the contaminants monitored varied being mainly metals and metalloids. To fulfil the SML monitoring requirements most MS need to improve their monitoring practices considerably. Overall, the technical details of all the found diffuse and related databases were heterogenous on metadata availability as well as used metadata standards and on formats and services the datasets were available.

Local contamination databases and current situation in MS was also summarised in the ISLANDR D1.1 Data summary (Nuottimäki et al., 2025). The status of local soil contamination is regularly assessed across the European Union Member States, providing valuable data for managing and mitigating this critical environmental issue. Currently, indicator LSI003 "Progress in management of contaminated sites" is the only EU/European-wide repository of information about contaminated sites. It is a part of European Environment Agency (EEA) Land and Soil indicator set. The indicator gives national estimates on potentially contaminated sites and on the progress in remediation. The data collected through standard questionnaire forms for the indicator updates has been used in overall picture in local soil contamination in Europe (e.g. Panagos et al., 2013, Vieira et al., 2024).





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According to the literature review, web search and questionnaire, most of the EU Member States (n=21) have a local soil contamination database. Also 5 other EU Member State have related local database. However, there are differences e.g. in data availability, management and use. Two national local soil contamination databases (from Finland and Poland) were studied as examples of how a national data inventory can be applied as an input to the EEA soil contamination indicator and in the future proving EUSO comparable data. The examples show that there is remarkable variation in national soil contamination inventories. Even one national answer to the EEA indicator update can depend on the interpretation of the person who is submitting the data. These conclusions are in line with the remarks given by Payá Pérez & Rodriguez Eugenio (2018): "*Progress (in the management of contaminated sites) is analysed on a respondent basis, and, because of the remaining uncertainties, cross-country comparisons should be avoided*." Also, recent report on The State of Soils in Europe (Arias-Navarro et al. 2024) recognises a harmonised inventory and an impact assessment of contaminated sites across the EU Member States as an unavailable knowledge product.

The SML entered into force in 2025, while also updating the LSI003-indicator was under preparation. The updated indicator specifications (Baritz & Swartjes 2025) follow the requirements of the SML to the extent possible, which enhances harmonisation of national data inventories. The key definitions of SML and LSI003 indicator are aligned, and outlines for register of potentially contaminated sites and contaminated sites are set in the article 17 and Annex VI. Hereby the existing EIONET data collection networks can be used and combined with legislation binding on all the EU Member States.

## 1.5. Soil Mission Projects

Several Soil Mission Projects contribute together to the definition and provision of pieces of a new version of EUSO / ESDAC. Yunta et al., (2025) presented an overview of on-going Soil Mission Projects that contribute to EUSO development.

This includes:

- SoilWise: https://soilwise-he.eu/
- BENCHMARKS: https://soilhealthbenchmarks.eu/
- ARAGORN: https://aragorn-horizon.eu/
- EDAPHOS: https://www.edaphos.eu/
- And of course, ISLANDR https://islandr-project.eu

The Yunta et al., (2025) report highlighted solutions for harmonizing datasets. These solutions included developing common metadata frameworks that could be shared across projects, storing data in centralized repositories, using European standardization and INSPIRE principles and developing platforms for data sharing to facilitate harmonization and integration. These solutions can help to address the challenges of harmonizing datasets and facilitate the integration of data from different projects and sources. This could be a challenge for some dataset (such as remote sensing-acquired data) which require large storage capacities, that are not always available. Likely these will be hosted by ESA and only referred to by EUSO.





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In addition, Mission Soil Clusters have been created by Soil Mission projects to work together in different soil topics. In 2025, Soil Pollution and remediation Cluster was created to share information between Mission Soil projects focusing on soil pollution. Soil Data & Knowledge Management Cluster especially focuses on supporting harmonized practices for FAIR data and knowledge outputs.

One goal in future EU Soil Health Data Portal or a related soil info portal for non-SML data sources is to collect and have repository for the Soil Mission project outputs metadata. The SoilWise project and JRC are developing a Soil Metadata template for, among others, Soil Mission projects soil-related data and other outcomes (methods, software, reports) to gather the projects' outputs in a harmonized way. The current version (v0.3) of template defines a set of metadata items summarized in Figure 5, which lists all field names required for dataset documentation. Please note that the template is still a work in progress and may change in the final version. The final form of implementation has also not yet been decided. Key fields include the dataset identifier, which ensures unique and persistent identification; project affiliation, linking the dataset to the originating initiative; and Mission Soil participation, indicating whether the dataset is part of the broader Soil Mission framework. Other critical fields, such as keywords, geographic extent, and temporal reference, provide essential context for dataset discovery and interpretation. Specific soil-related fields, like soil properties, functions, and threats, ensure thematic consistency using controlled vocabularies provided by EUSO. By focusing on these fields, the template allows Soil Mission Projects, including SoilWise, ISLANDR, ARAGORN, EDAPHOS, BENCHMARKS, SOILPROM and PHISHES, to harmonize the documentation and publication of datasets, methods, software, and reports. This facilitates integration into centralized repositories and supports interoperability, reuse, and policy-relevant analysis across Europe.

| Mandatory | | Optional | |
|---|---|---|---|
| 1 | Identification | 2 | Project Affiliation |
| 3 | Mission Soil Affiliation | 6 | Keywords |
| 4 | Title | 8 | Geographic Extent |
| 5 | Description | 10 | Date of Sampling |
| 7 | File Format | 13 | Related Resource |
| 9 | Temporal Reference | 14 | Processing steps |
| 11 | License | 15 | Data Collection Procedures |
| 12 | Contact | 16 | Language |
| | | 17 | Coordinate reference system |
| | | 18 | Citation |
| | | 19 | Spatial resolution |
| | | 20 | Resource URL |
| | | 21 | Soil properties |
| | | 22 | Soil function |
| | | 23 | Soil threats |
| | | 24 | Note |

**Figure 5: Preliminary Soil Metadata template, proposed by SoilWise project and JRC, for Soil Mission projects outcomes (January 2026).**





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# 2. Solutions adopted elsewhere

## 2.1. Directive examples

### 2.1.1. EU Water Framework Directive

The objective of the EU Water Framework Directive (WFD) (Directive 2000/60/EC) is to achieve "good status" for all EU waters (surface, groundwater, coastal) by setting up an integrated river-basin management approach (Figure 6). Good status means both good chemical and good ecological status. It applies to inland, transitional and coastal surface water as well as groundwater.

It ensures an integrated approach to water management, respecting the integrity of whole ecosystems, including by regulating individual pollutants and setting corresponding regulatory standards. It is based on a river basin district approach to make sure that neighbouring countries cooperate to manage the rivers and other bodies of water they share.

It requires the EU Member States to use their River Basin Management Plans (RBMPs) and Programmes of Measures (PoMs) to protect and, where necessary, restore water bodies to reach good status, and to prevent deterioration (Figure 6).

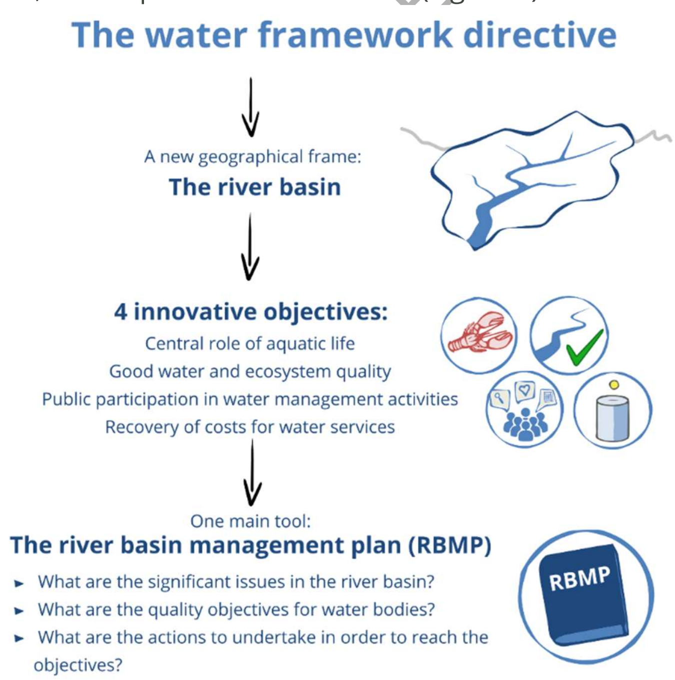


**Figure 6: The Water Framework Directive in brief. Infographics from the European Union water Initiative Plus (EUWI+) project[6].**



[6] https://www.euwipluseast.eu/en/component/content/article/444-all-activities/activites-global-project-2/awareness-documents-global-project/473-infigraphics-the-water-framework-directive-in-brief



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The Table 3 below provides key characteristics and mechanisms of the Water Framework Directive implementation:

**Table 3: Key characteristics and mechanisms of the Water Framework Directive implementation**

| | |
|---|---|
| **Common Framework** | Establishes **River Basin Districts** (RBDs), often crossing national borders. |
| | Each RBD has a **River Basin Management Plan (RBMP)** updated every six years. |
| **Monitoring & Reporting** | The EU Member States must monitor **biological, chemical, and hydromorphological indicators** using harmonised EU standards. |
| | Data flows through **EIONET and WISE (Water Information System for Europe)**. |
| | Reporting cycles are strictly defined (every 3 or 6 years) with QA/QC protocols. |
| **Governance & Data Workflow** | National agencies collect data → send via WISE to **EEA/JRC** → aggregation and validation → public EU datasets and scorecards. |
| | Data is used for EU-level **State of Environment** reports and **compliance checks**. |
| **Integration** | Strong linkage with agriculture, industrial pollution, and habitat conservation laws. |
| | Uses **"one-out, all-out"** principle: if one indicator fails, the water body's status is not "good". |

#### 2.1.1.1. *Water Information System for Europe (WISE)*

The Water Information System for Europe (WISE) is a partnership between the European Commission and the European Environment Agency (EEA).
WISE was launched in 2007 providing a web-portal entry to water related information ranging from inland waters to marine areas (Figure 7).

WISE addresses several user groups.

- For users from EU institutions or other environmental national, regional and local administrations WISE provides input to thematic assessments in the context of EU water related policies.
- For water professionals and scientists WISE facilitates access to reference documents and thematic data, which can be downloaded for further analyses.
- For the general public, including private or public entities, WISE illustrates a wide span of water related information through interactive maps, charts and indicators.

Accessible from https://water.europa.eu/, WISE is divided into two main parts:




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- WISE Freshwater, that provides information and data on the state of Europe's rivers, lakes, groundwaters, the pressures affecting them, and the measures and actions taken to protect and conserve the aquatic environment.
- WISE Marine, that provides access to data and information on the state of and pressures on Europe's seas, and on actions that can be taken to protect and conserve them.

In a nutshell, WISE offers similar content about water to what EUSO provides for soil:


**Figure 7: Main content of the Water Information System for Europe (WISE)**

## 2.1.2. EU Ambient Air Quality Directive

The objective of the Ambient Air Quality Directives (AAQDs) (Directive 2008/50/EC and updates) is to protect human health and ecosystems by maintaining pollutant concentrations below EU limit values (for $PM_{2.5}$, $NO_2$, $O_3$, etc.).

The Table 4 below is providing key characteristics and mechanisms of the Ambient Air Quality Directive:

**Table 4: Key characteristics and mechanisms of the Ambient Air Quality Directive implementation**

| | |
|---|---|
| **Monitoring Network Requirements** | Each EU Member State establishes **monitoring stations** in urban, suburban, and rural areas. |
| | Sampling and data capture must meet **technical specifications** defined by the EU. |
| **Real-Time Data Exchange** | Data is transmitted hourly/daily to the **European Air Quality Portal managed by EEA**. |
| | Uses **automated dataflows** (Air Quality e-Reporting under Commission Implementing Decision 2011/850/EU). |
| | Enables near real-time validation, visualization, and public access. |
| **Compliance and Enforcement** | When exceedances occur, the EU Member States must prepare **Air Quality Plans**. |
| | The **European Commission** can take infringement procedures if limits are not met. |
| **Public Transparency** | Open access to near real-time pollutant maps across the EU. |
| | Mandatory public information on exceedances and health risks. |





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### 2.1.3. EU biodiversity monitoring: from birds and habitats Directive to Nature restoration law

The European Union is increasingly formalizing its commitment to halt biodiversity loss and restore natural habitats, embedding a strong monitoring and data-sharing dimension into its new nature legislation. The Birds Directive (1979) and the Habitats Directive (1992) are the core legal framework for biodiversity conservation in the EU. In 2024 the Nature Restoration Law (European Parliament & Council of the European Union, 2024) completed the existing regulation when it came into force by laying down legally binding restoration targets and obliging the EU Member States to monitor habitat status and ecosystem recovery — a key step toward a future comprehensive biodiversity framework at EU level. The Birds and Habitats Directives have a long-established monitoring and reporting system completed by the more recent Nature restoration law monitoring (Table 5).

**Table 5: Key characteristics and mechanisms of Birds and habitats Directives & Nature restauration law implementation**

| | |
|---|---|
| **Monitoring Network Requirements** | Each EU Member State establishes **monitoring** in targeted ecosystem (terrestrial, freshwater, marine, urban). |
| | Sampling and data capture must meet **technical specifications** defined by the EU. |
| **Near Real-Time Data Exchange** | Nature restoration law: Condition & restoration progress of all ecosystems |
| | Birds and Habitats directive: Article 12 reporting for birds, Article 17 for habitats/species |
| | Enables near real-time sources (Copernicus). |
| **Compliance and Enforcement** | The EU Member States must submit a **National Restoration Plan** every 2-3 years (Nature Restoration law).<br>Article 12 and 16 reports Every 6 years (Birds and habitat directive) sent to EEA who aggregate data |
| | The **European Commission** can take infringement procedures if targets are not met. |
| **Public Transparency** | • Main platform for exchanges is BISE Nature Restoration Portal.<br>• Public datasets aggregated by EEA available in EIONET and Biodiversity Information System for Europe (BISE)<br>• Natura 2000 map viewer by EEA[7] |
| | Mandatory public information on restoration progress maps, national indicators. |

Concurrently, EU-wide organisations and research networks (e.g. Biodiversa+) are refining biodiversity monitoring protocols and promoting harmonised indicators (such as

[7] natura2000.eea.europa.eu/



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Essential Biodiversity Variables, EBVs) across terrestrial, aquatic, urban and soil ecosystems. In practice, this emerging "Biodiversity Monitoring Law" paradigm will require robust infrastructures (Figure 8): standardized data models and services, interoperable metadata catalogues, shared sampling protocols, and reliable long-term observation systems. It aims to align environmental, land-use, agriculture, and climate policies under a unified monitoring and reporting framework.

For soil and ecosystem-health observatories such as EUSO or ESDAC, this context offers a strategic opportunity: by aligning with EU biodiversity monitoring standards, these platforms can ensure that soil becomes a fully integrated component of EU-wide biodiversity and ecosystem restoration efforts.

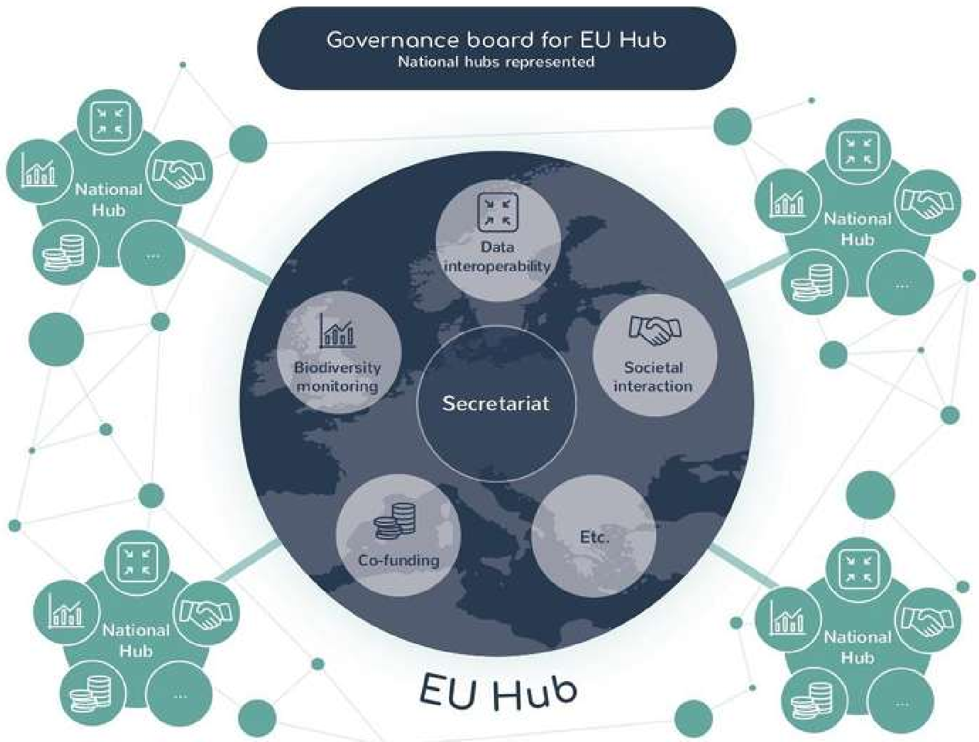


**Figure 8: Illustration of the expected multiscale governance model of the European Biodiversity hubs.**

### 2.1.4. Summary of key characteristics of EU Environmental Directives implementations

To compare the EU Environmental Directives implementations and better figure what could be done for soil, a summary table is provided (Table 6):





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**Table 6: Key characteristics of EU Environmental Directives implementation**

| Aspect | Water Framework Directive (2000/60/EC) | Ambient Air Quality Directives (2008/50/EC) | EU Biodiversity Monitoring (NRL 2024 & EBV frameworks) |
|---|---|---|---|
| **Governance Level** | River Basin Districts with cross-border coordination; national authorities + EU oversight | National monitoring networks coordinated by EEA; strict EU oversight | Multi-level governance: EU, national, regional ecological monitoring networks |
| **Strategic Planning** | Mandatory River Basin Management Plans (RBMPs) | Mandatory Air Quality Plans when exceedances occur | National Restoration Plans + Monitoring Frameworks |
| **EU Data Hubs** | WISE (Water Information System for Europe) | European Air Quality Portal | BISE (Biodiversity Information System for Europe) |
| **Legally Binding Targets** | "Good status" (chemical + ecological) | Limit/target values for pollutants | Binding restoration and monitoring obligations |
| **Enforcement** | EC infringement possible | EC infringement for exceedances | - Birds and Habitat Directive enforced<br>- Enforcement emerging for NRL |
| **Monitoring Requirements** | Comprehensive water body monitoring: chemical, biological, hydromorphology | Dense sensor-based air monitoring in urban/suburban/rural areas | Standardised biodiversity indicators, EBVs, habitat condition surveys |
| **Data Collection** | National agencies → WISE | Automated station data → EEA | Field surveys, species/habitat assessments/National agencies → EEA |
| **Reporting Frequency** | 3 or 6-year cycles | Hourly/daily data reporting | 2-3 years (NRL)<br>6 years (Birds/Habitat Directive) |
| **Interoperability Tools** | EIONET, WISE XML schemas | AQ e-Reporting + INSPIRE | EIONET, EEA, EBV standards, Darwin Core, INSPIRE |





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| | | | |
|---|---|---|---|
| **Public Access** | WISE open datasets & scorecards | Near real-time public access | Not fully centralised yet : BISE, Nature2000 access |
| **Level of Automation** | Semi-automated | Highly automated (hourly) | Moderate (manual + automated) |
| **Indicator Logic** | "One-out-all-out"; biological and chemical indices | Pollutant concentration thresholds | EBVs: species, habitats, ecosystem function, restoration |
| **Standardisation Level** | Very high (normative annexes, common methods) | Very high (CEN/ISO standards for instruments and protocols) | Growing; harmonising protocols (Biodiversa+, EEA) |
| **Core Data Models** | WFD Reporting Schema; WISE Data Model | AQ e-Reporting + Exchange Network (EN) schemas | INSPIRE, EBV frameworks (Darwin Core, ObsCore) |
| **Metadata Requirements** | Strict, INSPIRE-based | Strict, INSPIRE + AQ-specific | Growing harmonisation |
| **Integration With Other Domains** | Agriculture, climate, nature protection | Health, transport, climate | Climate, agriculture, ecosystem services, urban planning |

The Soil Monitoring Law (SML) sits at the crossroads of these three frameworks. Its design could draw on:

- The governance clarity of the WFD (management regions + 6-year plans).
- The dataflow automation of the AAQD (APIs, real-time ingestion where possible).
- The ecosystem perspective of biodiversity monitoring (multi-scale, multi-taxa, long-term).

The SML would thus combine the maturity of water and air governance with the ecosystem integration emerging in biodiversity, while building the necessary soil-specific standards (sampling, thresholds, data models, interoperability schemas).

## 2.2. Examples on soil pollution data and knowledge management in EU Member States

### 2.2.1. Italy – from regional to national registers

#### *2.2.1.1. Actors and roles*

In Italy, the management of contaminated sites has developed gradually, moving from fragmented regional initiatives to a coordinated national system. The first national regulatory framework was introduced in 1997, followed by Ministerial Decree 471/1999, which defined procedures for the identification and remediation of contaminated sites.





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Subsequently, Legislative Decree 152/2006 introduced a risk-based approach. Unlike France, where polluting activities are explicitly listed, in Italy the identification of potentially contaminated sites is based on preliminary investigations launched following accidents, industrial activities, or the discovery of historical contamination.

Responsibilities are distributed across several institutional levels:

- **Municipalities and Regions**: responsible for site management and remediation procedures, with the support of the provinces.
- **Ministry of the Environment and Energy Security**: responsible for Sites of National Interest (SIN), which are part of a special national remediation program launched in 1998.
- **ISPRA (Higher Institute for Environmental Protection and Research)**: develops and manages the national system for registering contaminated sites (MOSAICO), supports data harmonization, and issues guidelines to support risk assessment and management of contaminated sites.
- **Regional environmental protection agencies (ARPA/APPA)**: maintain regional registers of contaminated sites, manage monitoring networks, and provide public access to data through geoportals.

This governance model has resulted in a strong regional dimension, with highly heterogeneous practices and levels of updating. Since 2016, projects have been launched to build a shared data collection structure, culminating in the launch of the national **MOSAICO** platform in 2020.

#### 2.2.1.2. National registers and databases

The Italian system for managing data on contaminated sites is based on two main registers.

**MOSAICO**, created in 2020, is the national reference point and integrates data collected by the regions, providing administrative, geographical, and procedural information on sites, indicating their status as suspected, confirmed, or remediated. MOSAICO includes a database, a web application for data entry and verification, and **WebGIS** tools for visualization, but does not contain analytical information on contaminant concentrations or the perimeter of contaminated areas. An online public consultation section was made available in 2023.

The **SIN Register**, managed by the Ministry of the Environment and Energy Security, lists the most significant contaminated sites, identified based on the characteristics and quantity of pollutants, health and environmental risks, and damage to cultural heritage. The official list of SINs can be consulted through a dedicated portal. Although these two registers form the backbone of the national system, much of the operational knowledge remains rooted in regional registers.





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#### *2.2.1.3. Regional registers and practices*

Before MOSAICO, each region had developed its own register of contaminated sites, with very different levels of implementation and updating.

Today, regional registers remain fundamental for local management. Some significant examples are:

- **Piedmont – ASCO Register**: distinguishes potentially contaminated sites from those undergoing remediation.
- **Tuscany – SISBON**: public system that tracks the status of remediation procedures with maps and data available for consultation.
- **Autonomous Province of Trento**: WebGIS platform that integrates geographic data and remediation procedures.
- **Liguria**: register of environmental remediation and restoration activities.
- **Aosta Valley**: database and maps of contaminated sites managed by the regional ARPA.
- **Emilia-Romagna** – Portale minERVa (Informazioni - minERva)

This variety of tools and formats shows the difficulties of harmonization and standardization at the national level.

#### *2.2.1.4. Toward interoperability: MOSAICO as a unifying platform*

The launch of MOSAICO represented a decisive step towards integrating regional registers into a single system, with the aim of standardizing administrative data, providing a national overview of the status of contaminated sites, and offering GIS tools to support decision-makers, researchers, and citizens, while ensuring transparency through public consultation.

However, the system does not yet include technical data such as contaminant concentrations or geochemical background values, which remain under regional jurisdiction.

Future prospects include expanding interoperability with regional databases, integrating data on widespread contamination, currently managed only by some regions, and aligning with the future European Soil Monitoring Law to ensure consistency with infrastructures such as the **EU Soil Observatory (EUSO)**.

In summary, Italy is moving from a mosaic of regional registers to a coordinated national system. MOSAICO is now the unifying platform (Figure 9), but the technical content still needs to be consolidated, and full interoperability achieved at national and European level.





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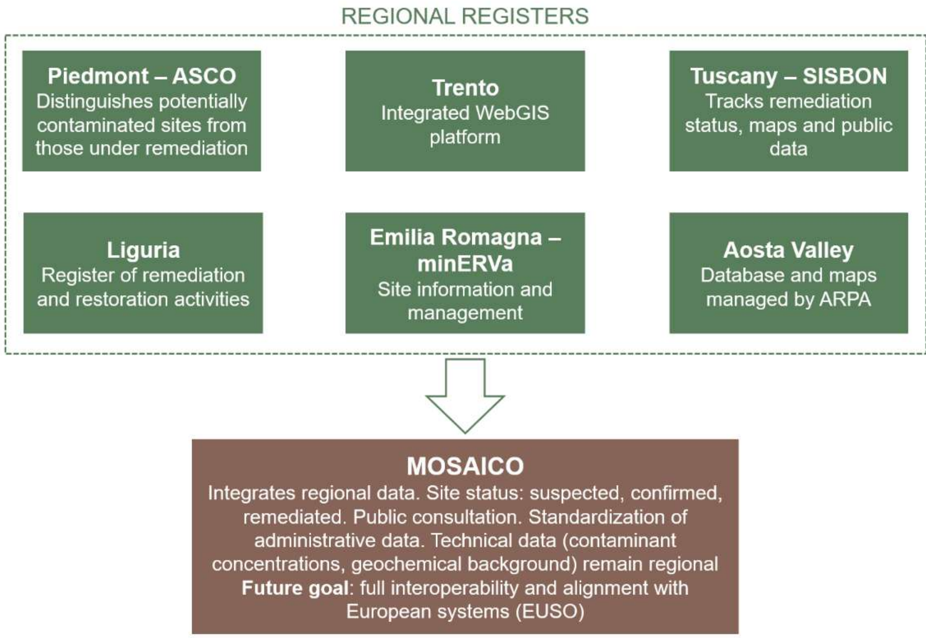


**Figure 9: From Regional Registers to the National MOSAICO Platform.**

### 2.2.2. France – modernizing data management structure for contaminated soils

#### 2.2.2.1. Actors and roles

Several institutions play complementary roles in structuring soil data in France:

**Green Data for Health (GD4H)** promotes the use of environmental data (including soil) for public health purposes. It offers a catalogue of 130+ datasets, legal guidance, and a collaborative community of >450 users.

**GIS Sol (Scientific Interest Group for Soil)** coordinates soil inventory, monitoring, and information systems. Bringing together ministries, agencies, and research bodies, it promotes national and international cooperation on soil quality data.

**BRGM**, the national geological survey, operates subsurface data infrastructures and manages the InfoSols contaminated sites database as well as BDSolU, the national urban soil database.

**INRAE**, the agricultural and environmental research institute, manages the national soil database DoneSol and leads major soil monitoring programmes such as IGCS and RMQS.

**IGN**, the mapping and geospatial agency, ensures reference systems, grids and geospatial infrastructures that guarantee interoperability among soil and other environmental datasets.





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Although major progress has been made, soil information systems in France still require stronger interoperability—similar to what biodiversity (**SINP**) and water (**EauFrance**) information systems have achieved. The following scheme (Figure 10) is an overview of soil databases and platforms in France as described for the French water resources[8].

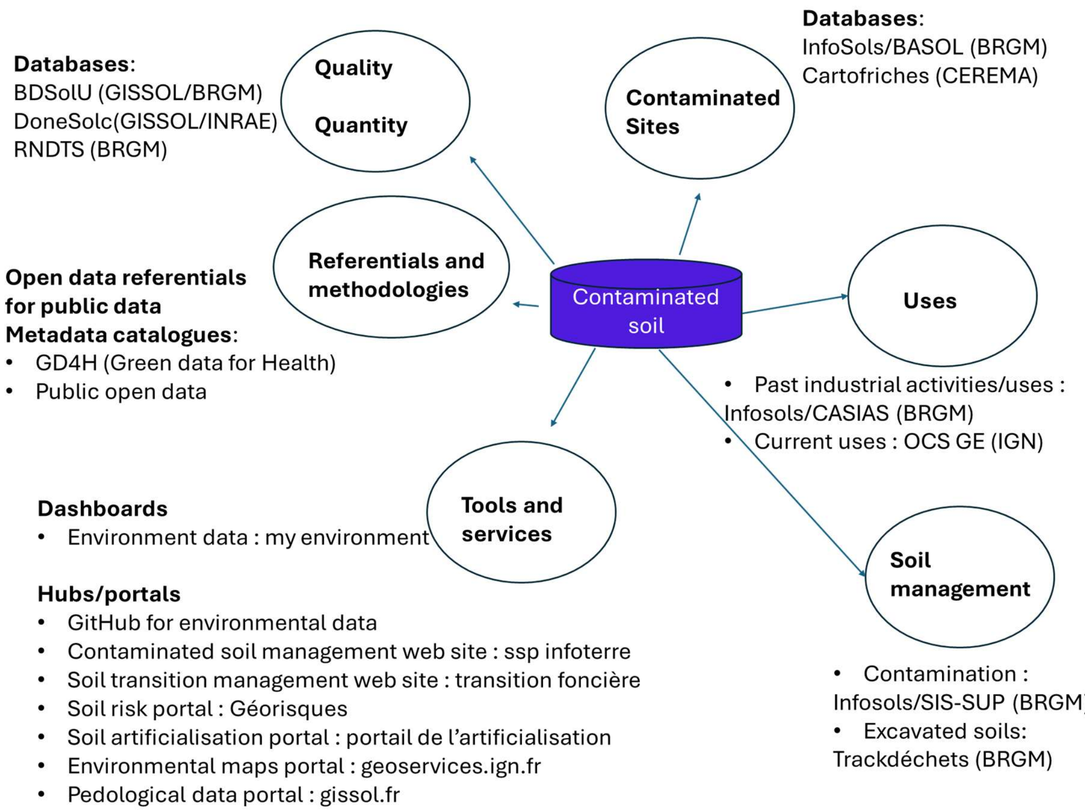


**Figure 10: French contaminated soil data and tools ecosystem adapted from the French water information system (eaufrance.fr).**

#### *2.2.2.2. BDSolU, the national database dedicated to urban soil management*

Urban soils differ significantly from rural soils due to anthropogenic influences such as atmospheric deposition and heterogeneous fill materials. No national or European standard exists for defining urban soil contamination, making reference values essential for local assessment.

**BDSolU**, managed by BRGM with ADEME's support, addresses this gap by establishing *pedogeochemical reference values* and consolidating chemical analyses from urban territories. As of 2025, the database contains 160,000+ samples from 600+ cities. The system integrates metals and persistent organic pollutants along with metadata on sampling locations, analytical methods, and contributors. Key objectives include supporting:

[8] https://www.eaufrance.fr/les-donnees-des-sites-eaufrance





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- contaminated sites management,
- excavated soil management,
- creation of fertile soils,
- urban planning,
- health protection,
- environmental impact and post-accident assessments.

**BDSolU** is aligned with Sandre, IGN, Corine Land Cover, BSS, CASIAS, and INSPIRE Directive (Directive 2007/2/EC) requirements (formalisation, interoperability, dissemination). Data are contributed through structured Excel templates and formal agreements. ADEME financially supports municipalities that conduct sampling campaigns. Future developments include:

- expanding datasets,
- improving interoperability with other French soil databases,
- integrating advanced cartography,
- strengthening alignment with the Soil Monitoring Law.

**BDSolU** also supports real-time querying, statistical analyses, geostatistical mapping with uncertainty quantification, and confidentiality-preserving visualisation, as demonstrated by Brunet et al., (2023).

#### *2.2.2.3. GISSOL, a national Soil observatory to support BDSolU interoperability*

**GIS Sol**, created in 2001, provides the overarching coordination framework for France's soil data. Its missions include monitoring soil quality, storing and organising samples and analyses, and ensuring accessibility for research and policy.
Governance includes:

- Ministries of Agriculture and Environment,
- National Agencies for Environment and Biodiversity,
- Research institutes: INRAE, IRD, IGN, BRGM.

**GIS Sol** coordinates five national programmes:

- IGCS – Soil inventory and mapping.
- RMQS – Long-term soil quality monitoring.
- BDAT – Database of routine soil analyses from approved labs (GEMAS).
- BDETM – Trace metal analyses linked to sewage sludge spreading.
- BDSolU – Urban soil database (managed by BRGM and integrated into GIS Sol since 2021) Le Guern et al. (2022).

The DoneSol database (created in 1992) remains the central harmonised soil information system, storing results from national programmes (Rennes et al., 2023; Froger et al., 2023).

Recent interoperability work between DoneSol and BDSolU aims to:

- enlarge datasets used for background value calculation,
- allow combined queries across rural/urban interfaces,
- support national policy and scientific research.





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**GIS Sol**'s 2023 scientific evaluation recommended (Buy & Saudubray, 2023):

- stronger collective governance,
- creation of a national soil data scheme (SNDS),
- harmonised financial and management rules,
- mandatory reporting for soil data where possible,
- engagement with EU-level soil monitoring initiatives,
- closer involvement of regional partners,
- improved legal frameworks for a soil information system.

These recommendations provide valuable insights for aligning national systems with EUSO and broader European efforts.

#### *2.2.2.4. Preliminary interoperability work*

Recent studies (Le Bas et al., 2024) explored interoperability between BDSolU (BRGM) and DoneSol (INRAE) using the OGC SensorThings API, already implemented within BRGM. This API provides:

- a unified object/sensor-based data model,
- predefined structures and formats,
- built-in tools for publishing interoperable data,
- strong alignment with OGC Observations & Measurements (O&M).

A field-by-field comparison revealed 32 matching fields, with varying levels of direct compatibility. Others are complementary and require semantic alignment. Initial interoperability tests confirmed the feasibility of exposing both databases through a unified SensorThings service model, and the need for harmonised vocabularies, code lists, and ontologies beyond structural interoperability.

The next steps would involve:

- completing mapping of DoneSol to SensorThings,
- jointly defining controlled vocabularies and thesauri,
- preparing for cross-database querying,
- extending to broader collaborations (LUCAS, EUSO).

A conceptual diagram (Figure 11) illustrates these future developments toward full interoperability.





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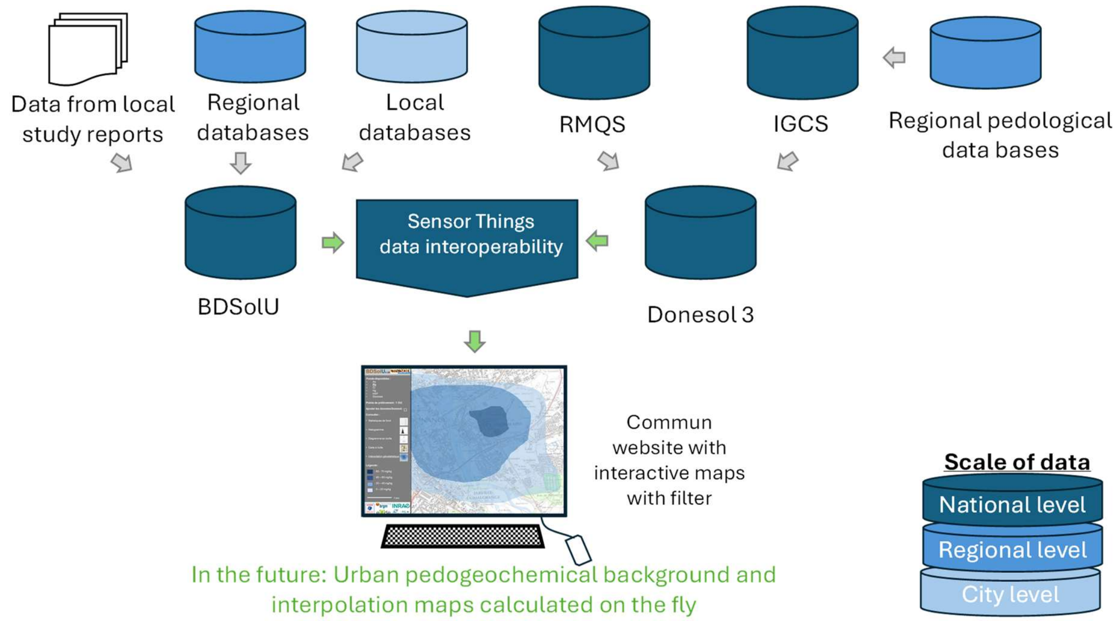


**Figure 11: Toward Interoperability of BDSOLU and DoneSol adapted from Le Bas et al. (2024).**

### 2.2.3. Greece - fragmented structures and steps toward a unified soil data system

#### 2.2.3.1. *Actors and roles*

In Greece, the management of contaminated soils is not yet organised under a unified national framework and thus responsibilities are distributing among several actors, resulting in fragmented data governance (*"Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'EU soil strategy for 2030 — reaping the benefits of healthy soils for people, food, nature and climate,"* 2021; European Environment Agency, 2024).

The Ministry of Environment and Energy (YPEN) is the main regulatory body responsible for permitting procedures (*"Specification of the procedures for opinions, public information, and participation of the interested public in the public consultation process during the environmental permitting of Category A projects and activities under Ministerial Decision No. 1958/2012 (Government Gazette A' 21), pursuant to Article 19, paragraph 9 of Law 4014/2011 (Government Gazette A' 209), as well as any other relevant detail.,"* 2014).

Regional and local authorities, such as Decentralised Administrations, Regional Environmental Directorates, and Municipalities, are authorised for site supervision, specific remediation procedures mainly through Environmental Impact Assessments and monitoring obligations attached to environmental permits (OECD, 2020). The Hellenic Survey of Geology and Mineral Exploration (HSGME) is the main scientific organisation responsible for geological and geochemical mapping, providing substantial datasets





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related to soil, sediments, and heavy metals, although these are not integrated into a national contaminated soils register.

Several Greek research and academic institutions contribute indirectly to soil quality and soil pollution data through geochemical surveys, environmental monitoring and project-based investigations. The Hellenic Centre for Marine Research (HCMR), which provides heavy-metal and organic-pollutant datasets from coastal sediments and is the only organisation providing marine soil information (Botsou et al., 2011; Tsoutsia et al., 2016; Vasileiadou et al., 2016).

National Technical University of Athens and Aristotle University of Thessaloniki have produced extensive geochemical maps and contamination assessments in mining districts, industrial zones and agricultural basins (Papadopoulos et al., 2025). Furthermore, The University of Crete generated a specialised soil contamination dataset by combining topographic and geological information with magnetic susceptibility mapping and thermomagnetic analysis to identify potential heavy-metal pollution in near-surface urban soils around an industrial and traffic-intensive area of Heraklion (Kokinou et al., 2013), while the University of Patras and Democritus University of Thrace have contributed detailed soil geochemistry studies in Western and Northern Greece (Alexakis et al., 2021; Nikolaidis et al., 2010).

The University of Thessaly provides datasets for contaminated lands by analysing trace metals in urban, agricultural, and industrial soils of Central Greece, producing geostatistical maps, pollution indices, and baseline metal levels that identify spatial patterns and hotspots of contamination. (Golia et al., 2008, 2021). Additionally, CERTH/CPERI releases high-resolution soil contamination datasets from mining regions, industrial corridors and Horizon Europe research activities (Carvalho et al., 2025). These datasets are scientifically robust; however, they remain dispersed, and a national integrating mechanism is still absent.

Despite the existence of several competent bodies, Greece needs a unified coordinating authority specifically mandated to consolidate and standardise soil contamination data at national level (European Commission: Joint Research Centre, 2025; European Environment Agency, 2024).

#### *2.2.3.2. Registers and existing data practices*

Unlike other EU Member States' information systems, such as Italy's MOSAICO or France's multi-layered soil information system (GIS Sol, BDSolU, InfoSols), Greece has not yet adopted a nationally operable registry for contaminated sites. Instead, relevant information is spread across thematic platforms, institutional catalogues and project-based outputs (*"Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'EU soil strategy for 2030 — reaping the benefits of healthy soils for people, food, nature and climate,"* 2021; European Environment Agency, 2024).





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Principle sources include environmental permitting databases, containing site-specific remediation studies and monitoring results. However, these are stored as case files and not as harmonised datasets (OECD, 2020). Regarding the Hellenic Survey of Geology and Mineral Exploration (HSGME) geochemical mapping programmes, provide an extensive dataset on metals but do not classify contamination status or remediation progress. At regional and municipal level, GIS portals have publicly accessible data about industrial activities, waste facilities, and land use, without standardised soil indicators (*"Commission Implementing Decision (EU) 2019/1372 of 19 August 2019 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards monitoring and reporting (notified under document C(2019) 6026),"* 2019; Minghini et al., 2020). Research project datasets, particularly from EU-funded initiatives (e.g., Horizon Europe, LIFE) often provide valuable soil-quality measurements but these remain decentralised.

Thus far, Greece has not deployed a systematic reporting procedure of contaminated sites to the European Environment Agency beyond case-by-case input for the LSI003 indicator, which lacks homogeneous interpretation across the EU Member States (European Environment Agency, 2024).

#### 2.2.3.3. Challenges for harmonisation and data interoperability

The Greek context presents several structural obstacles that reflect, and in some cases intensify, the challenges for harmonisation and data interoperability. The absence of a centralised register for contaminated lands affects the implementation of a national database for site classification after suspicion, confirmation, or remediation, and limits the national alignment with EUSO expectations (European Commission: Joint Research Centre, 2025; European Environment Agency, 2024).

Additionally, there is lack of common sampling, analysis and metadata standards, as measurements are carried out by various laboratories using different protocols and thus tackling the technical interoperability in line with FAIR principles (European Environment Agency, 2024). Geospatial infrastructures still confront fragmentation, as INSPIRE-compliant services exist but thematic soil datasets are insufficient and not connected through a shared reference system (*"Commission Implementing Decision (EU) 2019/1372 of 19 August 2019 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards monitoring and reporting (notified under document C(2019) 6026),"* 2019).

Open data availability is restricted due to the unpublished soil-related datasets, which are accessible only through project deliverables, impeding systematic reuse and integration into ESDAC (European Environment Agency, 2023). Regarding soil monitoring is not yet strategic because data are typically collected within EIA obligations or investigations following incidents, rather than under a national monitoring framework (European Environment Agency, 2024; OECD, 2020).

These obstacles impede Greece's capacity to contribute harmonised datasets to EU-level infrastructures and to meet the requirements of the Soil Monitoring Law (SML).





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#### *2.2.3.4. Opportunities and alignment with EU Soil Observatory (EUSO)*

Despite these gaps, Greece is towards the shifting point where new European obligations and national digitalisation efforts can promote a more integrated system. The establishment of the Soil Monitoring Law will be obligatory for each EU Member State to implement a national soil monitoring network, to adopt harmonised sampling and analytical methodologies, and promote a national contaminated sites register aligned with EUSO indicators (European Commission Directive 2025/2360 on Soil Monitoring and Resilience (Soil Monitoring Law) (European Parliament, 2025). These will be vital for the development of a Greek national soil information system.

The ongoing digitalisation of environmental data by the Ministry of Environment and Energy, Regional Authorities and HSGME, combined with INSPIRE services is the foundation for future integration through a common metadata and data-sharing framework ("Commission Implementing Decision (EU) 2019/1372 of 19 August 2019 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards monitoring and reporting (notified under document C(2019) 6026)," 2019).

The Greek participation in EU research projects related to research-driven data harmonisation, including ISLANDR, already contributes to the adoption of FAIR principles, standardised protocols, and semantic approaches. These outputs can inform a technical blueprint for the Greek registry, directly supporting interoperability. HSGME's geochemical maps represent a significant resource for establishing geochemical reference values, similar to the French approach (BDSolU). Under appropriate harmonisation procedures, these datasets would set the fundamentals for the forthcoming EU Soil Health Data Portal.

## 2.3. Project examples

Several projects include the collection and harmonisation of data from the EU Member States or local providers, in particular ANSIS in Australia, USDA in the United States or EPOS and EGDI in Europe.

### 2.3.1. ANSIS

The Australian National Soil Information System (ANSIS) is a national-scale initiative led by the Australian government to consolidate, harmonise, and disseminate soil and land information across federal, state, and territory agencies. Its purpose is to provide a unified, standards-based framework for soil data management, improving discoverability, interoperability, and long-term accessibility of Australia's diverse soil datasets.

ANSIS integrates legacy soil survey data, laboratory analyses, point observations, and modelled products, while aligning with international best practices for metadata and soil data representation.

The system supports programmatic access through modern web services and is designed to interoperate with global infrastructures such as the Global Soil Partnership (GSP), the





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International Soil Reference and Information Centre (ISRIC), and the Open Geospatial Consortium (OGC) data standards ecosystem.

### 2.3.2. USDA

The United States Department of Agriculture (USDA) is the federal institution responsible for developing and executing policies on farming, food, natural resources, rural development, and agricultural research in the United States.

Within USDA, the Natural Resources Conservation Service (NRCS) and the Agricultural Research Service (ARS) play central roles in soil-related knowledge and data. NRCS maintains the USDA Soil Survey that provides detailed soil descriptions, classifications, and interpretations through the widely used Web Soil Survey[9] and the Soil Survey Geographic Database (SSURGO). ARS conducts scientific research on soil processes, soil health, erosion, carbon sequestration, and sustainable land management.

The USDA has also developed influential standards and data frameworks, such as the United States Soil Taxonomy[10], which is widely adopted internationally and used as a reference in global soil initiatives (e.g., FAO and GSP).

### 2.3.3. EPOS and EGDI

The European Plate Observing System (EPOS) and the European Geological Data Infrastructure (EGDI) are two major European research and data infrastructures that provide essential reference frameworks for geoscientific data management.

EPOS focuses on integrating solid Earth science data, such as seismology, volcanology, geodesy, geology, and geotechnical observatories, into a harmonised, interoperable infrastructure that supports multidisciplinary research. Through its Thematic Core Services and Integrated Core Services, EPOS offers standardised access to diverse datasets, analytical tools, and computational services, applying FAIR principles and advanced interoperability standards such as OGC APIs and semantic metadata.

EGDI, operated by EuroGeoSurveys, provides a pan-European platform for geological datasets produced by national geological surveys, covering domains including geochemistry, groundwater, geothermal energy, minerals, and soil. It focuses on harmonisation of data models, controlled vocabularies, and shared services to make geological information accessible and comparable across Europe.

Both EPOS and EGDI rely on some harvesting systems to collect data from local or national providers and make them accessible at the EU scale (eg. borehole data from EPOS and mineral commodities in EGDI).



[9] https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx
[10] https://www.nrcs.usda.gov/resources/guides-and-instructions/soil-taxonomy



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For soil-related initiatives like EUSO/ESDAC, both EPOS and EGDI offer useful models: EPOS demonstrates how to connect distributed national data sources through shared standards and APIs, while EGDI illustrates how geological surveys can collaboratively maintain harmonised datasets at EU scale. Together, they embody mature, operational infrastructures that can inform the technical, organisational, and governance choices needed to implement the Soil Monitoring Law.





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# 3. Roadmap to EUSO based on ISLANDR experiences

## 3.1. General recommendations

### 3.1.1. FAIR principles and Environmental Interoperability Framework

The evolution of European environmental legislation demonstrates the long-term value of adopting FAIR principles (Findable, Accessible, Interoperable, and Reusable) together with the broader Environmental Interoperability Framework (EIF), which provides the legal, organisational, semantic, and technical conditions for sustainable data sharing. Both the Water Framework Directive (2000/60/EC), adopted in 2000, and the Air Quality Directive (2008/50/EC), adopted in 2008, established comprehensive monitoring and reporting systems grounded in shared data models, common indicators, harmonised metadata, and interoperable exchange protocols, illustrating early adoption of what would become EIF-aligned practices. A matrix table (Table 7) is proposed to highlight how FAIR principles and EIF dimensions match.

**Table 7: Mapping between the FAIR Principles and the EIF Dimensions**

| | Findable (F) | Accessible (A) | Interoperable (I) | Reusable (R) |
|---|---|---|---|---|
| **Legal Interoperability** | – | Licenses, usage conditions | – | Legal clarity on reuse, licenses |
| **Organisational Interoperability** | Policies on metadata responsibilities | Clear access procedures, roles | – | Governance and stewardship |
| **Semantic Interoperability** | Common vocabularies for metadata | – | Shared ontologies, data models, vocabularies | Provenance and quality metadata |
| **Technical Interoperability** | Persistent identifiers, searchable catalogues, APIs | Standardised protocols, machine-readable access | Standardised APIs, protocols, formats | Technical formats and metadata supporting reuse |

These frameworks encouraged the EU Member States to collect, manage, and disseminate environmental data through interoperable infrastructures, which have since evolved into robust European data ecosystems (e.g., WISE for water, AQD for air), ensuring





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that datasets are findable, accessible, interoperable, and reusable while being supported by strong organisational and legal structures.

In the same spirit, the forthcoming Soil Monitoring Law should build upon these successful precedents—embedding interoperability, open standards, and FAIR-compliant data practices within an EIF-based governance and technical framework. By combining these standards with modern digital infrastructures such as the EU Soil Observatory (EUSO), the Soil Monitoring Law can achieve long-term sustainability, comparability, and cross-domain integration—placing soil on equal footing with water and air in Europe's environmental knowledge base yet relying on more modern technologies.

### 3.1.2. Key challenges

Assuming the target of EUSO is to make available high quality soil data at EU scale, some coming from the EU Member States and Soil Mission projects and some provided by JRC, several challenges have to be addressed. For simplicity those are organised into four main categories: P.I.A.F.

**P: (Sustainable) Positioning**: the interest to the platform can only be maintained in the long run if both content and functionalities match the expectations. This mean the purpose of the platform must be clear with relationship with other platforms defined. The combination of a clear positioning and user satisfaction will then justify maintaining the platform. Note: this criterion has similarities with the Reusable criteria from FAIR yet focusing on the data maintenance.
**I: (Semantic) Interoperability**: clear semantics is required to make data understandable and usable. If data that originate from several sources must be comparable then some standards must be defined and applied to ensure their compatibility.
**A: (Automatized) Access**: large amounts of data with possibly regular updates justify the adoption of automatized solutions for data access and provision. The setting of those processes will be eased by the standardization of the content.
**F: (Easy) Findability**: a capacity to easily find data and information based on multicriteria would offer a better user experience and greatly contribute to the platform attractiveness.

Yunta et al., (2025) identified some challenges regarding data interoperability. Those actions are dispatched following the proposed PIAF categorization in Table 8.

**Table 8: Harmonization challenges identified by Yunta et al., 2025 and classified per topic**

| | |
|---|---|
| **Understand the objectives and focus areas of each database**: different databases have distinct objectives and focus areas, which influence the type of data collected and the methods used. Understanding these differences is essential for harmonizing databases and ensuring compatibility of data. | P |
| **Harmonize data collection methods and protocols**: Standardize data collection methods and protocols to ensure consistency across databases. Use internationally recognized standards and guidelines, such as ISO and CEN ones, to facilitate reproducibility and harmonization. | P/I |
| **Focus on common data elements and parameters:** Identify common data indicators and parameters across databases, such as soil texture, pH, and organic | P/I |





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| | |
|---|---|
| carbon content. Prioritize harmonization of these common soil parameters to facilitate data integration and comparison. | |
| **Consider the spatial and temporal scales of data collection**: Different databases may have different spatial and temporal scales of data collection. Consider these differences when harmonizing databases and ensure that data are compatible and comparable. | I |
| **Encourage collaboration and data sharing among database providers:** Collaboration and data sharing among database providers are essential for harmonizing databases. Encourage data sharing and collaboration to facilitate the development of harmonized databases and to promote the use of data for policymaking and research. | P/A |
| **Develop a common data format and data exchange protocol**: Develop a common data format and data exchange protocol to facilitate data sharing and integration. Use generic standardized data formats, such as XML or CSV, to ensure compatibility and ease of data exchange. | I/A |
| **Ensure data quality and validation:** Ensure that data are of high quality and validated to guarantee accuracy and reliability. Use data quality control measures, such as data validation and cleaning, to ensure that data are reliable and accurate. | I |
| **Provide metadata and documentation for harmonized databases:** Provide metadata and documentation for harmonized databases to facilitate data use and interpretation. Include information on data collection methods, data quality, and data limitations to ensure that data are used correctly and effectively. | F |

## 3.2. Specific recommendations

### 3.2.1. Positioning

#### *3.2.1.1. Platform objectives*

One main question to address regarding EUSO is its positioning and typology. Regarding data, there are three main kind of data platforms[11]:

- Data warehouse: they host data and make them available,
- Data catalogue: they do not host data, only reference them and help to find them,
- Data catalogue and warehouse: they do both. Often mostly referencing data from elsewhere but also offering capacity to host them.

The Figure 12 shows some data platform (or databases) and their typology: dark colour being for data warehouses, light colour for data catalogues and everything in between hybrid solutions. It also highlights existing or possible data and metadata workflows. Some names of existing platforms (based on France) are also given as examples. Note that some components may not (yet) exist in some countries: e.g. a national scale platform for soil data.



[11] Only relationships with data are addressed here. Some platforms (e.g. EOSC) can offer additional capacities such as data conversion and treatments.



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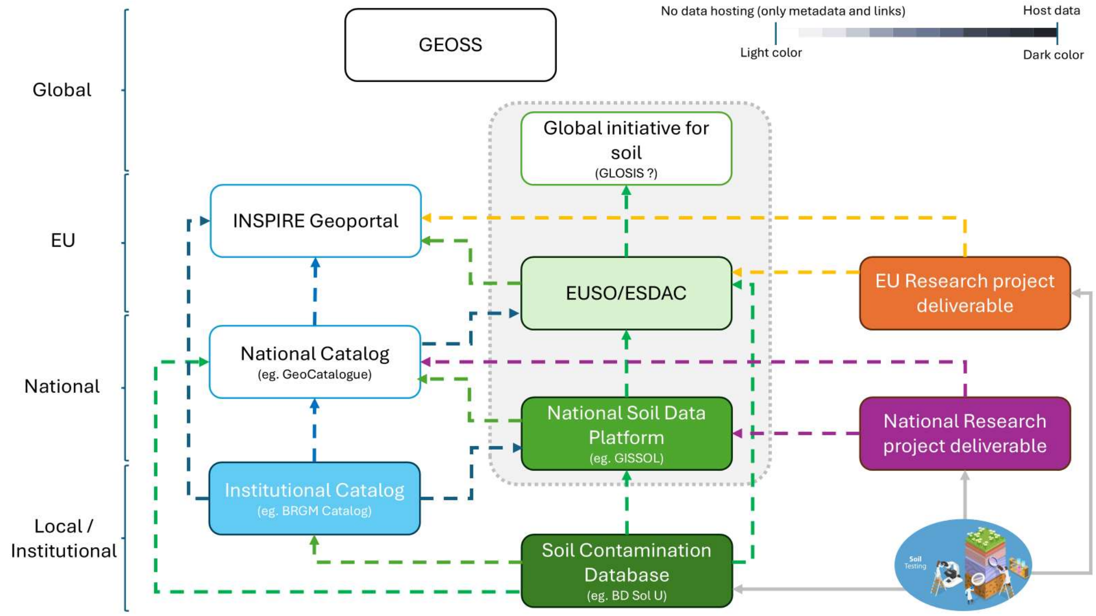


**Figure 12: Data catalogue, data warehouses and possible or existing connections between them. Including examples from France.**

The general behaviour is that the higher the scale (going from local, to national, EU, global) the less and less they are hosting the data but only referencing them.

National or EU platforms mostly reference and link to resources hosted somewhere else but can also play a role of conservation of data produced during national or EU projects that were not designed to go in existing data warehouses. During the project life (and often few years after) those data are made available from the project website. A more sustainable solution that is often used is to associate them to a paper and entrust them to repository like Zenodo.

#### *3.2.1.2. Level of standardization*

As mentioned in the section 1.4, the heterogeneity of practices and data for soil in EU introduces some interoperability challenges. This topic was studied in EJP Soil:

- Froger et al., (2024) proposed a comparison between the LUCAS Soil and 12 EU Member States national soil information systems (N-SIMS). It highlighted strong variability in terms of spatial coverage, land-use representation and soil typologies.
- van Genuchten et al., (2024) also highlighted the pros and cons of following a country driven approach vs setting a standard at EU scale. While noticing the diversity of methods used when studying data (Figure 13) and stating that probably the choices were justified by the national needs. Three options were then envisaged to match interoperability at the EU scale:
    - Serving data as is and set a metadata catalogue (e.g. GeoNetwork), noticing standardization will be needed each time data are used,
    - Serving standardized data in a catalogue, which will save standardization time but will disable data queries,




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  - Serving standardised data and put up web services for machine approachable data endpoint, which will meet the FAIR principles yet require a (big) standardization effort.
- Mason et al., (2025) assessed the key differences in sampling strategies, parameters and accessibility between EU soil monitoring systems (scope in agricultural soils) through survey across the EJP SOIL countries. The study also identified gaps between the EU soil monitoring systems and SML criteria and proposed solutions to harmonise the national systems for SML criteria while respecting national contexts.

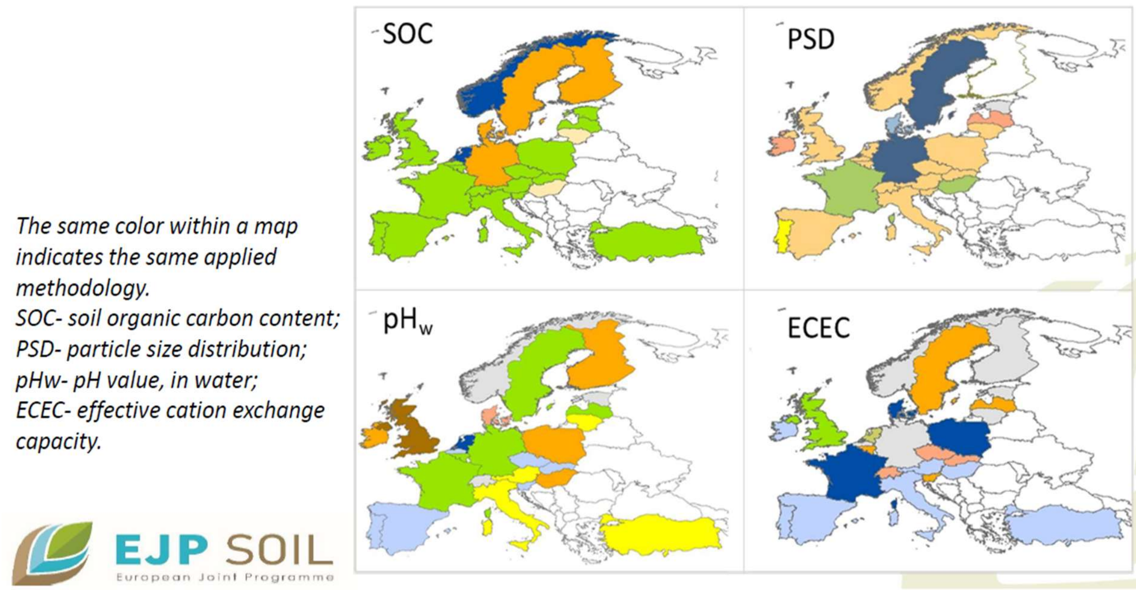


**Figure 13: Maps of methods used to measure a given soil property in each country after van Genuchten et al., (2024).**

In the domain of biodiversity, Biodiversa+ proposed a guide (Silva del Pozo et al., 2023) that aims to support the integration and harmonisation of biodiversity monitoring across Europe by offering a framework for making data from diverse programmes comparable and reusable at multiple scales.

Stating standardization can for sure help harmonization yet can be difficult to set, especially when sharing practices are already in place, Biodiversa+ analyses three main strategies:

- Strict shared protocol with joint data analysis: maximises comparability but reduces flexibility,
- Locally tailored protocols and harmonised Essential Biodiversity Variables (EBV) production: maintains local ownership but requires agreement on EBV definitions,
- Flexible protocols + parallel data workflows (sharing raw data and EBVs, see Figure 14) allowing maximum adaptability and comparability, though requiring robust data infrastructures.





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The guide favours the latter two strategies, arguing they provide better compromise between scientific rigor, stakeholder ownership, and feasibility across diverse contexts (Figure 14).

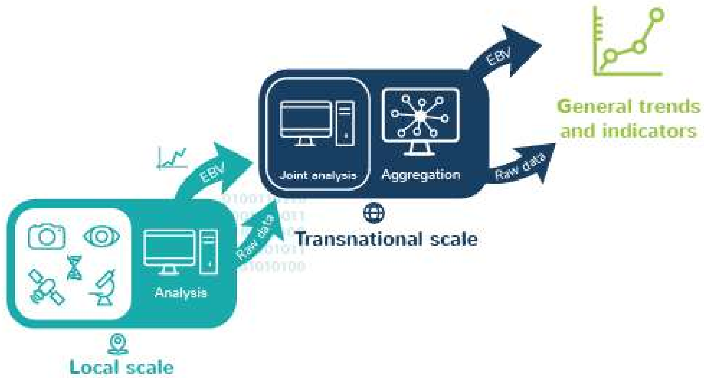


**Figure 14: A suggested data workflow to make local data and indicators available (Silva del Pozo et al., 2023).**

#### *3.2.1.3. Recommendations*

Standardization, that is to say adopting same practices ensuring to get comparable results, is obviously the way to privilege. It can however be challenging when existing practices exist, especially when they appear as more appropriate by those who collect the data.

Converting every single data to a common format can be a huge effort but also will not avoid the need to keep the original data as they may be more fitted for some particular use cases.

Refining the scenarios identified by EJP Soil, the approach introduced by Biodiversa+ proposing to both share standardized data for EU indicators and raw data is an interesting compromise to follow:

- Guaranteeing minimum interoperability and data comparability for EU,
- Keeping full richness of the initial information yet still offering the opportunity for conversion if needed.

An additional gain would be to keep the information on data provenance when mapping or conversion have been performed.

### 3.2.2. Semantic interoperability and data reusability

In a classical data discovery process semantics is not what first appears, yet this is the first thing to care about when addressing the data provision. The nature of the data can also impact the technical solutions (APIs) to be used for its provision.

The *Interoperable* principle from FAIR ensures that data from different sources can be integrated, combined and interpreted unambiguously by machines and humans. This





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requires the adoption of shared semantic vocabularies, taxonomies, and ontologies (e.g., GEMET, INSPIRE code lists, the Soil Health vocabulary, OGC/ISO models).

The *Reusable* principle ensures that data can be used in contexts other than the one in which they were originally produced. To achieve this, datasets must include detailed provenance, methodology descriptions, quality indicators and clear permissive licenses (e.g., CC-BY, CC-BY-SA, or equivalent). Reusability requires standard formats, well-documented metadata, and references to controlled vocabularies so that future users understand exactly what each variable means.

Data should be structured following standard data models such as ISO 19156 (Observations & Measurements), INSPIRE Soil, or OGC API schemas. ISO 19156 perfectly illustrates a data model designed for data reusability: the observations need to be associated to several meta-information such as the unit, observed property, method of observation, identity of the observer, date and possibly other key information data consumers may need to know to understand the observation context.

Using harmonised units, reference systems, sampling methods, and concept definitions ensure that soil datasets from the EU Member States can be merged without ambiguity. Interoperability also means linking data across domains—soil, water, biodiversity, climate—through common identifiers and semantic mappings. Ultimately, interoperability allows soil data to be processed automatically, reused across platforms, and combined for integrated assessments.

#### 3.2.2.1. Data models vs ontologies in practice

Ontologies and data models both structure information, but they differ significantly in purpose and implementation.

**Data models**, whether defined by international standards (such as ISO 28258), European directives like INSPIRE, or domain-specific best practices, provide a precise, rigid schema defining how data must be stored, structured, and exchanged. They prescribe classes, attributes, data types, and relationships in a way that supports validation, interoperability, and consistent database or API implementation. In practice, data models translate directly into database schemas, services such as OGC API – Features, or file formats like GML, JSON, or CSV.

**Ontologies**, by contrast, focus on formal semantics rather than structure. Using controlled vocabularies and logical relationships, ontologies like SSN/SOSA enable machine-understandable meaning and flexible linking of concepts across datasets. They are implemented using semantic web technologies (RDF, OWL, SKOS) and are designed for reasoning, alignment, and integration with external knowledge graphs.

While a data model enforces how data must be stored, an ontology ensures how data can be understood and interpreted. In many modern architectures, data models provide the





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backbone for implementation, while ontologies provide the semantic layer that gives the data meaning beyond its original context.

In other words, while ontologies are designed for knowledge management, for a use case like "setting a data base structure in which data collected from several providers are stored" ontologies must be derived into more classical XSD or JSON schema before being implemented. A good example of this is the ANSIS Ontology that had to be "transformed" into a JSON schema for proper implementation[12].

#### *3.2.2.2. Existing data models and ontologies for soil*

An inventory of relevant data models and vocabularies for soil was already made for the ISLANDR D1.3 deliverable (Beaufils et al., 2025a, 2025b) with a particular attention paid to vocabularies. Figure 9 provides an adaptation of this inventory with a focus made on data models and ontologies. Another standard (ISO 19135) is also included for vocabulary management.

**Table 9: Overview of relevant standard ontologies, data models and data management processes for soil data**

| Topic | Reference | Format |
|---|---|---|
| **Metadata (generic)** | | |
| **Dublin Core** | https://www.dublincore.org/specifications/dublin-core/ | RDF TTL |
| **DCAT** | https://www.w3.org/TR/vocab-dcat-3/ | RDF TTL |
| **ISO 19115** | https://www.iso.org/fr/standard/53798.html | UML / XSD |
| **ISO 19139** | https://www.iso.org/fr/standard/67253.html | UML / XSD |
| **Observations, Measurements, Samples and related (generic)** | | |
| **ISO 19156** | https://www.iso.org/fr/standard/82463.html | UML / XSD |
| **SOSA-SSN** | https://github.com/w3c/sdw | RDF TTL |
| **OGC SensorThings API datamodel[13]** | https://docs.ogc.org/is/18-088/18-088.html | UML / JSON Schema |
| **I-ADOPT** | https://i-adopt.github.io/ontology/ | RDF TTL |
| **Soil domain** | | |
| **GloSIS** | https://glosis-ld.github.io/glosis/ | RDF TTL |
| **ANSIS ontology** | https://raw.githack.com/ANZSoilData/def-au-domain/main/doc/domain.html | RDF TTL |
| **ISO 28258** | https://www.iso.org/standard/44595.html | UML / XSD |
| **ANZSoilML** | https://github.com/ANZSoilData/ANZSoilML | UML / XSD |
| **ANZSoilData** | https://github.com/ANZSoilData/def-au-schema-json | RDF TTL |
| **INSPIRE Soil Data Model** | https://github.com/INSPIRE-MIF/technical-guidelines/tree/main/data/so | UML / XSD |
| **OGC Soil IE** | https://github.com/opengeospatial/SoilDataIE | UML / XSD |
| **Vocabulary governance** | | |
| **ISO 19135** | https://github.com/opengeospatial/SoilDataIE | Text |

[12] https://ansis.net/data/information-model/

[13] The OGC SensorThings API is an API that comes with its own data model. The data model is very close to ISO 19156.





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#### 3.2.2.3. Recommendations

The data models or ontologies to use depends on the information that must be shared. For EUSO, those constraints are identified:

- Mandatory: Conformance to EU Directives: INSPIRE (Directive 2007/2/EC), Directive on open data and the re-use of public sector information (Directive (EU) 2019/1024),
- Highly suitable: Compatibility with the EU Member States' national systems,
- (Very) suitable: Compatibility with GLOSIS.

Some data models like the INSPIRE data models (eg. for the thematics of Soil or Environmental Monitoring Facilities) or ISO 28258 were designed for direct implementation with OGC web services and APIs (e.g. OGC API Features and OGC SensorThingsAPI). A prerequisite for implementation could yet to update the models to take advantage of the latest version of some key standards (GML, O&M). To provide observations, measurements and sampling data (OMS based) that can easily be implemented with the OGC SensorThingsAPI.

Ontologies are interesting to consider for a longer-term perspective as they can highlight the similarities and differences between terms that are used in different models. They can greatly help to figure out if some data, while not exactly using the same wording can still be used. Initiatives like SOSA-SSN and GLOSIS are on-going and benefit from regular updates.

However, for a use case that would consist in storing data, making them available on the web through API, potentially handling versioning too, the implementation will require extra efforts, like conversion in JSON/XSD schemas (see the ANSIS reference). Attention will be required on maintaining the connection between the initial ontology and its derived schema.

#### 3.2.2.4. A focus on the ISLANDR vocabularies

The ISLANDR vocabularies work (described in D1.3) provides a foundation for a harmonized and FAIR-compliant soil terminology framework across Europe.

The harmonized vocabularies are hosted in the European Geoscience Registry (EGR): https://data.geoscience.earth/ncl/ operated by BRGM for EuroGeoSurveys. This platform enables publication in web-semantic formats (RDF, SKOS, TTL) and provides persistent URIs for each term. Relationships between vocabularies are encoded using SKOS and OWL (e.g., exactMatch, broader, related), connecting EU and ISO terms and supporting ontology reuse.

Over 1,200 terms from ISO and EU sources have been added to EGR, including those from the forthcoming EU Soil Monitoring Law, ISO TC190 (Soil Quality) standards such as ISO 11074, ISO 18504, ISO 19258, and ISO 21365 or other EU Soil projects LANDMARK,





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BENCHMARK). These vocabularies are now accessible in multilingual[14], machine-readable formats, ensuring their interoperability and long-term accessibility.

The ISLANDR ontology aligns conceptually with the FAO Global Soil Information System (GloSIS) ontology, which provides a global framework for soil property definitions, observations, and classifications. ISLANDR terms can be mapped to GloSIS classes for consistency with international soil data exchange practices.

The European Geoscience Registry is regularly updated based on user feedback and needs to include or adjust new terminology for geoscience projects, including Soil Mission projects (e.g. ISLANDR, SPADES, PHISHES, ...).

### 3.2.3. Data accessibility

The *Accessible* principle ensures that once data are found, users can retrieve them, through open and standardised protocols. Accessibility does not necessarily mean "open to everyone", but rather that clear access conditions are defined, including licenses, authentication rules, and download procedures when needed.

Data should be retrievable via standard APIs, ensuring machine-to-machine access. Metadata should remain accessible even if the data are restricted, ensuring transparency. Accessibility also includes long-term availability, meaning systems must commit to preservation and stable endpoints. For environmental monitoring—like soil health—this principle is essential for automated reporting, reproducibility, and integration with large-scale platforms such as EOSC, EUSO, or Copernicus.

#### *3.2.3.1. Status*

Currently, access to EUSO and ESDAC data often requires users to fill out a request form before downloading datasets. While this approach allows ESDAC to monitor usage and ensure responsible access, it also introduces friction for users: the process is partially manual, delays data retrieval, complicates machine-to-machine interactions, and is not fully aligned with modern FAIR and open-data practices.

Many research infrastructures and environmental data portals have progressively moved away from form-based access toward automated, standards-based distribution mechanisms, where metadata catalogues, APIs, and persistent identifiers enable immediate, traceable, and reusable access to information.

On the legislative side, the High Value Datasets Implementing Act (EU, 2022) builds on INSPIRE and introduces additional requirements aimed at maximising the reuse and impact of public sector data. Beyond interoperability, High Value Datasets (HVD) mandates free access, open licences, and machine-readable formats, with a strong emphasis on API-based and bulk access. Its perimeter includes Environmental Data.



[14] Vocabularies from ISO are available in English, French and sometimes German too.



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#### *3.2.3.2. Recommendations*

For EUSO and ESDAC, adopting technologies like web services or APIs would significantly improve usability. These technologies would streamline user experience, support programmatic access for modelling and monitoring workflows, and better integrate ESDAC data into the wider European data ecosystem—including INSPIRE, EOSC, Copernicus, and national soil information platforms.

If authentication or authorization are required to access some resources, then additional layers are needed. Several technologies can be used:

- Trust and identity frameworks (like iShare[15]) manages who can access what, provides legal and organisational rules for authentication, supports federated identity, and issues access tokens.
- Federated middleware (like SIMPL-Open[16]) manages how data flows, enforces access policies, integrates multiple data providers, and provides connectors to APIs and services.

A combination between SIMPL-Open for federated access and policy enforcement, iSHARE for trust and identity, and OGC-compliant APIs for machine-readable delivery would provide a robust, modern approach to managing restricted data while adhering to FAIR principles and ensuring interoperability. For now such combination has not been properly implemented and would require to be tested.

The Table 10 indicates suitable web services and APIs for making data accessible based on their nature. Open-Source Tools for implementation, with the most suitable mentioned first, are also suggested.



[15] https://ishare.eu/
[16] https://digital-strategy.ec.europa.eu/en/policies/simpl



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**Table 10: Recommended open-source web services, APIs or tools for soil data provision and management**

| Type of Data or Use Case | Recommended Web Service / API Standard | Purpose / What It Enables | Open-Source Tools for Implementation |
|---|---|---|---|
| **Spatial vector data (soil monitoring points, sampling sites, administrative units)** | OGC API – Features[17], legacy WFS | Query and retrieve vector datasets with full attribute access | **GeoServer**, pygeoapi, MapServer, QGIS Server |
| **Raster and gridded maps (soil erosion risk, soil moisture maps, remote sensing products)** | OGC API – Coverages, legacy WMS/WCS | Serve raster layers; subset, extract and download | **GeoServer**, MapServer, pygeoapi |
| **Environmental observations & sensor time series (soil moisture probes, repeated sampling, contamination monitoring)** | OGC SensorThings API[18] | Query by time, depth, position, trajectory; extract subsets Publish/subscribe workflows, real-time monitoring | **FROST Server (Fraunhofer)**, GOST, SensorThings modules in pygeoapi |
| **Map and tile-based visualisation** | OGC API – Maps, OGC API – Tiles, legacy WMTS/WMS | Web-friendly visual layers for dashboards and portals | **GeoServer**, MapServer, TileServer GL, QGIS Server |
| **Data storage & modelling back end** | Not an API standard, but key components for soil data | Robust database and geospatial storage | PostgreSQL/PostGIS, Rasdaman (coverages), GeoPackage, Parquet/GeoParquet |
| **Cataloguing soil vocabularies / ontologies** | SKOS, DCAT, SHACL, OGC Naming Authority practices | Semantic interoperability & consistent terminology | VocBench, Skosmos, EuroVoc/GEMET integration tools |

### 3.2.4. Facilitate data discovery

The *Findable* principle ensures that data and metadata can be reliably located by both humans and machines. This requires the use of persistent identifiers (PIDs) such as DOIs, stable URLs, or unique codes for soil sampling sites or monitoring points. Metadata must be rich, structured, and indexed so that catalogue systems (e.g., DCAT, OGC API Records, GeoNetwork) can harvest and expose them.

[17] OGC API Features and OGC SensorThings API have been assessed as suitable APIs for INSPIRE Download Services in Kotsev et al., (2018).
[18] Same as 17.




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A key aspect is that data are registered in searchable, machine-readable catalogues following standard metadata schemas like ISO 19115 or DCAT-AP. "Findable" also means that the metadata remain available even if the datasets move, ensuring traceability and long-term discoverability. Ultimately, findability enables cross-border soil data comparison, automated data discovery, and transparent reporting across the EU Member States.

#### *3.2.4.1. Recommendations for implementation*

Several mature tools exist to support the publication and dissemination of geoscientific and geotechnical metadata, among which pycsw (https://pycsw.org/) and GeoNetwork (https://geonetwork-opensource.org/) are the most widely used open-source solutions.

Pycsw is a lightweight, Python-based CSW server fully compliant with OGC Catalogue Service standards. It is easy to deploy, integrates well with Python workflows, and offers strong performance for simple catalogue needs. However, its functionality focuses primarily on metadata harvesting and CSW operations, with limited native support for user interfaces, data visualisation, multilingual cataloguing, or advanced administration features.

In contrast, GeoNetwork provides a much more comprehensive environment, including a powerful web interface, extensive metadata editing tools, support for multiple standards (ISO 19115/19139, INSPIRE, DCAT), integrated harvesting, APIs, user/group management, and strong interoperability with common geospatial platforms. GeoNetwork is also widely adopted by national geological surveys, environmental agencies, EU infrastructures and OGC-aligned initiatives, which ensures long-term maintenance, documentation, and community support.

Considering the ambition of EUSO /ESDAC (requiring robust metadata management, advanced user functionalities, interoperability with European standards, and alignment with FAIR principles), GeoNetwork would offer a richer and more sustainable solution than pycsw in the long run. Especially if EUSO is not only harvesting (meta)data from other places but is also hosting some data (notably those produced by JRC, e.g. LUCAS), the GeoNetwork GUI will greatly help users to provide and update their (meta)data.

#### *3.2.4.2. A focus on the ISLANDR Metadata Catalogue*

The ISLANDR metadata catalogue, built on the GeoNetwork platform and hosted by GreenDecision, simplifies the management, sharing and access to data related to soil contamination. It is already publicly available and will continue to be maintained beyond the project's lifetime. GeoNetwork was chosen for its open-source nature, its specificity for geospatial data, and its advanced spatial search and GIS integration capabilities, which are essential for this type of information. The catalogue follows the INSPIRE directive (Directive 2007/2/EC) and ISO standards 19115, 19115-3:2023 and 19139-1:2019, ensuring that it remains relevant and compatible over time. Development is also guided by FAIR principles, so that data is easy to find, open to users, interoperable with other systems and ready to be reused in different contexts.




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Metadata records can be downloaded in ZIP, PDF and XML formats. Users can search and filter datasets using key fields such as Country, Data Coverage, Database Type and Organisation, making it easier to locate and compare information. For up-to-date catalogue, the ISLANDR Metadata catalogue has a mechanism to check, if the links to original data and services still exists.

Collaboration has been crucial in the catalogue's development. The ISLANDR metadata catalogue is fully compatible with SoilWise, with metadata updated weekly and synchronized between both systems. This ensures that users can access consistent and comprehensive soil data across projects. Integration with the European Soil Observatory (EUSO) strengthens ISLANDR's role within the European soil health network, while sharing metadata with ARAGORN extends its impact and reach.

The connection with SoilWise is particularly important: by aligning standards, update schedules, and metadata structures, both catalogues reinforce each other, enabling easier cross-project data analysis, comparison, and integration. This approach also supports potential joint initiatives for soil monitoring, research, and policy implementation across Europe.

Following the seminar on soil pollution held in Ispra (July 2024), ISLANDR collaborated with the Joint Research Centre (JRC), SoilWise, ARAGORN, EDAPHOS and CEN/TC 444 WG to produce a joint report on soil pollution data and metadata needs in Europe (Yunta et al., 2025).

The ISLANDR Metadata Catalogue was updated until November 2025 and expanded to support broader environmental applications, such as cross-border contamination assessment and sustainable land management practices. Metadata catalogue website: (https://geonetwork.greendecision.eu/geonetwork/srv/eng/catalog.search#/home).

Summary of ISLANDR main contributions to support data flow and harmonisation to EUSO in Table 11.

**Table 11: ISLANDR main contribution to support EUSO roadmap are as follow.**

| EUSO roadmap | ISLANDR contribution | Ref of ISLANDR deliverable |
|---|---|---|
| Watch list for contaminants | CEC prioritization | D2.1 CECs prioritisation |
| Pollution dashboard | ISLANDR data summary and Metadata catalogue, roadmap to EUSO, vocabularies, interpolation algorithm, regional risk assessment | D1.1 Data Summary, D1.4 Roadmap to EUSO, D1.3 Ontology, D1.2 Hot spot identification, D2.2 Large scale risk assessment |
| Tools and methods | Regional risk assessment, interpolation algorithm | D2.2 Large scale risk assessment, D1.2 Hot spot identification |





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# 4. Conclusion

The transition toward a harmonized, interoperable, and FAIR-compliant European soil information ecosystem is now both a necessity and an opportunity. The Soil Monitoring Law (SML) marks a turning point by establishing a binding framework for soil health assessment, data reporting, and long-term monitoring across the EU Member States. Yet the current landscape, characterized by heterogeneous methodologies, fragmented databases, inconsistent indicators, and uneven accessibility, shows that significant efforts are required to reach the level of integration achieved in other environmental domains such as water or air quality.

The EU Soil Observatory (EUSO) and the Soil Health Data Portal as well as the future versions of ESDAC are poised to become the central reference infrastructures for soil data. However, their success will depend on the capacity of the EU Member States, research projects, agencies, and expert communities to converge towards shared standards, interoperable technologies, and coordinated governance.

Harmonisation concerns two aspects: the data collected (e.g. sampling strategies, analytical methods) and the data flow (e.g. metadata, formats, interoperability protocols). The constraints identified for soil contamination data make clear that additional steps are still required to achieve harmonisation in line with the SML guidelines even though the directive lays the foundations for collecting comparable soil data from the EU Member States.

The ISLANDR findings on data gaps, particularly the limited availability of soil contamination databases and missing metadata in the Deliverable 1.1, emphasize the need for aligned standards governing both data flows and database structures. While JRC and EUSO will make datasets publicly available through the EU Soil Health Data Portal and will harmonise them in aggregated form, the EU Member States may also submit aggregated data. In such cases, harmonized and transparent protocols for preparing these aggregated datasets are essential.

In this deliverable the combined experiences from ISLANDR, national case studies (France, Italy, Greece), and international initiatives (ANSIS, USDA, EPOS/EGDI) illustrate both the feasibility of this transition and the remaining challenges. They also highlight concrete technical pathways, ranging from semantic vocabularies and metadata catalogues to modern APIs and harmonized data models.

The overview of existing EU Environmental Directives (Water, Air Quality, Biodiversity) shows that data collection methods are adapted to each domain's monitoring needs (such as the higher frequency for air quality) while addressing similar challenges related to stakeholder coordination, technological choices and fragmented data infrastructures.

National case studies demonstrate that the EU Member States can adopt different organisational models for soil data such as mosaic or layered structures while still complying with SML requirements if data formats and technologies are harmonized at the





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EU level. They also show that soil information systems must remain adaptable, evolving alongside scientific progress, new regulations and innovations in data management. Building a resilient framework that ensures consistent data use while preserving flexibility requires a comprehensive long-term perspective with continuous analysis, and monitoring of the soil systems at national level.

The "Roadmap to EUSO" (Deliverable D1.4) provides pragmatic recommendations: adopting open and modern web services for data provision, aligning with recognised standards (OGC, ISO, INSPIRE), using shared vocabularies such as those developed in ISLANDR (Deliverable D1.3), and supporting both raw and harmonized datasets to balance scientific flexibility with EU-wide comparability. It also recommends mature open-source technologies (e.g. GeoServer, GeoNetwork, FROST Server) for implementing the data workflow.

Deliverable D1.4 also identifies key elements required to establish a solid foundation for an EUSO capable of supporting soil health monitoring at EU and national levels. Each block demands clear technical specifications from both soil and data experts and a well-defined stakeholder engagement framework (clarifying roles and responsibilities):

- Sampling and analysis capacity
- Data formatting and transformation
- Data flow and storage
- Data dissemination

An overarching structure that integrates these elements into a coherent framework would support adaptation to emerging technologies, evolving regulations, and societal expectations. Ensuring that all stakeholders share a clear understanding of the evolving soil data ecosystem is as important as the technical solutions themselves.

Lastly, it is important to highlight the diverse needs for future soil data services through EUSO. They should not only cover policy makers and citizens but be able to answer the soil expert's needs on soil contamination data in the EU. As the aggregated form avoids the restrictions some countries have on the geographically exact or personal data and enables creating comparable results for the EU, raw data is needed to analyse and understand the soil processes. To apply the data for improving soil health, transparency on the methods used in data processing is essential.

Achieving this vision requires long-term coordination, investment in digital infrastructures, and active collaboration between soil scientists, data providers, and policymakers.





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