# Soils4EU
# Providing support in relation to the implementation of the EU Soil Thematic Strategy

## Identification of priority areas for improving consistency and inter-operability of EU-wide and national soil monitoring and information systems

Deliverable 1.5

Revision: final

11 November 2019

Service contract No 07.0201/2016/742739/SER/ENV.D.l

PREPARED FOR:

EUROPEAN COMMISSION
DG ENVIRONMENT

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|---|---|
| Client | European Commission, DG Environment |
| Title | D 1.5 Identification of priority areas for improving consistency and inter-operability of EU-wide and national soil monitoring and information systems |
| References | Contract no. ENV.D.1/SER/2016/0041 |

Providing support in relation to the implementation of the EU Soil Thematic Strategy is a three-year contract commissioned by the Directorate-General (DG) for Environment (ENV) of the European Commission (Service contract No 07.0201/2016/742739/SER/ENV.D.I, duration 6 Dec 2016 - 5 Dec 2019). The overall objective is to support DG ENV with technical, scientific and socio-economic aspects of soil protection and sustainable land use, in the context of the implementation of the non-legislative pillars (awareness raising, research, integration) of the Soil Thematic Strategy and the implementation of the European Soil Partnership.

The support includes the production of six in-depth reports providing scientific background on a range of soil and soil-policy related issues in Europe, three policy briefs, logistic and organisational support for six workshops, and the organisation and provision of content to the European website and the wiki platform on soil-related policy instruments. This report is deliverable 1.5: Identification of priority areas for improving consistency and inter-operability of EU-wide and national soil monitoring and information systems

## Document Information

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| **Title** | Identification of priority areas for improving consistency and inter-operability of EU-wide and national soil monitoring and information systems |
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| **Distribution** | DG ENV |
| **Report Number** | 1.5 |

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## Document History

| **Date** | **Version** | **Prepared by** | **Organisation** | **Approved by** | **Review by** |
|---|---|---|---|---|---|
| 15-05-2019 | 0.1 | Laura Vonhögen | Deltares | | |
| 01-10-2019 | 0.2 | Laura Vonhögen | Deltares | | |
| 11-11-2019 | 1.0 | Laura Vonhögen | Deltares | Henriette Otter | Linda Maring |

# Content

# 1 Introduction

## 1.1 Aim of the report

Land and soil are under pressure, threatening their ability to deliver ecosystem services (ESS). To manage and protect these valuable resources, it is important to understand the condition of the soil and how this condition changes over time.

As soil functions and threats are not restricted by borders of individual member states (MS), there is a need for soil inventories and mapping on a European Union (EU) level. While doing so, the EU is faced with a challenge, as it is not always known which information is available in each country. It is often unclear whether countries cannot or will not contribute when input is requested. Also, if data are available and sharable within one Member State, they often lack consistency at EU-scale, making it very difficult to compare the different datasets and combine them in one map.

Soil monitoring and information systems (SMIS) are critical to store and process collected data, guarantee consistent datasets, and to enable sharing of the available information within and between countries. SMIS already exist on different levels, from global and European to national and regional systems. Unfortunately, these systems are initiated based on a broad range of incentives (e.g. controlling legislation, available funds, the choice of indicator, etc.) and hence the interoperability on an EU level is not guaranteed.

For the EU to manage the potential of our soils to deliver soil functions, for reaching set societal goals at different spatial scales and assess the impact of current and upcoming EU Directives and Regulations, action must be taken to improve the consistency and interoperability of SMIS. To achieve this goal, it is important to know what data and information MS have available, what the data and information gaps are and what is holding MS back from sharing information. These questions will be addressed in this report: What are the incentives for SMIS? What do you want to measure, who is paying, what regulation is pushing it?

## 1.2 Approach

The starting point to find the answers on the above-mentioned questions, was an inventory of current, similar initiatives (e.g. LANDMARK[1], ENVASSO[2], etc.) on a global, EU and MS level by means of a desk study. With aid of some of the key-members of these initiatives, gaps in our understanding of the why and what of these initiatives and the lessons learned were investigated.

Using earlier inventories like the *"Inventory and Assessment of Soil Protection Policy Instruments in EU Member States"* Wiki, but also by using the experience of the broad soil network and targeted investigations of our partners, we tried to fill the gaps on the availability of data and information in the MS and the barriers that withhold MS to share data.

A targeted workshop at the INSII meeting[3] (further called: SOILS4EU workshop), not only provided valuable additional information on these latter questions, but also shed light on feasible solutions and priorities.

[1] URL http://landmark2020.eu/

[2] URL https://esdac.jrc.ec.europa.eu/projects/envasso

[3] SOILS4EU workshop at 7 November 2018, during the 4th working session of the International Network of Soil Information Institutions (INSII), 6-8 November 2018, FAO Rome (López- Francos, et al., 2018)

## 1.3 Reading manual

Chapter 2 provides a brief overview on data, information and soil monitoring and information systems (SMIS) in general. Chapter 3 first provides an overview of the state of affairs of SMIS on different levels and the interaction between these levels. The focus then shifts towards individual MSs and the gaps and barriers that have been observed. Chapter 4 provides a lookout of possible solutions and priority areas. Conclusions and recommendations are included in Chapter 5.

# 2 Soil Monitoring and Information Systems

Soil Monitoring and Information Systems (SMIS) allow users to capture data and information in a systematic way, thus improving the understanding of soil processes. Increased knowledge of these processes enables sustainable management of soils, soil functions and ecosystem services. To enable sustainable soil management, it is important to understand the soil functions of different soils across Europe, and how they change overtime.

By monitoring and forecasting the condition of soil resources (data, information) and by understanding how the system can be influenced (knowledge), it is possible to make evidence-based decisions and policies on land use (action) and assess the impact of these actions on the soil system (status) (Figure 1, left).

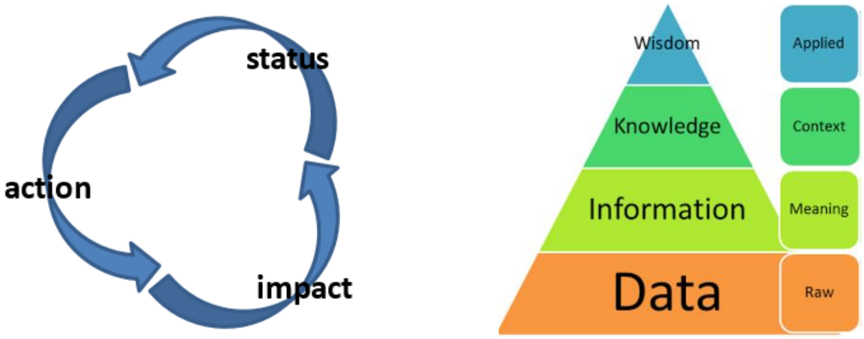



*Figure 1: Status, action, impact loop (left); DIKW Pyramid – Ackoff (right)*

*How to effectively manage data, information and knowledge to develop appropriate actions?*
Action is the result of a chain that adds meaning and context to the initial data. Thus, it is important to consider each of these building blocks individually (Figure 1, right). Data are raw facts and figures that on their own have no meaning (e.g. reading from sensors, survey facts, etc.). Information is a meaningful selection of data that has been processed (e.g. by a computer) and hence provides relevant clues on how the system works (e.g. trends). Knowledge derives from information by applying rules or context to it. It is the understanding of how the information is connected and hence how the system can be influenced. Wisdom is knowledge applied in action, thus knowledge should lead to well-founded deeds or decisions (measures must be taken to change the trend).

For this approach to work, it is necessary to measure baseline (status based on one-off measurement), trend (based on at least two, preferably more, measurements or monitoring campaigns), background and threshold values.

Background values reflect values, trends and processes that occur in natural or "accepted" conditions. As soil is continuously changing in space and time, background values enable the investigation of anomalous or relative changes resulting from, for example, increased anthropogenic influences.
The threshold value should be determined for each indicator, depending on the effect of a soil indicator on its soil function. The threshold value can either be a critical value of the indicator itself or the critical value for the soil function. In the latter case, the threshold value can relate to a clear decline in land quality or to a significant impact of degradation on land productivity or environmental functions. (after Lynden *et al*., 2004).

## 2.1 Data

Sometimes the main incentive of measuring or monitoring campaigns is to hoard data. The campaigns are executed without proper consideration of the information and knowledge that is needed to make the appropriate decisions, set up actions and policies. A proper incentive is that the goal (obtain, remain or lose soil functions) is driving the data collection, processing and information needs.
Therefore, it is important to determine beforehand which soils functions are relevant at specific locations, which data and information is needed to determine the status of the goal, and which indicators or attributes are needed to be measured, estimated or modelled (after Maring *et al*., 2018).

*Indicators / attributes*

The type of data that is required depends on the goal why this information is needed for a specific location. In case of soils, a soil attribute or indicator provides key data to facilitate the quantification of the soil functions. A soil attribute can be described as a characteristic or set of characteristics of the soil, which can be measured, estimated (expert judgement), or modelled. This information can be used to quantify the performance of soil functions (van Leeuwen *et al*., 2017).

In the ENVASSO and LANDMARK projects main indicators and attributes have been identified and defined to enable quantification of nine soil threats (ENVASSO, Table 1) and five soil functions (LANDMARK, Table 2). A more elaborate overview of these projects can be found in chapter 3.1.3.

| Soil threat | Key Issue | Indicator |
|---|---|---|
| Erosion | Water erosion | Soil loss by rill, inter-rill, and sheet erosion |
| Decline Soil Organic Matter | Soil organic matter status | Topsoil organic carbon content |
| | | SOC stocks |
| Contamination | Diffuse contamination by inorganic contaminants | Heavy metal contents |
| | Diffuse contamination by soil acidifying substances | Critical load exceedance by S and N |
| | local soil contamination. | Progress management of cont. sites |
| Compaction | Compaction and structural degradation | Density (bulk density, or packing density, total porosity) |
| | | Air-filled pore volume at a specified suction |
| | Causes of soil compaction | Vulnerability to compaction (estimated) |
| Salinisation | Soil salinisation | Salt profile |
| | Sodification | Exchangeable sodium percentage (ESP) |
| | Potential soil salinisation/sodification | Potential salt sources |
| Decline in biodiversity | Species diversity | Earthworms and fresh biomass |
| | Species diversity | Collembola diversity |
| | Biological functions | Microbial respiration |
| Soil sealing | Soil Sealing | Sealed Area |
| | Land consumption | land take (CLC) |
| | Bona Fide redevelopment | New settlement area on previously developed land |
| Landslides and flooding | Landslide activity | Occurrence |
| | Landslide activity | Volume/weight displaced material |
| | Vulnerability to land sliding | Hazard assessment |
| Desertification | Desertification | Land area at risk |
| | Desertification | Land area burnt by wildfires |

*Table 1: ENVASSO – Soil threats*

| Soil function | Main attribute |
|---|---|
| **Primary production** | Organic C/N/P/K |
| | Soil moisture |
| | Bulk density |
| | pH |
| **Water Regulation** | Organic C/N/P/K |
| | Drainage Class |
| | Earthworm community |
| | Bulk density |
| **C sequestration** | Microbial biomass |
| | Organic C/N/P/K |
| | C mineralisation rate |
| | Drainage class |
| **Biodiversity** | Microbial biomass |
| | Earthworm community |
| | Bacterial community |
| | Microarthropod community |
| **Nutrient cycling** | Organic C/N/P/K |
| | pH |
| | C:N ratio |
| | C mineralisation rate |

*Table 2: LANDMARK - Soil functions*

*Soil Monitoring Network*

Data (field or desktop) collected using a Soil Monitoring Network (SMN) and stored in a SMIS are more likely to be of use for soil inventories and mapping on an EU-level. O'Sullivan *et al*. (2017) even states that the achievement of a legally binding framework for soil protection relies on the implementation of a soil monitoring network (SMN) that can detect changes to soil quality over time.

A SMN is a set of sites where periodic documentation and assessment of chemical, physical and biological soil parameters is carried out using specific attributes (after Morvan *et al.,* 2008). However, van Leeuwen *et al*. (2017) discovered that within the EU, predominantly chemical soil parameters were measured using a wide range of measurement methods.

*Data collection*

Whether data are characteristic for a specific location and ready to be used, largely depends on a couple of considerations beforehand:

- Sampling campaign:
    - Number of samples; the more data points are used, the better the reliability and accuracy of the product.
    - Site area; depends on the homogeneity of soil types and land use.
    - Sampling strategy and resolution; how and where (including georeferenced) samples are taken.
    - Sampling design; which indicators/attributes are measured by which methods.
    - Time interval of repetition (depending on type of indicator/attribute).
- Documentation of the data, methodology and the metadata

*Data quality*

The quality of data is essential for reliable information. If data input is poor (i.e. corrupt, inaccurate, etc.), the resulting information will also be poor. Thus, it is important to consider the following when using data:

1) Is the data fit for purpose; is the data suitable to answer the question asked?
2) Is the data accurate (technical)?
3) Is the data biased; e.g. non-random selection when sampling, reporting data in misleading groupings, only collecting data that confirm predefined hypotheses?

Data that is available with a low(er) quality is often better than no data at all. Sharing not only the data but also metadata renders it possible to assess the uncertainty of the data, which also needs to be communicated when converting the data into information, so that users are aware of the uncertainty.

*Data storage*

It is important to store the original data together with the metadata, informing any user on how, when and why the data was collected. After storing the raw data, quality checks should be performed. If such a check requires adjustment of the data, these data should be stored as a new dataset, including an overview of the adjustments done.

*Data accessibility*

If data is publicly available, it is often not easy to find this data as it is stored in different (online) databases or only available in paper reports, etc. How can information be presented and disseminated in a user-friendly manner? How can information be stored accessibly for all stakeholders?

## 2.2 Information

Individual pieces of data are rarely useful alone. Therefore, the collected and modelled data needs to be converted into information (e.g. soil maps, graphs, tables) showing temporal and spatial trends of the soil functions. Preferable, digital soil mapping is used, so data and information are available online for different users. Cooperation is needed between geodata-managers, scientists (who collect the data and convert it into required information) and the users of this information (policy makers and land managers responsible for sustainable land management) (after Maring *et al.*, 2018) (Figure 2). Based on obtained knowledge, actions can be specified to reach the set of (societal) goals and ambitions for sustainable land management.

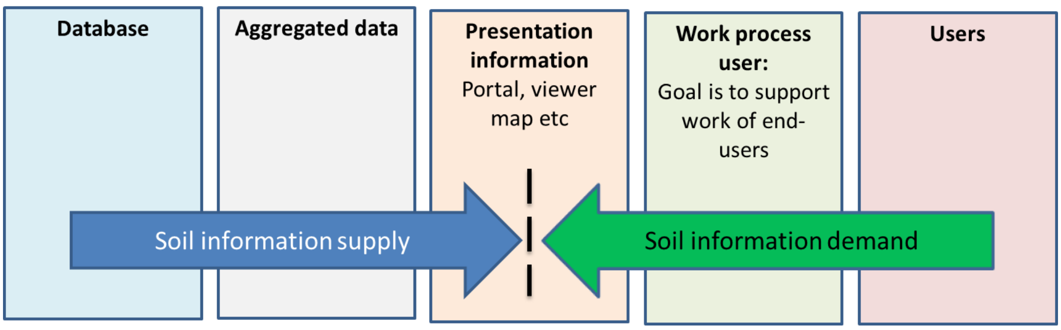



*Figure 2: The chain from data to information (adapted picture from MMG advies, The Netherlands)*

*Storage*

Not only data but also information needs to be stored in a systematic way, including proper documentation (metadata) on how the information was generated and what can or cannot be concluded from this information. For example: a map showing potential areas for acid soils based on technical information (e.g. amount of rainfall, type of plant growth, weathering of soils) gives a different picture and different discussion than a map which also includes policy and regulation (where is the use of fertilizer limited or prohibited). Other ways to prevent misuse of data is for example to limit the zoom possibility of online viewers, as the spatial scale on which information is usable depends on the resolution of the data.

# 3 State of affairs

Soil monitoring and information systems (SMIS) are critical to store and process collected data, guarantee consistent datasets and enable sharing of the available information within and between countries. SMIS exist on different levels, from global and European to national and regional systems and are initiated based on a broad range of incentives.

## 3.1 Level of information available

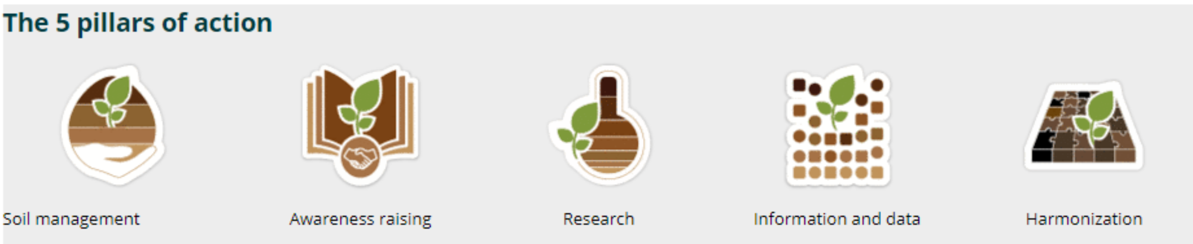
In this chapter an overview will be given of networks and recent SMIS on Global and EU-level that are relevant for this report.

### 3.1.1 Global level: Global Soil Partnership (GSP)

Global Soil Partnership (GSP)

- Global Soil Information System (GLOSIS),
  - Product: Global Soil Organic Carbon Map (GSOC map)
- International Soil Information Institutions (INSII)
  - Global Soils Spatial Data Infrastructure Centre (GSSDIC)
  - System for monitoring, forecasting & reporting on the status of global soil resources (SoilSTAT)

The Global Soil Partnership[4] was established in December 2012 as a mechanism to develop a strong interactive partnership and enhanced collaboration and synergy of efforts between all stakeholders. From land users through to policy makers, one of the key objectives of the GSP is to promote sustainable management of soils. The mandate of the GSP is to improve governance of the limited soil resources of the planet in order to guarantee agriculturally productive soils for a food secure world, as well as to support other essential ecosystem services, in accordance with the sovereign right of each State over its natural resources. To achieve its mandate, the GSP addresses five pillars of action, to be implemented in collaboration with its (macro) regional soil partnerships: 1) Soil Management, 2) Awareness raising, 3) Research, 4) Information and data, 5) Harmonisation.




Pillars 4 and 5 are the most relevant ones for this report:
**Pillar 4** strives to "Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines."
**Pillar 5** strives to "Harmonization of methods, measurements and indicators for the sustainable management and protection of soil resources."

[4] URL http://www.fao.org/global-soil-partnership/en/

The EU and MS are members of the GSP and contribute to its SMIS and harmonization. Since the inception of the GSP, additional budgets have been made available for GSP activities, among which by the European Commission (EC).

### *GLOSIS: Global Soil Information System*

**SMIS:** The goal of GLOSIS[5] is to enhance quantity and quality of soil data and information at global level. It will be based on soil data sets provided by national and international soil information institutions according to product specifications. GLOSIS is built on a country driven approach. Therefore, the improvement of soil information on the global level comes from the improvement on the national level, through support of the cooperation between national soil information institutions (INSII; International Network of Soil Information Institutions). The first product of the GLOSIS and a proof of concept of the distributed approach is the Global Soil Organic Carbon Map (GSOC map) which was developed jointly by the countries within the GLOSIS framework (Figure 3).

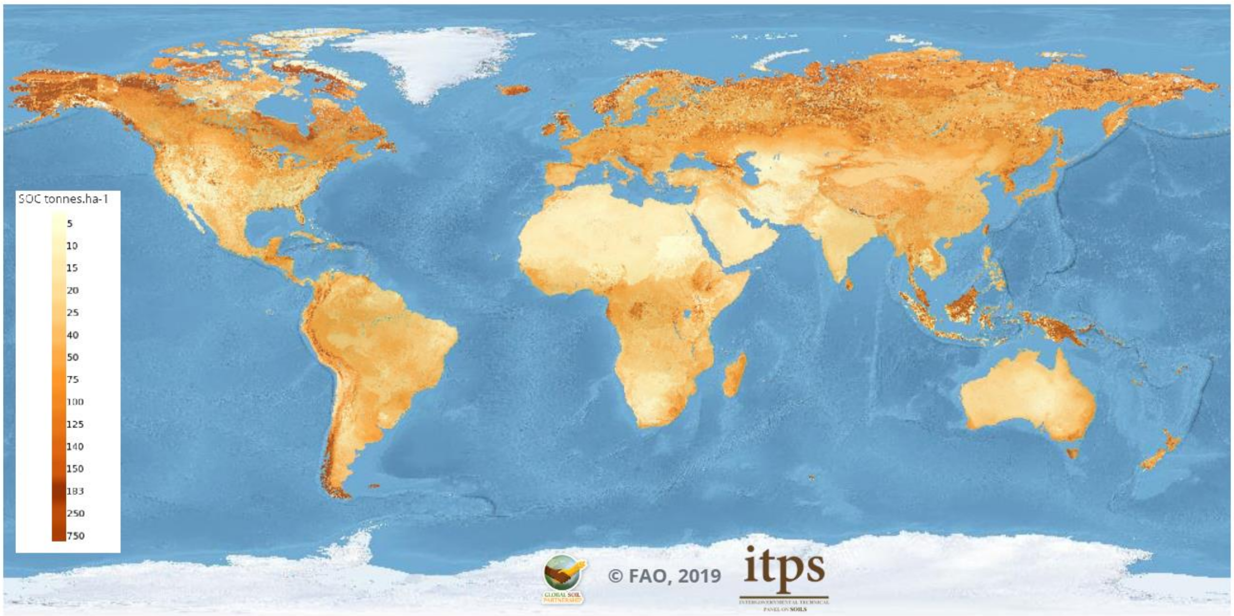



*Figure 3: Global Soil Organic Carbon Map (GSOC map, v1.5.0). URL http://54.229.242.119/GSOCmap/#*

Each GSP member (governmental and other partner organisations) willing to support the 'Pillar 4 - Plan of Action', may select one or several institutions to participate in the implementation of this Plan of Action. These institutions already possess, or will develop, the technical ability to develop and share selected national soil information and data. Main components of GLOSIS include: development of SoilSTAT (next paragraph), soil profile and point data, global soil polygon coverage, global grids of soil properties, and capacity development programme on soil information.

[5] URL http://www.fao.org/global-soil-partnership/pillars-action/4-information-data/glosis/en/

#### *SoilSTAT*

**SMIS**: SoilSTAT[6] is a system for monitoring, forecasting and reporting periodically on the status of global soil resources. In November 2018 a concept note of SoilSTAT was prepared and shared during the 4th working session of the International Network of Soil Information Institutions (INSII), first testing is expected in 2020. SoilSTAT will be based on indicators describing the current condition of, and trends in, soil quality. Indicators will cover soil threats such as erosion, compaction, salinisation and the loss of soil organic matter. It will build on baseline inventories and soil monitoring systems established by countries. It is expected to evolve as the common denominator for national systems in a global effort to share harmonized information on indicators of soil health.

#### *GLOSOLAN: Global Soil Laboratory Network*

**Network**: The main task of Pillar 5 of the GSP is to build an over-arching system for harmonized soil characterisation. GLOSOLAN[7] is aiming to strengthen the performance of laboratories in support of the harmonization of soil data sets and information towards the development of global standards. Basically, every involved country can identify one or several leading soil laboratories, which may act as national reference centres for soil analysis. The harmonisation of soil analysis is a critical component of making soil information comparable and interpretable across laboratories, countries and (macro)regions.

### 3.1.2 European Union level: networks, SMIS and directives

The European Union, often extended to other European countries, already has multiple, longstanding networks for valuable data exchange and collaboration. The networks mentioned in this chapter are relevant as they are also responsible for the collection and storage of soil data and information. Besides, several soil monitoring system programs are mentioned that are either initiated by the EU or an EU directive. Finally, paragraph 3.1.3 focusses on soil monitoring systems on EU-level that have a scientific incentive.

European Environment Agency (EEA)
- European Environment Information and Observation Network (EIONET)
- the European Topic Centre on Urban, Land and Soil systems (ETC/ULS), is supporting the EEA and is embedded and part of EIONET

The European Environment Agency (EEA)[8] is an agency of the European Union, whose task is to provide sound, independent information on the environment. The EEA aims to support sustainable development by helping to achieve significant and measurable improvement in Europe's environment, through the provision of timely, targeted, relevant and reliable information to policymaking agents and the public.

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6 URL http://www.fao.org/land-water/databases-and-software/soilstat/en/
7 URL http://www.fao.org/global-soil-partnership/pillars-action/5-harmonization/glosolan/en/
8 URL http://www.eea.europa.eu/

The EEA's mandate is to: 1) help the community, member and cooperating countries to make informed decisions about improving the environment, integrating environmental considerations into economic policies and moving towards sustainability, and 2) coordinate the European environment information and observation network (EIONET). Finally, the website of the EEA (eea.europa.eu) is one of the most comprehensive public environmental information services on the internet. It contains the full texts of all reports, summaries and articles, as are interactive graphs and map-based applications as well as the datasets and background information supporting the reports.

*EIONET: European Environment Information and Observation Network*

**Network**: EIONET, the European Environmental Information and Observation Network, is a partnership network of the EEA and its 33 members and six cooperating countries. The EEA is responsible for developing EIONET and coordinating its activities, together with national focal points (NFPs) in the countries, which are based in national environment agencies or environment ministries. The NFPs are responsible for coordinating networks of national reference centres (NRCs), bringing together experts from national institutions and other bodies involved in environmental information. The EIONET portal[9] provides a platform for networking and information sharing, and tools for collection and management of environmental data and information.

*ETC/ULS: European Topic Centre on Urban, Land and Soil systems*

**Data:** As the further sustainable growth of urban areas represents a challenge both for internal management and planning as well as for the surrounding environment (land, soil, biodiversity), regional assessments of rural, mountainous, urban or coastal areas and impact analysis of policies are needed. ETC/ULS[10] is supporting the European Environment Agency in monitoring of urban development in Europe, creating seamless European wide spatial reference data, and develop and analyse various land related indicators. Besides, this ETC is involved in developing open source solutions to follow the INSPIRE directive[11] and the European policy on Shared Environmental Information System (SEIS) fitting into a network of distributed resources and simplifying the data access for the public. ETC/ULS is processor of seven downloadable datasets about Europe's environments e.g. European Forest Areas based on Copernicus data, Corine Land Cover Accounting Layers, Management related pressures on forest ecosystems, etc.

*CLMS: Copernicus Land Monitoring Services*

**Data and Information:** Copernicus is a European programme for monitoring the earth, in which data is collected by earth observation satellites and combined with observation data from sensor networks on the earth's surface. The Copernicus Land Monitoring Service (CLMS)[12] has been jointly implemented by the European Environment Agency (EEA) and the Joint Research Centre (JRC) since 2011. CLMS provides geographical information on land, including land use, land cover characteristics and changes, vegetation state, water cycle and earth surface energy variables.

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[9] URL https://www.eionet.europa.eu/
[10] URL https://uls.eionet.europa.eu/
[11] Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community
[12] URL https://land.copernicus.eu/

On the pan-European scale the High-Resolution Layers (HRL) provide information about different land cover characteristics and is complementary to land-cover mapping datasets of CORINE[13] (Coordination of Information on the Environment). The data are freely accessible by any citizen or organisation in the world.

**European Commission (EC)**

- Joint Research Centre (JRC), hosting:
  - European Soil Data Centre (ESDAC)
  - European Soil Bureau network (ESBN)
- Land Use / Cover Area frame statistical Survey (LUCAS)
- Infrastructure for Spatial Information in Europe (INSPIRE)

*JRC: Joint Research Centre (JRC)*

**Information to knowledge:** The JRC supports EU policies with independent scientific evidence throughout the whole policy cycle. They create, manage and make sense of knowledge and develop innovative tools that are available to policy makers.[14] The Joint Research Centre is partnering with policy departments across the European Commission to operate six Knowledge Centres for: Food Fraud and Quality, Territorial Policies, Migration and Demography, Disaster Risk Management, Bio-economy, and Global Food Security. The JRC provides assessments of available soil resources at the global scale and provides soil data and information linked to climate change, biodiversity and desertification, for use by the European Commission and others. The JRC also helps the EU Member States to fulfil their assessment obligations regarding their soil resources.

*ESDAC: European Soil Data Centre*

**Data and Information:** ESDAC[15] is the thematic centre for soil related data in Europe and is hosted by JRC. Its ambition is to be the single reference point for and to host all relevant soil data and information at European level. It contains several resources that are organized and presented in various ways: datasets, services/applications, maps, documents, events, projects and external links. ESDAC datasets are organized in four broad categories: A first category contains the European Soil Database (ESDB), datasets that have been derived with the help of the ESDB and general European datasets that contain soil properties. A second category offers data that are related to soil functions and soil threats (erosion, soil organic carbon, landslides, compaction, salinisation, soil biodiversity, contaminated sites, soil sealing, etc.). A third category offers soil point data[16] (LUCAS, Land Use / Cover Area frame statistical Survey and SPADE, Soil Profile Analytical Database of Europe). A fourth category contains data that stem from projects.

[13] URL https://www.eea.europa.eu/publications/COR0-landcover
[14] URL https://ec.europa.eu/jrc/en/about/jrc-in-brief
[15] URL https://esdac.jrc.ec.europa.eu/
[16] URL https://esdac.jrc.ec.europa.eu/resource-type/soil-point-data

*ESBN: European Soil Bureau network*

**Network:** The European Soil Bureau Network (ESBN)[17], is a Network of "Centres of Excellence". Its main task is to collect, harmonise, organise and distribute soil information for Europe. Since October 2000, the ESBN has become part of the Land Management Unit of the Environment Institute (IES), one of the four institutes at the Joint Research Centre (JRC).

*ESP: European Soil Partnership*

**Network:** The Global Soil Partnership (GSP) is supported by 9 (macro) regional soil partnerships (RSPs). In Europe the continental-specific aspects are considered by the European Soil Partnership (ESP)[18]. The ESP acts as an operational arm of the GSP, supporting continental soil policies and research, and building the bridge among many national and European-level activities supporting healthy soils. In the decision-making process of the ESP, the national focal points (NFPs) from the European countries play a prominent role. The ESP has set up a Regional Implementation Plan (RIP), with clear implementation activities for all pillars for the period 2017-2020.

The Europe-specific conclusions are that the successful implementation of GSP Pillar 4 depends on national/regional soil data being made accessible and, to a certain extent, harmonized at European and global levels. Besides, mechanisms need to be put in place to encourage data sharing, minimise infringements of data sovereignty and protect intellectual property. For Pillar 5 the harmonisation of terminology (soil classification and description), methods, indicators and evaluation methods, and models are needed to develop (macro) regional policies for sustainable management of soil resources in Europe. It is recommended to make use of competencies in previous and existing networks (ESBN, EIONET), soil data centres (ESDAC, ETC/ULS) and directives (e.g. INSPIRE), to build a European infrastructure for environmental spatial data sets, using web services. (ESP Secretariat, 2017).

LUCAS

- **L**and **U**se/**C**over **A**rea frame statistical **S**urvey (LUCAS)
- Topsoil survey targeting physio-chemical properties
- ~45,000 soil samples in Europe
- measurements in 2009/2012 and 2015, next planned in 2018

*LUCAS: Land Use / Cover Area frame statistical Survey*

**SMIS:** LUCAS[19] is an EU-wide land use program, initiated in 2009 by the European Statistical Office (EUROSTAT) in close cooperation with the DG-AGRI and with the technical support of the JRC. LUCAS organises regular, harmonised surveys across all Member States to gather information on land cover and land use. The main aim of the LUCAS Soil programme was to create the first harmonized and comparable dataset of topsoil properties at the EU scale.

[17] URL https://esdac.jrc.ec.europa.eu/networkcooperations/european-soil-bureau-network
[18] URL https://esdac.jrc.ec.europa.eu/networkcooperations/european-soil-partnership
[19] URL https://esdac.jrc.ec.europa.eu/projects/lucas

LUCAS focuses on the methodology used to collect the information. Estimates of the area occupied by different land use or land cover types are computed on the basis of observations taken at approx. 260,000 permanent monitoring locations throughout the EU rather than mapping the entire area under investigation. The number of points selected in each country was proportional to both the surface area and the percentage of each type of land use and cover, according to the classes proposed by the CORINE Land Cover dataset (CLC, 2006). Hence, by repeating the survey every few years, changes to land use can be identified.

In 2009, the European Commission extended the periodic survey to sample and analyse the main properties of topsoil in 23 Member States of the European Union (EU). For this survey a selection of approximately 20,000 points was made for the collection of soil samples. This topsoil survey represents the first attempt to build a consistent spatial database of the soil cover across the EU based on standard sampling and analytical procedures, with the analysis of all soil samples being carried out in a single laboratory.
Since this first edition in 2009 topsoil samples have been analysed for the percentage of coarse fragments, particle size distribution, pH, soil organic carbon, carbonates, total nitrogen, extractable nutrients, cation exchange capacity and multispectral properties. In 2012 trace elements were included. The third edition (2018) also covers visual assessment of soil erosion, measurement of the thickness of the organic horizon in organic-rich soil, soil bulk density (in 9000 locations) and soil biodiversity in selected 1000 locations (targeted at Bacteria and Archaea, Fungi, Eukaryotes, nematodes, arthropods, earthworms, metagenomics). Soil information can be correlated to land cover (crop) and land use type described in the sampling location. Soil information from 2009 have been released to public whereas analyses of samples collected during 2015 are ongoing and data became available at the middle of 2018

Users: universities (50%), research organisations (23%), public administrations (11%) and private sector (12%)

INSPIRE

- **IN**frastructure for **SP**atial **I**nfo**R**mation in **E**urope
- Directive that aims for one spatial data infrastructure within Europe,
- 'Soil' is one out of 34 spatial data themes
- Can be anything related to soil

*INSPIRE: Infrastructure for Spatial Information in Europe*

**Directive & SMIS:** The 'INSPIRE Directive' came into force in 2007, aiming to share environmental spatial information of all MS in a harmonized way. The directive aims to create a European Union spatial data infrastructure for the purposes of EU environmental policies and policies or activities, which may have an impact on the environment. The Directive addresses 34 spatial data themes needed for environmental applications. Based on the definition given by the Directive (2007/2/EC), the scope for the soil theme covers:
a) Soil inventories, providing one-off assessments of soil conditions and/or soil properties at certain locations and at a specific point in time, and allow soil monitoring, providing a series of assessments showing how soil conditions and/or properties change over time.

b) Soil mapping, providing a spatial presentation of the properties linked to the soils, including soil types; typically, soil maps are derived with the help of data available in soil inventories. Also, other soil related information derived from soil properties, possibly in combination with non-soil data are within the scope.

### 3.1.3 European Union level: Scientific projects

*FP6 ENVASSO: ENVironmental ASsessment of Soil for mOnitoring*

**SMIS**: ENVASSO[20] (2005-2008) was funded as Scientific Support to Policy (SSP) under the European Commission 6th Framework Programme. The objective of the ENVASSO project was to define a monitoring system, describe its potential implementation and develop a framework for European soils monitoring. Indicators (Table 1) were selected to monitor threats to soil, including erosion, organic matter decline, contamination, compaction, salinisation, decline in biodiversity, soil sealing, landslides and desertification. A monitoring network covering different soil types and land uses was subsequently established. Existing networks were incorporated in the developed system, which was enriched with additional sites. Data management requirements were defined, and a prototype database was developed. The alternative procedures for estimating indicators were tested in pilot studies, which covered representative regions and land uses. The existing methods for monitoring some of priority indicators proved to be inadequate or were not available, therefore new approaches were needed e.g. for a continental scale estimation of wind and tillage erosion and estimation of peat stocks. As a result, a two-tiered approach was recommended. The first tier established a network for estimation of the easily identifiable indicators. The second tier consisted of a sub-set of the first tier sites with more extended and intensive monitoring, for cases when measuring procedures were too demanding for general implementation. The ENVASSO Consortium, comprised 37 partners drawn from 25 EU Member States. The key deliverables have been hosted on ESDAC after the end of the project.

*H2020 LANDMARK: LAND Management, Assessment, Research, Knowledge base project*

**Indicators and SMIS**: LANDMARK[21] (2015-2019) is a pan-European multi-actor consortium of leading academic and applied research institutes, chambers of agriculture and policy makers that has developed a coherent framework for soil management aimed at sustainable food production across Europe.

The LANDMARK project builds on the concept that soils are a finite resource that provides a range of ecosystem services known as "soil functions". Functions relating to agriculture include: primary productivity, water regulation & purification, carbon-sequestration & regulation, habitat for biodiversity and nutrient provision & cycling. Trade-offs between these functions may occur: for example, management aimed at maximising primary production may inadvertently affect the 'water purification' or 'habitat' functions. This has led to conflicting management recommendations and policy initiatives. There is now an urgent need to develop a coherent scientific and practical framework for the sustainable management of soils.

[20] URL https://esdac.jrc.ec.europa.eu/projects/envasso & https://cordis.europa.eu/project/rcn/78618/reporting/en

[21] URL http://landmark2020.eu/ & https://cordis.europa.eu/project/rcn/193323/factsheet/en

LANDMARK will uniquely respond to the breadth of this challenge by delivering (through multi-actor development):
1. Local scale: A toolkit for farmers with cost-effective, practical measures for sustainable (and context specific) soil management.
2. Regional scale: A blueprint for a soil monitoring scheme, using harmonised indicators (Table 2): this will facilitate the assessment of soil functions for different soil types and land-uses for all major EU climatic zones.
3. EU scale: An assessment of EU policy instruments for incentivising sustainable land management.

There have been many individual research initiatives limited to a local scale, that either address the management & assessment of individual soil functions or address multiple soil functions. LANDMARK will build on these existing R&D initiatives: the consortium partners bring together a wide range of significant national and EU datasets, with the ambition of developing an interdisciplinary scientific framework for sustainable soil management.

*FP7 RECARE*

**Soil policies and mapping**: The RECARE project[22] (2014-2018) was funded under the European Union 7th Framework Programme. Although there is a large body of knowledge available on soil threats in Europe, this knowledge is fragmented and incomplete, in particular the complexity and functioning of soil systems and their interaction with human activities. The main aim of the RECARE project was to develop effective prevention, remediation and restoration measures using an innovative trans-disciplinary approach, actively integrating and advancing knowledge of stakeholders and scientists in 17 case studies, covering a range of soil threats in different bio-physical and socio-economic environments across Europe. Within these case study sites,

i) the current state of degradation and conservation is assessed using a new methodology, based on the WOCAT[23] mapping procedure,
ii) impacts of degradation and conservation on soil functions and ecosystem services were quantified in a harmonized, spatially explicit way, accounting for costs and benefits, and possible trade-offs,
iii) prevention, remediation and restoration measures were selected and implemented by stakeholders in a participatory process will be evaluated regarding efficacy,
iv) the applicability and impact of these measures at the European level were assessed using a new integrated bio-physical and socio-economic model, accounting for land use dynamics as a result of for instance economic development and policies. Existing national and EU policies were reviewed and compared to identify potential incoherence, contradictions and synergies. Policy messages were formulated based on the Case Study results and their integration at European level. A comprehensive dissemination and communication strategy, including the development of a web-based Dissemination and Communication Hub, accompanied the other activities to ensure that project results are disseminated to a variety of stakeholders at the right time and in the appropriate formats to stimulate renewed care for European soils.

[22] URL https://www.recare-project.eu/
[23] WOCAT: World Overview of Conservation Approaches and Technologies (URL https://www.wocat.net/en/)

The main results of the RECARE project are that through participation with stakeholders it is possible to implement practical solutions to many of the problems that are degrading and damaging the soil. The solutions discussed focus on a range of management practices, such as the use of mulching with forestry residues or straw to prevent soil erosion after forest fires, and technological solutions, such as the use of submerged drains to avoid the loss of organic matter in peat soils.

## 3.2 SMIS in Members States (MS):

The networks and initiatives (on global and/or EU-level) mentioned in the previous chapters are very difficult to compare, as they all have their specific incentives and types of output. However, from the contribution of individual EU Member States to mentioned networks and initiatives (Table 3), one could conclude that almost every MS has some soil related data or information available on national level. Still, the format (data point, maps, reports) in which the data and information is available, as well as the incentive for the data collection, differs between and within the individual MS. This is confirmed by the analyses of Frelih-Larsen *et al*. (2017) and summarized in the so-called Soil Wiki[24].

*Overview from the Soil Wiki*

With the Soil Wiki, an effort was already made to create an overview of what data and information is available at Member State level concerning soils. However, the relevance of this study for this report is complicated, as the Soil Wiki contains a wide range of policy instruments, including soil monitoring tools, but also regulations, decrees, registers, etc. Hence, it is not limited to SMN or SMIS alone. Besides, the Soil Wiki is not complete, as each page had to cover a lot of detail[25] and the MSs contribution to this work was voluntary. As a result, some countries are blank, or the number of policy instruments is incomplete, depending on the knowledge and effort of the approached contact and/or organization.

*Thus, it is very difficult to create an overview of all existing data and information at MS level.* There are many and sometimes large differences between MS on the topic of SMIS. Some countries have established experience with SMIS, while others do not, or are just getting started. There are also differences in availability and findability of data and in objectives for setting up a SMIS.

The next paragraph attempts to give an overview of what is available, to gain some insight in the history and current state of SMN and SMIS in the individual MS. The given overview is not exhaustive; not all MS are discussed, as the focus was on countries that did not contribute or had varying contributions to mentioned initiatives.

[24] Updated Inventory and Assessment of Soil Protection Policy Instruments in EU Member States (Ecologic, 2017)

[25] For each MS, a page was created in the Soil Wiki that followed the same structure of sub-headings. These include: Brief description of the instrument, Institution(s) responsible for the implementation and/or evaluation of the policy instrument, Type of instrument, Status of policy instrument, Budget dedicated to soil protection, Territorial coverage, Sectoral coverage, Soil threats addressed by instrument, Soil functions addressed by instrument, Land cover classes addressed by the instrument, Evaluations of the instrument, Monitoring mechanisms and indicators, Soil protection measures promoted through the policy instrument, Which EU-wide policy instrument(s) does the instrument implement?, National Initiatives, Links to reference documents

The level of confidence of the information is not high due to possible incompleteness or risk of being outdated, because of the exclusive use of publicly available information. Literature, targeted investigations of our partners and input from the participants of the SOILS4EU workshop were used to fill in the gaps on the availability of data and information in the MS and, when possible, the barriers that withhold MS to share data.

| | GSP | LUCAS 2009 | LUCAS 2015 | LUCAS 2018 | INSPIRE- Metadata | INSPIRE-viewable | INSPIRE-downloac | ENVASSO (2008) | LANDMARK (2017) | Soil WIKI (2017) |
|---|---|---|---|---|---|---|---|---|---|---|
| | GSOC map (origin) | ~20000 (2009) + ~2000 (2012) points | ~22000 (EU) + ~1000 (outside EU) points | ~26000 points (28 EU countries) | Data/ maps/ reports | Data/ maps/ reports | Data/ maps/ reports | Monitoring site densit | Physical, biological, chemica | Policy instruments |
| Austria | country | + | + | + | 9 | 9 | 8 | + | + | - |
| Belgium | country | + | + | + | 16 | 10 | 0 | + | + | + |
| Bulgaria | LUCAS | added in 2012 | + | + | 0 | 0 | 0 | + | + | + |
| Croatia | - | not a MS | + | + | 0 | 0 | 0 | | - | + |
| Cyprus | LUCAS | - | + | + | 0 | 0 | 0 | | ? | + |
| Czech Republic | LUCAS | + | + | + | 2 | 2 | 0 | + | - | + |
| Denmark | country | + | + | + | 2 | 0 | 0 | + | - | 1 |
| Estonia | LUCAS | + | + | + | 2 | 1 | 0 | + | - | + |
| Finland | country | + | + | + | 4 | 0 | 0 | fine | - | + |
| France | country | + | + | + | 803 | 0 | 34 | medium | + | + |
| Germany | country | + | + | + | 290 | 0 | 65 | medium | + | + |
| Greece | LUCAS | + | + | + | 0 | 0 | 0 | few | grey - No SMN | 0 |
| Hungary | country | + | + | + | 0 | 0 | 0 | + | + | + |
| Ireland | LUCAS | + | + | + | 0 | 0 | 0 | + | + | + |
| Italy | country | + | + | + | 300 | 1 | 0 | few | + | + |
| Latvia | LUCAS | + | + | + | 3 | 0 | 0 | medium | - | + |
| Lithuania | LUCAS | + | + | + | 2 | 0 | 0 | medium | - | + |
| Luxembourg | country | + | + | + | 9 | 1 | 9 | medium | - | + |
| Malta | LUCAS | + | + | + | 1 | 1 | 1 | few | ? | + |
| Netherlands | country | + | + | + | 3 | 3 | 0 | + | + | 2 |
| Poland | LUCAS | + | + | + | 8 | 0 | 3 | medium | - | 1 |
| Portugal | LUCAS | + | + | + | 10 | 1 | 1 | fine | + | - |
| Romania | LUCAS | added in 2012 | + | + | 4 | 0 | 0 | + | - | + |
| Slovakia | country | + | + | + | 8 | 0 | 0 | + | - | + |
| Slovenia | country | + | + | + | 1 | 0 | 0 | + | + | + |
| Spain | LUCAS | + | + | + | 5 | 1 | 0 | few | grey - No SMN | + |
| Sweden | country | + | + | + | 1 | 1 | 0 | medium | + | + |
| UK | country | + | + | + | 133 | 1 | 2 | + | + | + |
| Switserland | - | - | + | - | 1 | 0 | 0 | - | + | + |
| Liechtenstein | - | ? | ? | ? | 1 | 0 | 0 | | ? | - |
| Norway | - | - | - | - | 3 | 0 | 0 | medium | - | - |
| Iceland | LUCAS | - | - | - | 1 | 0 | 0 | | + | - |

*Table 3: Contribution of individual EU Member States (MS) to networks and initiatives mentioned in chapter 3.1. Colours of the MS are indicative for the area within the EU: Central and western Europe (green), northern Europe (white), southern Europe (yellow), eastern Europe (blue), and outside EU (grey). Colours in the main table are indicative for the amount of contribution done for each network and initiative: red is no contribution, orange and yellow are limited, green is major contribution, and white is unknown. Contribution to INSPIRE changes daily, status mentioned is of 01 April 2019.*

### 3.2.1 Observations from comparison between countries

The starting point of this paragraph was the contribution of the individual to the networks and initiatives mentioned in chapter 3.1 (Table 3). By investigating the history and current state of SMN and SMIS for the MS that stood out in this overview, we tried to shed light on what is holding MS back from sharing data and information on a European level.

*Central and western Europe*

A number of countries (Austria, Belgium, France, Germany, Luxembourg, Netherlands, Ireland and the UK) seem to have an SMN through which they collect data related to soils and which they are willing to share. The following paragraphs elaborate on the situation in Germany, France, UK and Ireland.

**Germany** has extensive national soil monitoring managed by the Environmental Protection Agency (Umweltbundesamt, UBA) and information networks for soil protection and for contaminated sites such as the "LABO" (Federal/State soil protection working group) or "The contaminated-sites standing committee" (ALA). Based on information provided by UBA[26] about 800 measure points on soil data across the country exist; they are based on cropland, grassland, forests and other sites (e.g. settlements). Data are gathered and stored for monitoring purposes by the federal states (due to the decentralised political system) but are also more or less regularly forwarded to the UBA to be stored in a knowledge base. They measure data on climate, deposition, soil water, groundwater, soil biology, emissions, imissions, pollutant infiltration and discharge and substance conversion (Glante *et al.*, 2011). Reports / analysis from soil monitoring are published by the federal states[27] but also by the UBA. The UBA also commissioned a study for developing a systematic, comprehensive and federal states overarching documentation of requested investigation methods (see Jacobs *et al.*, 2018 on more details of the study).
In addition to the national soil monitoring, Germany has a long history of agricultural long-term field studies, some of them dating back to more than 100 years. The BonaRes research project provides an updated map of the local and specific information of the agricultural long-term field studies in Germany.[28] The Thünen Institute just published the results of the first nationwide consistent and comparable database concerning organic carbon in agricultural soils in Germany (Jacobs *et al.*, 2018).

Since 2000, **France** has a very comprehensive Soil Quality Monitoring System, the "Réseau de Mesures de la Qualité des Sols" (RMQS). Every fifteen years, soil samples, measurements and observations are made at 2240 sites across the country, which are spread evenly across of a 16 x 16km grid. The first sampling campaign took place from 2000 to 2009 and enabled the setting up of 2170 sites. The second campaign will run from 2016 to 2027.

[26] URL https://www.umweltbundesamt.de/themen/boden-landwirtschaft/boden-schuetzen/boden-beobachten-bewerten#textpart-1
[27] See Höper and Meesenburg (2012) as an example for Lower Saxony.
[28] URL https://ltfe-map.bonares.de/

The **UK** does not have a national monitoring network. They have patches of several measuring campaigns, executed by different organizations. So, while there are a lot of data points across the country, the data collection is not harmonized, and information is not necessarily comparable. The UK has submitted a country contribution to the GSOC map and has contributed to all investigated initiatives. The submissions done within the INSPIRE initiative seem to encompass maps of Northern Island and the individual countries within Great Britain (no data with national coverage are submitted), which are submitted by various, responsible organisations. It is unclear if all these individual organisations do have a soil monitoring network and/or information system.

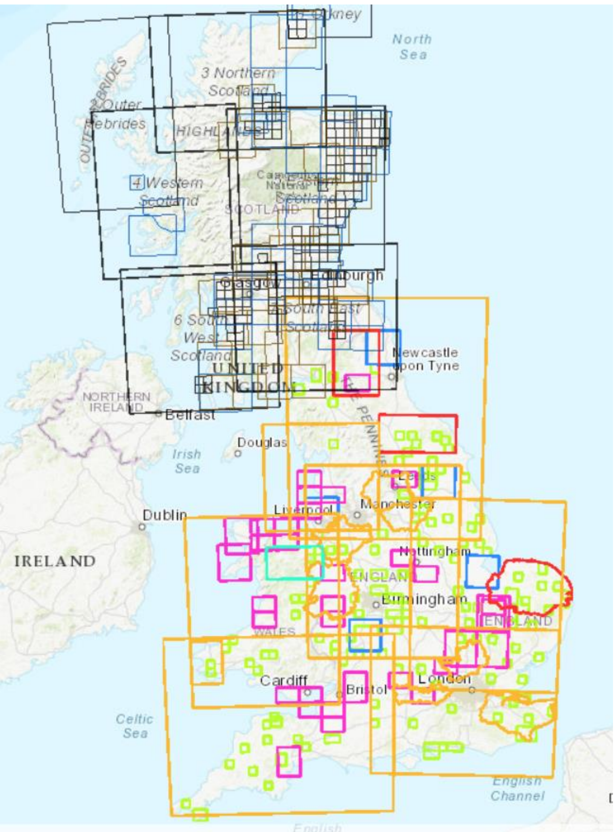


*Figure 4: Extent of different Soil Maps (from different sources) available through the UKSO map viewer*

The UK Soil Observatory (UKSO)[29] is an online archive of UK soils data from 11 partners, including e.g. British Geological Survey (BGS), British Society of Soil Science (BSSS), Forestry commission and Research, Cranfield University, etc. The UKSO provides access to fully described datasets, including static maps and an interactive map viewer (Figure 4), allowing everyone to work with the latest UK soil research outputs. A large quantity of soil datasets is available and downloadable, including soil type and a wide range of physical, chemical and biological properties. Each partner organisation has contributed data covering a mix of these topics.

For example, the BGS has an extensive soil archive totalling 67.000 samples resulting from the ongoing geochemical baseline survey (G-BASE[30]).

[29] URL http://www.ukso.org/quick-links.html

[30] URL https://www.bgs.ac.uk/gbase/home.html

Beginning in the late 1960s, the primary focus was mineral exploration, however the project has now evolved into a high-resolution geochemical survey producing baseline data relevant to many environmental issues. The G-BASE project has an annual campaign of geochemical sampling within many parts of the UK.

**Ireland** did not submit anything to the INSPIRE initiative yet and has not used national information for the GSOC map, but they have three national soil data sets. Between 2008 and 2014, the first phase of the Irish Soil Information System project (by Teagasc, the Environmental Protection Agency (EPA) and the Science, Technology and Research & Innovation for the Environment (STRIVE) program) has gathered existing information and data from previous soil survey work in Ireland and augmented it with a new field campaign, leading to the production of a new national soil map at a scale of 1:250.000. Together with an associated digital soil information system, it provides both spatial and quantitative information on soil types and properties across the country. Both the map and the information system are freely available to the public. Phase 2 continued into 2015 and produced standardised soil attribute maps for use by a wide variety of research, policy and land use stakeholders.

The National Soil Database (provide by EPA) has produced a national database of soil geochemistry including point and spatial distribution maps of major nutrients, major elements, essential trace elements, trace elements of special interest and minor elements. In addition, this study has generated a National Soil Archive, comprising bulk soil samples and a nucleic acids archive, each of which represent a valuable resource for future soils research in Ireland. This study applied large-scale microbiological analysis of soils for the first time in Ireland and in doing so also investigated microbial community structure in a range of soil types to determine the relationship between soil microbiology and chemistry.

### *Northern Europe*

Similar to countries of central and western Europe, Denmark, Finland and Sweden do contribute to the above-mentioned initiatives.

Although **Finland** does have an uneven distribution of soil measurement points according to ENVASSO, the south is much denser than the northern part of the country, they do have several soil data(bases). The primary obstacle as stated in the metadata on the INSPIRE website is lack of spatial soil data in digital form. Abundant data on soil characteristics exist in Finland but have been scattered among various sources, making it difficult for authorities to develop country-wide presentations and predictions. This could also be the obstruction for contributing to the LANDMARK initiative. They did create a georeferenced soil map and database according to the instructions of the European Soil Bureau using data from existing databases and collecting some new data and made a country contribution to the GSOC map.

Soil mapping in **Denmark** has a long history and a series of soil maps based on conventional mapping approaches have been produced. The Nationwide Danish Soil databases have been widely used for planning of rural land at county and national level. From 2000, there has been increasing interest in soil data from European authorities, and the Danish soil databases have been used as the national input to various European projects (Greve and Breuning-Madsen, 2005). In the study of Adhikari *et al*. (2014), a national soil map of Denmark was constructed using existing soil profile observations and environmental data. In the study from Jensen *et al*. (2016) a follow-up to previous national soil monitoring programs on heavy metals, could evaluate trends for a 28-year period in Danish soils, due to its historical efforts on monitoring. So, apparently Denmark does have soil data and databases available and it is therefore unclear why they did not contribute to e.g. the LANDMARK study.

In **Sweden** systematic soil monitoring, at national level, is carried out by different departments of the SLU – the Swedish University of Agricultural Sciences – (commissioned by the Environmental Protection Agency) and the National Board of Forestry. In addition, soil monitoring is also performed on a regional scale under the responsibility of County Boards but with a common protocol. The data collected by the SLU are publicly available. The first systematic surveys and mapping undertaken in Sweden with some relevance for soil conditions were undertaken by the Geological Survey of Sweden (SGU - in the middle of the last century. They still collect data and information concerning about, amongst others, soil depths and geochemistry. The purpose of SGU's soil chemical mapping activities is to produce data on the natural occurrence of metals and other substances in a given area. Data is obtained on the natural occurrence of more than 30 elements in soils, especially in forest-covered moraines, and on soil acidity (pH). All the information collected by SGU by means of mapping, surveying etc. is stored in (open) databases.

*Southern Europe*

According to ENVASSO, Soil Monitoring Networks are much denser in northern and eastern Europe, than in southern parts of Europe (Spain, Greece, Italy, Malta, Portugal). Two countries in southern Europe, Spain and Greece, do not seem to have a proper SMN or SMIS at all according to the LANDMARK initiative.

Ibáñez *et al*. (2005), concludes about soil surveys, soil databases and soil monitoring in **Spain** that the country has experienced a serious decline in resources for soil survey in the past decades. As from the 1980s, the CSIC (Consejo Superior de Investigaciones Científicas-Spanish National Research Council) lost its role as the institution responsible for the coordination of the national soil survey activity. The absence of a National Soil Survey Organisation, the transfer of responsibility for Soil Survey to the Regional Autonomous Institutions, where it suffered from a lack of coordination and the temporal discontinuity of survey programs (frequently caused by short-term contracts) aggravated this decline. Regarding the new sites needed to reach a soil monitoring network with a minimum density of 1 site per 300 km² (the median density of EU sites, analysed in 50 km x 50 km cells within the ENVASSO project) Spain presents the maximum needs in EU (Kibblewhite *et al*., 2008).

The actual existence and accessibility of the output gathered in these survey programs, e.g. maps generated by the CSIC or the developed soil databases[31], are unknown. They compiled analytical data from more than 2.000 profiles. However, technical details and specific targets of this initiative are not available (Ibáñez *et al*., 1999). The information about LUCDEME and RESEL networks of land use change and soil erosion measurement plots are spread across Spain (Ibáñez *et al*., 2005), but detailed information about these has yet to be collated. A soil database was produced by IRNAS (CSIC) in co-operation with FAO/AOLS and ISRIC throughout more than 40 years (mainly from the Western Andalusian provinces of Seville, Córdoba, Cádiz and Huelva) included almost 1,000 profiles, and analytical results from about 20.000 samples (Ibáñez *et al*., 1999).
Within the INSPIRE initiative, Spain has uploaded metadata and one viewable map of the "National Inventory of Soil Erosion – 2002-2012" (Inventario Nacional de Erosion de Suelos) by the Ministry of Agriculture and Fisheries, Food and Environment (MAPAMA). However, the methodology is unclear, and it is indistinct if Spain has been working on data monitoring more recently.
Soil database and mapping initiatives in Spain need a national institution in charge of collecting, compiling and maintaining the spatial and temporal information on soil at state level, with the participation of the Autonomous Communities. There is a lack of coordination, different standards and methods between regions, uneven correlation, different scales of mapping, difficulty with the availability of information, and different length of the various programmes (Ibáñez *et al*., 2005).

Yassoglou (2005) states that soil survey in **Greece** was initiated in the 1930s. Over the ensuing years it has followed several stages of development. Programs have been interrupted several times and restarted by different agencies, such that there has never been a continuous program likely to result in the complete mapping of the country. At present, little systematic soil monitoring exists in Greece. Some monitoring is being conducted as part of a research project funded by the European Union. Soil databases exist in a number of institutions; they are not interlinked, and data are not freely available to the public. However, there are recent signs of a much better appreciation of soil data by local authorities and communities.

Traditionally, it is mainly at regional level (there are some twenty administrative Regions) that soil survey staff in **Italy** are operating as centres for soil surveying, mapping and for information system implementation. Since 1999, soil survey activities, as well as soil mapping and building soil databases, have significantly increased. Following the indications coming from the European Environment Agency in 2001 and from the Soil Thematic Strategy Technical Working Group on Monitoring, the Italian National Topic Centre (NTC) on Soil and Terrestrial Environment, promoted by the Italian Environmental Protection Agency together with some Regional EPA, conceived a project for a national soil monitoring network (SMN) (Filippe, 2005)

ISPRA (Institute for Environment Protection and Research) carries out scientific and technical activities at a national level, providing protection, enhancement and improvement for the environment, water resources and soil. However, what these activities encompass in relation to soils is unclear.

[31] A regional database emanating from a CSIC centre (IRNAS Soil database) and a national Soil Database belonging to the CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas i.e. Energy, Environment and Technology Research Centre – of the Ministry of the Environment)

The Italian system of national and regional services dealing with soil is not clearly structured. However, excessive duplication of effort and dispersion of activities are avoided because of the current level of co-operation amongst most of the institutions involved. For each application, specific soil information should flow from regional soil surveys into national and European levels. Instead of the homologation, the aim is coherence among methods and comparability of data and of the assessment outcome (Filippe, 2005).

Given this information, it is unclear why Italy shows a low density of monitoring sites in the ENVASSO study and didn't contribute to the INSPIRE initiative. Possibly, recent coordination at national level between different regional initiatives has improved the situation significantly, as the recently launched Italian Soils Partnership aims to bring together and coordinate all soil management actors in the country (monitoring and information included). This initiative was being referred to as a good example of an effort to develop a SMIS at national level.

*Eastern Europe*

The way the European Union took shape, as well as the history of the individual MSs seems to be of influence on the availability of national data (SMN) and information (SMIS). The Baltic states (Estonia, Latvia, Lithuania), Poland, Hungary, Slovakia, Czech Republic, Slovenia, and the Republic of Cyprus joined the EU in 2004, Bulgaria and Romania in 2007 and Croatia only in 2014.
According to LANDMARK, it is very difficult to receive any data from former East-European countries. Although these countries have most likely extensive datasets from the Soviet time, these are very difficult to locate. Even if good points of contact exist in these countries, for various reasons the local people are hardly able to access the actual data [32].

*Eastern Europe - Baltic states: Estonia, Latvia, Lithuania*

Even though these three countries are close together, there are some differences between them. Estonia seems to be ahead of Latvia and Lithuania in terms of sharing the information (maps) they do have available through for example INSPIRE. Furthermore, according to ENVASSO, **Estonia** does have a much denser monitoring network (similar to south of Finland) than the other two Baltic states. Estonia currently has a soil monitoring system, while it is however not accessible online. The data and information can be obtained through the governmental agency 'Agriculture Research Centre'. Estonia is in the starting phase of using big data for mapping, in which also soil data will be incorporated.

In **Lithuania** several national survey networks do exist. For example, the Lithuanian Geological Survey under the Ministry of Environment is responsible for soil monitoring in the 71 agricultural land sites in the context of State Environmental monitoring. Monitored soil properties within this program are related to general soil condition (soil acidity, loss of carbon, etc.) and diffuse soil contamination from agriculture and industry. This State Environmental Program was initiated in 2010 and covered the period between 2011 and 2017.

[32] Spoken correspondence with Landmark- Pillar 2 team

The report[33], in Lithuanian, is stored in the library/archives/DB Geolis of the Lithuanian Geological Survey and is publicly available for all private/state/national/foreign bodies. Other soil data are available from other national soil data holders and responsible institutions, that are part of the Ministry of Environment and Ministry of Agriculture. The National Land Service is the institution that according to the national Land Law is officially responsible for national land/soil monitoring.

*Eastern Europe - Central: Czech Republic, Slovakia, Poland, Hungary*

In the **Czech Republic** a Soil Monitoring System has existed for more than 25 years, managed by the 'Central Institute for supervising and testing in Agriculture' (ÚKZÚZ). It focusses on long-term monitoring of content of available nutrients and microelements, content of risk elements in soils and agricultural products, development in monitoring of pesticides in soils, and soil microbiology. So, although there is a long history in soil monitoring, this is not reflected in the LANDMARK outcomes (Czech Republic is a white spot on the map).

However, on the INSPIRE website two maps (soil map and grainsizes) are shared by the Czech Geological Survey (CGS). The incentive for this institute to contribute to the INSPIRE initiative is that "According to the law, as the legally mandated organization (LMO) on behalf of the Czech Government, the CGS is obliged to provide access to sets of spatial data falling within the themes stated in Annexes II (geology) and III (included data about soils, about areas endangered by natural hazards, and about mineral resources) of the Directive 2007/2/EU."

**Slovakia** has made a contribution to the INSPIRE initiative by submitting several metadata files. One of these files provides information on a monitoring network that consists of 318 sites. Important soil characteristics and indicators in relation to possible soil threats (soil contamination, decline in organic matter and nutrient access, soil compaction, soil erosion) are monitored. Soil monitoring consists of three basic subsystems: a basic network of monitoring sites (agricultural, forest land, land above the top of the forest), two key monitoring sites and three area contamination surveys. The dataset represents digital data archived from the "Partial Monitoring System - Soil" as part of the Slovak Environmental Monitoring and is provided by National Agricultural and Food Center - Research Institute of Soil Science and Soil Protection (Národné poľnohospodárske a potravinárske centrum - Výskumný ústav pôdoznalectva a ochrany pôdy).

The quality of agricultural soil in Slovakia is indicated by the so called BPEJ number. BPEJ (simply also called "Bonita") stands for a five-digit numerical code. These five digits each refer to a separate quality character of the soil including aspects such as: climate location, morphogenetic properties, characteristic of soil-forming substrates, slope of the land, and depth of the soil profile and stoniness. The BPEJ numbers are summarized into nine different categories, one representing the highest quality soils, nine the lowest. Non-agricultural lands do not belong to any of these categories. The original measured data are collected every five years and are not are not publicly available; only the categories are available through a webpage. Exceptions are made for students, who can request original measured data from maximum three cadastres for studying purposes only.

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[33] Valstybinis laukų dirvožemio monitoringas (2011-2017 metų programa) / Gregorauskienė V.; Lietuvos geologijos tarnyba. - Vilnius, 2015. - 203 + CD : 13 pav. - (LGT fondas; Nr.19909) = Soil State Monitoring, for the years 2011–2017 / Gregorauskienė V.; Lithuanian Geological Survey. - Vilnius, 2015. 203 pages + CD : 13 figures

Soil of forest land is being managed by the National Forest Centre - Forest Research Institute (NFC-FRI Zvolen).

**Poland** launched permanent monitoring of agricultural soils in 1995. The Soil Monitoring is an element of the State Monitoring of the Environment with the aim to observe changes in soil quality under agricultural and non-agricultural anthropogenic pressure. Obligation of soil monitoring, and observation of changes in soil quality is established in the Environmental Protection Law. The program is financed by the State Fund for Environmental Protection and Water Management. The monitoring has been led by the Institute of Soil Science and Plant Cultivation since the program initiation in 1995. It covers 216 georeferenced sampling points throughout the entire country, located mainly on arable land. Samples are collected in five-year intervals, therefore data representing five campaigns are currently available (1995, 2000, 2005, 2010, 2015). A wide range of soil parameters is analysed each time, including soil texture, pH, SOC, nutrients, extractable nitrogen forms, total contents of contaminants (trace elements, PAH-s and since 2015 pesticide residues). The full monitoring dataset is publicly available through the monitoring website.

**Hungary** contributed to almost all initiatives. This is probably because they have a soil monitoring system since 1992, called “TIM” (carried out by organisation National Food Chain Safety Office). Based on physiographical-soil-ecological units 1236 representative survey points have been selected: 865 on agricultural land, 183 points in forest and 188 special points (degraded land, sensitive areas, contamination). These points are sampled every year between 15 September and 15 October, the sampling depths varying over the years (1992: 150 cm deep soil profiles, 1992-2000: sampling from pedogenic horizons, >2000 fixed sampling depths). From these samples, different parameters are measured at different periodicity.

Unfortunately, the structure of TIM points and the methodology of sampling was not suitable for detection of all soil threats identified by the EU Soil Thematic Strategy. Therefore, between 2010 and 2012 the Terradegra project was initiated, focussing on the production of soil data required for environmental impact on agriculture and on the environmental status of soils. Furthermore, the project involves the development of the Soil Degradation Information System (TDR) related to the National Environmental Information System (OKIR). During the project, for approximately 700.000 data points a soil survey was executed in spring and autumn of 2011. These data were not public, only those involved in the work could access it through the TDR portal. The data has been converted to information and is available as (pie) charts through the TDR website of the Ministry of Rural Development.

*Eastern Europe - South: Slovenia, Croatia, Bulgaria and Romania*
Of these four countries, Slovenia has been in the EU the longest. **Croatia** on the other hand only joined the EU in 2014. As a result, Croatia hardly participated in any of the initiatives as mentioned in the previous chapter. The country was only incorporated in the LUCAS monitoring network in 2015, a year after accession to the EU.

According to Bašić (2005), soil mapping in Croatia began in 1964 and lasted for 23 years, finally ending in 1986. The General/Basic Soil Map of Croatia (BSMC), at scale 1:50.000, containing data on physical, chemical and biological properties and the spatial distribution of soils of Croatia, collected with an observation density of approximately one soil profile per 1,000ha. Final products of the BSMC project were 186 (A2 paper format) soil map sheets, 165 manuscript reports, and about 10.800 profile descriptions with standard laboratory data (Hengl & Husnjak, 2006). Unfortunately, the BSMC sheets were designated as 'officially secret' in the period prior to 1990 and, as a consequence, were not accessible for public scrutiny, particularly for international exchanges of information (Bašić, 2005). Whether this is still the case remains unclear.
So, an imposing amount of diverse data and information on the distribution and properties of the soils of Croatia has been collected by modern methods since World War II.

However, according to Hengl & Husnjak (2006), the accessibility and distribution policy for the soil data in Croatia is neither clear nor transparent. Many usability problems—lack of metadata, inconsistent methodology, incompleteness, unpopular concepts used are typical of national inventories conducted in Eastern European countries after the Second World War, as well as in some more developed countries.
In anticipation of the accession to the EU, a pilot project was performed from 2006-2009 called "Development of the Croatian Soil Monitoring Programme with a pilot project" (LIFE05 TCY/CRO/000105). Within this project the Croatian Soil Monitoring Programme (CSMP) was developed and it was proposed that a Soil Information System of Croatia (SISC) should be established. Lack of money was the main reason for stopping all activities within this project. As part of the CSMP, more than 300 monitoring sites were established on different soil types (agricultural, forestry and contaminated soil types) from which data were gathered together with georeferencing each site. Based on this data, a GIS database was established with basic information on the situation of different types of soil (forests, agriculture and contaminated soils). Whether these data were actually collected and if they are accessible is unclear.

The developed CSMP is currently not operational; agricultural soil monitoring is implemented into legislation, but the actual monitoring process (sampling, analyses) has not started yet and it is unclear if / when it will. At the same time as the development of the CSMP, the CEA (Croatian Environmental Agency) initiated the establishment of the Croatian Soil Information System (CROSIS). Soil data collected by CEA should be publicly available for viewing and downloading through this portal.
Hence, Croatia currently does not have a national survey network for soil monitoring. There were few initiatives, among which gathering soil data for reporting to UNFCCC, but none came through.

Both Romania and Bulgaria were added afterwards (in 2012) to the LUCAS field survey of 2009, most likely because they only joined the EU in 2007. In **Bulgaria**, currently no soil monitoring network exists, and the only recent data are collected by LUCAS. The reason for this is that there is no incentive for setting up such a network. There is no specific policy for soil protection in Bulgaria. The existing data are not publicly available because soil monitoring is very expensive. Much soil monitoring was carried out up until the late '80s: there was a 1:10.000 and 1:25.000 map produced by the National Soil Survey. Unfortunately, those soil data are not maintained anymore.

**Romania** on the other hand, does currently have a Soil Monitoring System; one very similar with the one carried by the French Ministry of Agriculture. This system was initiated by the Ministry of Agriculture and Rural Development several years ago and is ongoing. The data are owned by the Ministry and can sometimes be used for scientific purposes. Some of the data are converted by the ICPA (Institutul National de Cercetare-Dezvoltare pentru Pedologie, Agrochimie si Protectia Mediului) into soils maps, some of which are shared through the INSPIRE initiative.

*Other countries*

As Iceland, Liechtenstein and Norway are not part of the EU, but of the European Economic Area (EEA), they are not further considered in this chapter, although these countries sometimes contributed to the mentioned initiatives.

# 4 Gaps and Barriers

The previous paragraphs investigated the historic and current status of Soil Monitoring Networks (SMN) and Soil Monitoring and Information Systems (SMIS) for each Member State (MS). It shows that (historical) soil data are available in almost all the Member States. However, this does not mean that the soil data is necessarily collected in an organized way (e.g. regularly, using practical indicators and a structured soil monitoring network) or consistently stored in one (national) database or SMIS that is easily accessible (e.g. findable, digital, publicly available, and open access). In other words, soil data are sometimes not collected or only in a primary state, sometimes available but not usable[34], and sometimes not shared.

The ESP comes to similar conclusions in its regional implementation plan 2017-2020 (ESP, 2017), stating that soil information in Europe is patchy and not comparable. The available soil data still have many gaps, are not sufficiently resolved, do not satisfy certain user requirements (e.g. soil monitoring for agricultural monitoring), do not meet increasing policy demands (e.g. climate change adaptation, greening in agricultural policies), or do not make use of opportunities created by the improved availability of other spatial environmental data sets (climate, land cover).

How could a consistent and interoperable soil monitoring and information system at national and EU level be developed? Ideally, regional and/or national organisations would provide soil data and information to the European Union and through that level to global initiatives. However, as mentioned above, it is difficult to obtain harmonized soil data from a national level.
As a response, LUCAS Soil was implemented to produce soil data at an EU-level, using one methodology and standard. As such, LUCAS is considered a valuable effort and is appreciated by MSs, especially in countries where they do not have any other tool available. However, in countries that do have detailed soil data and more advanced SMIS, LUCAS is sometimes considered competition to the national SMIS and a possible threat for funding needed for data collection at national level.

So, to achieve the necessary soil data and information, the approach could either be top-down or bottom-up. For the bottom-up approach, one should investigate what data MS have available, find common ground, and make maps of information on those topics at EU-level. For the top-down approach, the EU should clarify what information is needed on EU level (or across boundaries) to maintain policies and ask MS to provide this information (GLOSIS approach).

Both approaches do have their advantages and disadvantages. The major disadvantages of the bottom-up approach being that it requires an overview of all the soil data and information that is available in each MS, which will not be the case any time soon. The advantage of this approach on the other hand is that MSs are very much in control and the members won't have the (incorrect) impression that the EU is forcing any legislation on them. The major disadvantage of the top-down approach is that the MSs become the problem owners.

[34] Usability generally being divided in four categories: data quality (accuracy, completeness, logical consistency), data form(at), data accessibility and price, and quality of the metadata. The importance of each of these aspects may differ from user to user, depending on the incentive.

If they do not have the requested soil data and information available, they will need to collect them. On the other hand, the action needed from the MS will be focussed and clear.
The global participants of the SOILS4EU workshop[35] very much agreed with the latter, stating that the first thing that needs to be done by the EU before setting up a SMIS or harmonizing across countries, is to clarify the objectives. The reasons and benefits of harmonization for the MSs are key for getting more attention and raising awareness on SMIS. Soil information provides multiple benefits for food security, crisis management (prevention against natural disasters), soil protection and considering soil in general.

If the bottom-up approach is favoured, it must become clear what holds MSs back from collecting and sharing soil data and information and engaging in one interoperable SMIS at EU-level. These barriers can be related to technical (data collection, measuring vs monitoring, metadata, additional information), financial (obtaining data, data and information management), legislative (ability to share data, intellectual property) and communicational challenges (awareness, who knows what, willingness to share data, transparency in collected data and information, language) that need to be tackled. From the previous chapter and the input of the workshop participants, a coherent set of gaps, barriers and possible solutions emerged. These will be addressed in the next paragraphs.

*Legislations*

The Soil Wiki covers 35 EU level policies and 671 instruments across the 28 EU Member States (Frelih-Larsen *et al*., 2017). EU-level binding measures are, for example, the Common agricultural policy (CAP) and the Environmental policies on water, chemicals, waste and landfill. Examples of strategic initiatives at EU-level are: EU Soil Thematic Strategy, 7th Environmental Action Programme, Resource Efficiency Roadmap, Biodiversity Strategy, 2030 Climate and energy framework, Soil sealing guidelines, EU Forest Strategy, etc.

To ensure an adequate level of protection of soils in the European Union, the European Commission adopted the Soil Thematic Strategy in 2006, including a proposal for a Soil Framework Directive (the Directive). However, a minority of Member States (United Kingdom, Germany, France, Austria, and The Netherlands) could not agree on the text of the proposed Directive.
Stankovics *et al*. (2018) found that "the regulations concerning soil-dependent degradation and contamination issues in the above countries were generally well defined, complementary, and thorough. A common European legislation can be based on harmonized approaches between them, focusing on technical implementations. On the aspect of soil sealing we found recommendations, principles, and good practices rather than binding regulations in the scrutinized countries. Soil sealing is an issue where the proposed Directive's measures could have exceeded those of the MSs."

This statement suggests that blocking of the directive took place, because the directive would overrule the national legislation that was already in place.

[35] At 7 November 2018

Hence, countries that already have stringent regulations are not interested in European demands on soil status, whereas countries without soil policy would like to have stricter demands (through regulation, a directive) from EU level or national level about the soil status. This is in accord with information derived from the comparison mentioned in the previous chapter, where we learned that increased requests and concerns of the European Union in soils did stimulate MSs, especially in southern and eastern Europe, to organize their soil data nationally and make it accessible to international partners.
It is stated by participants of the SOILS4EU workshop of 2018 that an increase in awareness is needed in some MSs about the importance of healthy soils, as in some countries the policies are becoming less strict (for example in Hungary, pollution levels have increased) due to strong lobby. It might be necessary that the European Union stimulates that awareness.

## 4.1 Observations from comparison between countries

The contributions of the individual MSs to the INSPIRE website changes frequently, meaning that countries are still actively participating in this initiative. Although all available data should be submitted to INSPIRE, mainly metadata can be found (see Table 3). The reason behind this is, according to the participants of the SOILS4EU workshop, that not all countries are willing to share the data and information they have. This unwillingness is due to obstruction from legislation, but also because data collection is expensive and therefore countries do not want to give it away for free; i.e. what they get in return for this is not always clear for the MS.

However, the metadata is by itself very useful, as it states the responsible organisation and contact person which could be used in case more detailed information is needed. Sometimes it also mentions the incentive for data collection, the reason why the actual data is not shared and/or a link to a national database or web viewer.

The metadata on the INSPIRE website, as well as webpages of local organisations are often in the local language. Although automatic translation machines (for example eTranslation[36]) have massively improved over the years, the language still creates a barrier to easily share data and information on a European level and can lead to misunderstanding concerning the methods used, restrictions of the data, etc.

A lot of the available data and information (maps, graphs, etc) are not national products but patches of information related to soils. Some countries distinguish in their data collection between different land uses (forest, agricultural, urban, etc.) and soil types / geology, resulting in for example separate field surveys, different survey frequencies, and separate databases. Monitoring of soil pollutants (e.g. heavy metals, radioactive particles) is at present a priority for many countries, probably stimulated by increased concerns for human health and national legislations.

[36] URL https://ec.europa.eu/cefdigital/wiki/display/CEFDIGITAL/eTranslation, available to public service providers

In other countries, soils are historically the responsibility of separate regions or different institutes/organisations, which have different objectives and measure different parameters; this adds another level of heterogeneity to the European current situation in terms of SMIS.
There is a considerable difference between MSs in how much effort is put in organising these regions/institutions. Some have created new national initiatives to bring together the individual expertise in a new soil monitoring system, making it sometimes more difficult to incorporate historical data. On the other hand, some countries encouraged cooperation between the different institutions to avoid overlapping surveys, unnecessary activities and stimulating alignment of methods.

Unfortunately, there are also countries in which there is e.g. no incentive or budget to change this way of working. There are for instance national initiatives that have started recently but are delayed or lack funds to see them through. This is especially true in countries were soil monitoring is done on a project basis. As soon as the project stops, the monitoring seizes to exist.

LANDMARK had trouble with retrieving data from east European countries. Most of these countries though have a long history with data collection, mostly soil mapping based on dense networks of soil profiles. This information is often only partially available in a digital format and collected using methods, that are currently no longer used. References are made to other "basic" soil data that was collected simultaneously, but the availability and the accessibility of these data - e.g. detailed overview on the data collected, is unknown.

## 4.2 Observation from SOILS4EU workshop

Participants at the SOILS4EU workshop (7 November 2018) perceive the governance and coordination challenges as the most important ones. These problems are at the origin of other barriers, especially the low level of resources devoted by the administrations to the development of unified SMIS at national and EU scale.

### 4.2.1 Governance, coordination and communication challenges

At EU level, the lack of an EU Directive weakens the capacity to implement common/interoperable SMIS at EU level, as there is not a strong binding common legislative instrument to "force" countries to align their existing systems into a common one.
The situation in the EU countries is diverse, but the responsibilities and roles in soil information and monitoring (and in general on soils issues) are scattered among different departments and territorial levels (national/regional/local) of the State Administrations. Data collection is often based on different initiatives, different measuring and monitoring campaigns. These campaigns are carried out by different institutes, which do not always share the data. It is typical that the Agriculture and the Environment Ministries have their own objectives related to soil management and status, and that they develop separate systems of information and monitoring to support them to fulfil these objectives. This situation creates different sources of information, not always easy to find (sometimes not available), not interoperable and thus not resulting in an actual holistic SMIS. In some cases, this situation can also lead to duplication of efforts.

### 4.2.2 Financial challenges

All the participants agree that SMIS are expensive to implement. Moreover, as monitoring aims to discover and assess trends across time, the financial effort must be long term. Taking that condition into account, it is a huge challenge that cannot be easily overcome under the current situation where soil issues/responsibilities and soil information are scattered among different administrative services and research institutions and disciplines (see paragraph 4.2.1). The financial resources are thus scattered and respond to different objectives depending on which administration is supporting the information system.

Some ad hoc funds are released by national or EU programs (e.g. research projects) for measuring campaigns and even specific monitoring activities. They can produce interesting results, but their duration is limited. In case of some EU programs (e.g. project funded through Research Framework Programs), the work does not cover all member states, so the information can be very interesting but limited geographically. There have also been cases where SMIS costs were underestimated and programs ended before reaching its goals.

### 4.2.3 Technical challenges

Another challenge is the use of different analytical methods yielding different results. As an example, former Soviet states used different standards and guidelines, which makes harmonisation complex. Nutrients, etc., were not measured and there are no incentives to change this.

Standards on soil survey and monitoring are not unique at EU level. Even within countries different standards can be found if there are different SMIS. The main challenges in terms of standardisation are the definition of parameters to be measured, standard methods to measure those parameters, the periodicity of measurements and the density and distribution of the sampling points network.

If an EU wide system is to be implemented, standardisation will be a big challenge. Countries having stronger and older SMIS will be reluctant to adopt new standards which will hamper the comparison with their current systems. It is noted also that policy objectives and instruments regarding soils are different between countries, so the parameters to be prioritised in a SMIS are not always the same.

Concerning contaminants in soil, one of the challenges is the definition of thresholds above which there is a potential risk on human health or environment. It is difficult to define common thresholds due to the variability of soil conditions. Some Member States have their own thresholds, but they vary a lot from one country to the other.

*Technical gaps*

The group agreed that in any data system the actual value and the methods used for a parameter measurement must be available (for example: not only putting SOC content in a scale of low, medium, high, but provide the actual measurement result). This is conditional to the usefulness of systems in the light of decision taking and in enhancing knowledge.

Regarding the parameters to be measured, a new degree of complexity is added because the SMIS need to be adapted to the current needs of the society. For example, contrary to 10 years ago Soil Organic Content (SOC) has become a priority (next to organic matter), as it is identified as a crucial component of the C-cycle and a target for potential climate change mitigation and reduction measures. Thus, it is expected that SOC is a component of a modern SMIS.

Contaminants are other examples of evolving (increased) needs to incorporate parameters into the systems. As knowledge advances and society becomes more aware, emerging pollutants become more and more important to address and it is difficult for individual countries alone to do that. An example of these emerging contaminants is microplastics contamination. However, the analysis of those contaminants is very heterogeneous, and the availability of information is very diverse among countries and regions.

As for the soil-water relations, remote sensing is useful and is being implemented for monitoring surface soil moisture and availability for plants. However, there is a lack of large-scale information on water dynamics at deeper horizons, which would be of enormous interest for better assessing the soil role in the water cycle.

Erosion measurement also poses a huge challenge, as it usually relies on modelling to assess the risk of erosion, and in situ data are very often not available. A reinforcement of the hydrological measurement network (especially for sediments) could produce useful information for assessing water erosion. Wind erosion assessment poses another a big challenge.

The group did not comment any issue regarding IT technical standardisation needed for making systems accessible and interoperable.

### 4.2.4 Legal challenges

In general, legislation related to soil protection is scattered, there is no overarching soil legislation on national and European level, but soil is present in many different laws at different levels and under different responsibilities. National legislation on soil is scattered and each country has its own body of legislation, that will be harmonized only if an EU directive is adopted.

Regarding specific legislation on SMIS, the situation varies between countries, some of them having developed it at to certain extent while there is a complete lack in other MSs. Specific legislation on SMIS helps to maintain the systems across the years. A very practical issue that could be solved through a specific legislation on SMIS, would be to provide legal cover for the surveyors entering privately held land to collect soil samples. This can be easy in some cases but in others can be problematic and a legal protection could help surveyors.

A main concern is on legal issues of making all information publicly available, which is one of the aims of complete SMIS. Privacy and personal data protection laws on the publication of georeferenced soil data pose a specific and unresolved problem. Some sensitive parameters cannot be published without the landowner’s consent as this could infringe upon his/her privacy right. One example is the soil pollutants levels, especially when those levels are related to the soil/land management practices.

**Duality of LUCAS**

*Gaps*

LUCAS Soil was implemented to produce soil data at an EU-level, using a uniform methodology and standard. As such, LUCAS is considered a valuable effort and is appreciated by MSs, especially in countries where they do not have any other tool available.

However, in countries that do have detailed soil data and more advanced SMIS, LUCAS is considered competition to the national SMIS and a possible threat for funding needed for data collection at national level.

*Barriers*

Most participants would like to enhance synergies between LUCAS and the national SMIS, harmonizing their own national systems with the LUCAS methodology.

Besides the financial concerns, the main barrier for MSs to embrace the LUCAS approach on a national level is that the modification of methodology would make it impossible to ensure the continuity.

*Solutions*

It was suggested to decentralize the collection of LUCAS soil data, so that each MS can use the corresponding resources for building the EU system. This would only work if each MS would embrace the LUCAS standards and guarantee that the information will remain publicly available as it is currently in LUCAS.

Some MSs mentioned that a transition towards the LUCAS methodology could be possible as they use similar methods or international standards that would make interoperability theoretically feasible.

## 4.3 Look-out: possible solutions

From the above chapters, some possible solutions emerge.

### 4.3.1 Governance, coordination and communication solutions

Harmonisation of data is essential for addressing transboundary issues. The transboundary impacts of for example soil degradation can be economic, social and environmental, as it can be a driver of climate change, health problems and food shortage. Data is harmonised for water and air but not for soil. It would be good to define harmonized methods to measure soil information, similar to the approach to river basins.

An effort of coordination between the different administrations would be of great interest for the development of SMIS at national level. This coordination would define common objectives for the SMIS, approve shared technical standards or methodologies and use more effectively the scattered funds that are currently being used separately. As an example of an effort towards this direction, the Italian Soils Partnership, recently launched in the context of the Global Soil Partnership, aims to bring together and coordinate all soil management (monitoring and information included) actors in the country. France is also advancing in this direction, establishing a coordination among Agriculture and Environment Ministries and engaging many different soils stakeholders to establish holistic diagnostics and sharing objectives for soils management and monitoring. Another example is the Forest Soil Inventory, which was made in 2006 in all countries, where much data was collected. The European National Forest Inventory Network has established criteria to harmonize definitions and to provide tools to transform national data into internationally comparable data.

Specific national legislation on soils harmonized through an EU Directive would help to support SMIS. Some of the participants would welcome an EU Directive (provided it explicitly refers to SMIS) and think that a top-down approach is more effective for mobilizing Member States than proposed guidelines or recommendations for voluntary accomplishment. Strong requirements from the EU to Member States and equal considerations to all of them would probably help.
Raising awareness and exchanging experiences are key for getting more attention on SMIS and the need for harmonization. It is of utmost importance to show the society and the policy makers what is the importance of soils, what threatens them and what are the benefits of SMIS. This would convince policy makers to make institutional arrangements and to put resources on the SMIS. Besides, it would be good to gather and exchange data with the users (farmers) going beyond purely academic purposes.

### 4.3.2 Financial solutions

The cost of soil monitoring is a major barrier. A few solutions were mentioned to overcome this barrier. One solution is to prove that soil monitoring can be cost-effective. Examples (Japan, Uruguay) show that the use of soil data improves the competitiveness of farmers and avoids costs (e.g. reduction of fertilizers). Besides, techniques such as remote sensing (combined with in situ measurements) can be cost-effective monitoring methods, as large areas can be monitored with relatively small efforts in the field.
Another solution can be to collaborate with third parties to set up a SMIS e.g. with insurance companies. They can carry (part of) the costs for soil monitoring, because they can benefit from it (natural capital accounting).

A European Joint Partnership (EJP) on agricultural soil will be launched under H2020. Among its lines of actions, it will examine inventories, measurements, reporting and accounting activities. Sustainable agricultural productivity and environmental aspects will also be targeted in connection with climate change mitigation and adaptation. The EJP will include joint programming and execution of research and other joint integrative activities such as education and training (e.g. short-term missions, workshops), knowledge management, access to experimental facilities and databases, including also harmonisation and standardisation. State-of-art technologies for mapping and soil sampling (physical, chemical and biological parameters) will be explored for wider and simple use from national level to farm level. The EJP should also facilitate sampling and further development of LUCAS as well as supporting EU contribution to global soil mapping activities.

As proposals to overcome the resources problems, workshop participants mentioned sustained co-funding activities (EU/countries) and linking SMIS with other important natural resources issues where soils have a crucial role, as biodiversity or climate. For example, connect SMIS with the networks on measurement and assessment of GHG emissions in agricultural soils.

### 4.3.3 Technical and Legal solutions

Different indicators might lead to the same information on higher aggregational level. Besides, providing and sharing information instead of data, might encourage MSs to unify and share their knowledge on national level. Also, sharing information might be less sensitive than providing the actual data and stimulating development of knowledge (from information) through e.g. research, could bypass intellectual property issues.

# 5 Conclusions and recommendations

For the EU to manage the potential of our soils to deliver soil functions, for reaching set societal goals at different spatial scales and assess the impact of current and upcoming EU Directives and Regulations, action must be taken to improve the consistency and interoperability of Soil Monitoring and Information Systems (SMIS). To achieve this goal, it is important to know what data and information Member States (MS) have available, what the data and information gaps are and what is holding Member States back from sharing information.

## 5.1 Conclusions

There are many initiatives at a Global and EU level on soil monitoring and information. On an EU-level, soil data are available in almost all the Member States. However, it is very difficult to create a complete overview of all existing data and information within the Member States, not least because even within Member States several regions or organizations are responsible for collecting soil data, fragmenting the information on soils status and change. So, data availability and quality vary a lot through EU: soil data are sometimes not collected or in a primary state, sometimes available but not usable, and sometimes not shared.

An important reason not to share soil data and information is that developing and maintaining a SMIS requires a long-term financial investment. If it is unclear what the (added) benefit is for the Member States to share and harmonize its soil data and information, these investments are not easily done. Furthermore, if there is no soil (or less strict) legislation on national and/or European level, there is no incentive for Member States to overcome barriers, update existing SMIS to current or harmonized standards or even collect soil data. Finally, breaches of data sovereignty and protection of intellectual property are a continued concern.

As many initiatives concerning soils, standardisation and SMIS are already ongoing on Global, EU- and national level, there is no need to start from scratch. However, concerns regarding adaptability and flexibility of indicators (parameters) and methods must be addressed, to make sure that investments in time and money are not wasted.

By starting to share what each Members State has available, using the experience of others and existing guidelines for data collecting and storage, while aiming for a common goal, harmonization will follow and barriers will be overcome. The key to sustainable soil management is sharing soil data through web services, based on national soil data infrastructures (where available) and including soil research data infrastructures. If all the soil data are organised properly and in a harmonised way, we would be able to take appropriate action at matters such as food security, biodiversity and desertification at an international level. Latest developments could help to organise, document, preserve and publish the data (e.g. OpenEarth) and gain as much knowledge from it as possible (big data, machine learning, block chain, etc.).

## 5.2 Recommendations

Harmonisation of data is essential for addressing transboundary issues related to soils. Thus, it should be considered to approach the harmonisation per transboundary topic (soil-function/soil threat) and to stimulate transboundary monitoring by stimulating cooperation between different administrations and/or countries.

This cooperation can be achieved by either a top-down (EU-Directive) or bottom-up approach, which both have their advantages and disadvantages. Specific national legislation on soils harmonisation through an EU Directive would help to support SMIS and should thus be stimulated. As EU legislation and directives are adopted through a process that involves all MSs, it is probably through a combination of the two approaches.

However, the EU being a union of Member States, needs to translate the objectives (reasons and benefits) behind the ambition for harmonisation of soil information, to common objectives for the SMIS. These objectives will stimulate countries to work on SMIS on a national level by providing mutual goals and finances, especially if responsibility and cooperation for national SMIS are fragmented and coordination between the different administrations is needed.

To further encourage countries to work on SMIS, the EU must show the society and the policy makers what is the importance of soils, what threatens them and what are the benefits of using SMIS. Thus, by raising awareness, SMIS and the need for harmonisation will get more attention. By involving stakeholders and possible financers, soil monitoring can be made more cost-effective.

The use of harmonized SMIS could be further encouraged by providing practical guidelines for establishment and/or extension of existing SMIS and by exchanging experiences through education and training. It is recommended to make use of existing initiatives, networks, data centers, laboratories and expertise, also outside EU. LUCAS is in that sense considered a valuable effort, however caution much be taken to make sure is not considered competition to the national SMIS.

Common objectives for SMIS will stimulate shared technical standards and/or methodologies. A practical recommendation in that manner is to agree on a common language; both literally (e.g. English) and figurative (semantics and definitions).

An important step in a shared methodology is to define suitable indicators and thresholds preferably on EU-level. To standardize the method to measure those indicators, the periodicity of measurements and the density and distribution of the sampling points network, considering the different soils that are present would be a logical next step. Besides, it is recommended to have samples analysed using unified protocols at EU level and have soil analysis undertaken by a single laboratory to avoid biases.

When translating data to information, it is important to keep soil information flexible. Original data should be stored, including the method of collection and metadata, together with the tools used to convert the data to information. This way information can be easily adjusted according to future needs. Besides, when translating data to information, it is important to combine several types of information; it was suggested to share and combine point data with land use management (past and current).

Finally, it is recommended to solve the problem of privacy and personal data protection laws on the publication of georeferenced soil data and to provide common and clear data access and data protection standards.

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